

IRIS Performer™ Programmer's Guide

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Many of the techniques and methods disclosed in this Programmer's Guide are covered by patents held by Silicon Graphics including U.S. Patent Nos. 5,051,737; 5,369,739; 5,438,654; 5,394,170; 5,528,737; 5,528,738; 5,581,680; 5,471,572 and patent applications pending.

We encourage you to use these features in your IRIS Performer application on Silicon Graphics systems.

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About This Guide

Welcome to the IRIS Performer™ application development environment. IRIS Performer provides a programming interface (with ANSI C and C++ bindings) for creating real-time graphics applications and offers high-performance rendering in an easy-to-use 3D graphics toolkit. IRIS Performer interfaces to both the OpenGL® graphics library and the IRIS Graphics Library™ (also known as IRIS GL™); these libraries combined with the IRIX™ operating system form the foundation of a powerful suite of tools and features for creating real-time 3D graphics applications on Silicon Graphics® systems.

Why Use IRIS Performer?

Use IRIS Performer for building visual simulation applications and virtual reality environments, for rapid rendering in on-air broadcast and virtual set applications, for assembly viewing in large simulation-based design tasks, or to maximize the graphics performance of any application. Applications that require real-time visuals, free-running or fixed-frame-rate display, or high-performance rendering will benefit from using IRIS Performer.

IRIS Performer drastically reduces the work required to tune your application's performance. General optimizations include the use of highly-tuned routines for all performance critical operations and the reorganization of graphics data and operations for faster rendering. IRIS Performer also handles Silicon Graphics architecture-specific tuning issues for you by selecting the best rendering and multiprocessing modes at run time, based on the system configuration.

IRIS Performer is an integral part of the Silicon Graphics visual simulation systems, such as the and provides the interface to advanced features available exclusively with the Silicon Graphics product line, such as the InfiniteReality™, OCTANE™, and O2™ graphics subsystems. IRIS Performer teamed with InfiniteReality or OCTANE provide a sophisticated image generation system in a powerful, flexible, and extensible software environment. IRIS Performer is also tuned to operate at peak efficiency on each graphics platform produced by Silicon Graphics; you don't need the hardware sophistication of InfiniteReality graphics to benefit from IRIS Performer.

What You Should Know Before Reading This Guide

To use IRIS Performer, you should be comfortable programming in ANSI C or C++. You should also have a fairly good grasp of graphics programming concepts (terms such as “texture map” and “homogeneous coordinate” aren’t explained in this guide). It will help if you’re at least familiar with the OpenGL library. If you’re a newcomer to these topics, see the references listed under “Bibliography” at the end of this introduction and examine the glossary for definitions of terms or usage unique to IRIS Performer.

On the other hand, though you need to know a little about graphics, you don’t have to be a seasoned C (or C++) programmer, a graphics hardware guru, or a graphics-library virtuoso to use IRIS Performer. IRIS Performer puts the engineering expertise behind Silicon Graphics hardware and software at your fingertips, so you can minimize your application development time while maximizing the application’s performance and visual impact.

For a concise description of IRIS Performer basics, see the “Getting Started with Performer” guide.

Internet and Hard Copy Reading for the Performer Series

You can use a web browser to search through the Performer libraries. For the very latest version of Performer class names and definitions, method names and declarations, tokens, man pages, and sample code, use the API Search Tool. To do so, point your browser at:

- <http://<LOCALHOST>/performer>
- <http://techpubs.sgi.com/library/manuals/3000/007-3632-001/html>

Printed books in the IRIS Performer series include:

- *IRIS Performer Programmer’s Guide* (007-1680-*nnn*)
- *IRIS Performer Getting Started Guide* (007-3560-*nnn*)

You can read online versions of the following books:

- *IRIS Performer Programmer's Guide*
- *IRIS Performer Getting Started Guide*
- *IRIS Performer Class Reference Guide for C Programmers*
- *IRIS Performer Class Reference Guide for C++ Programmers*

To read these online books, point your browser at:

- http://techpubs.sgi.com/library/dynaweb_bin/0620/bin/nph-dynaweb.cgi/dynaweb/SGL_Developer/Perf_PG/@Generic__BookView

For general information about Performer, point your browser at:

- <http://www.sgi.com/Technology/Performer>

Answers to common questions

- Silicon Graphics maintains a publicly accessible directory of questions that developers often ask about IRIS Performer, along with answers to those questions. Each question-and-answer pair is provided in a file of its own, named by topic. To obtain any of these files, use anonymous *ftp* to connect to *sgigate.sgi.com*; then *cd* to the directory */pub/Performer/selected-topics* and use *ls* to see a list of available topics. Alternatively, use a World Wide Web browser to look at <ftp://sgigate.sgi.com/pub/Performer/selected-topics>.

Electronic forum for discussions about IRIS Performer:

- The *info-performer* mailing list provides a forum for discussion of IRIS Performer including technical and non-technical issues. Subscription requests should be sent to info-performer-request@sgi.com. Much like the *comp.sys.sgi.** newsgroups on the Internet, it isn't an official support channel but is monitored by several interested Silicon Graphics employees familiar with the toolkit.

For other related reading, see "Bibliography" on page xxxvi.

How to Use This Guide

The best way to get started is to read the “IRIS Performer Getting Started” manual. If you like learning from sample code, turn to Chapter 1, “Getting Acquainted With IRIS Performer,” which takes you on a tour of some demo programs. These programs let you see for yourself what IRIS Performer does. Even if you aren’t developing a visual simulation application, you might want to look at the demos to see high-performance rendering in action. At the end of Chapter 2 you’ll find suggestions pointing to possible next steps; alternatively, you can browse through the summary below to find a topic of interest.

What This Guide Contains

This guide is divided into the following chapters and appendices:

- Chapter 1, “IRIS Performer Programming Interface,” describes the fundamental ideas behind the Performer programming interface.
- Chapter 2, “Setting Up the Display Environment,” describes how to set up rendering pipelines, windows, and channels (cameras).
- Chapter 3, “Nodes and Node Types,” describes the data structures used in IRIS Performer’s memory-based scene-definition databases.
- Chapter 4, “Database Traversal,” explains how to manipulate and examine a scene graph.
- Chapter 5, “Frame and Load Control,” explains how to control frame rate, synchronization, and dynamic load management. This chapter also discusses the load management techniques of multiprocessing and level-of-detail.
- Chapter 6, “Creating Visual Effects,” describes how to use environmental, atmospheric, lighting, and other visual effects to enhance the realism of your application.
- Chapter 7, “Importing Databases,” describes database formats and sample conversion utilities.
- Chapter 8, “Geometry,” discusses the classes used to create geometry in Performer scenes.
- Chapter 9, “Graphics State,” describes the graphics state, which contains all of the fields that together define the appearance of geometry.

- Chapter 10, “ClipTextures,” describes how to work with large, high-resolution textures.
- Chapter 11, “Windows,” describes how to create, configure, manipulate, and communicate with a window in Performer.
- Chapter 12, “pfPipeWindows and pfPipeVideoChannels,” describes the unified window and video channel control and management provided by pfPipeWindows and pfPipeVideoChannels.
- Chapter 13, “Managing Nongraphic System Tasks,” describes clocks, memory allocation, synchronous I/O, error handling and notification, and search paths.
- Chapter 14, “Dynamic Data,” describes how to connect pfFlux, pfFCS, and pfEngine nodes, which together can be used for animating geometries.
- Chapter 15, “Active Surface Definition,” describes the Active Surface Definition (ASD): a library that handles real-time surface meshing and morphing.
- Chapter 16, “Light Points,” describes the calligraphic lights, which are intensely bright lights.
- Chapter 17, “Math Routines,” details the comprehensive math support provided as part of IRIS Performer.
- Chapter 18, “Statistics,” discusses the various kinds of statistics you can collect and display about the performance of your application.
- Chapter 19, “Performance Tuning and Debugging,” explains how to use performance measurement and debugging tools and provides hints for getting maximum performance.
- Chapter 20, “Programming with C++,” discusses the differences between using the C and C++ programming interfaces.

Sample Applications

You can find the sample code for all of the sample IRIS Performer applications installed under */usr/share/Performer/src/pguide*.

Conventions

This guide uses the following typographical conventions:

Bold is used for function names, with parentheses appended to the name. Also, bold lowercase letters represent vectors, and bold uppercase letters denote matrices.

Italics indicates filenames, IRIX command names, command-line option flags, variables, and book titles.

`Fixed-width` is used for code examples and system output.

Fixed-width indicates user input, items that you should type in from the keyboard.

Note that in some cases it's convenient to refer to a group of similarly named IRIS Performer functions by a single name; in such cases an asterisk is used to indicate all the functions whose names start the same way. For instance, **pfNew***() refers to all functions whose names begin with "pfNew": **pfNewChan()**, **pfNewDCS()**, **pfNewESky()**, **pfNewGeode()**, and so on.

Most code examples in this guide are written in C; some are in C++. All code examples are available in both C and C++ forms in the source directory `/usr/share/Performer/src/pguide`.

Bibliography

You should be familiar with most of the concepts presented in the first few books listed here—notably *Computer Graphics: Principles and Practice* and the OpenGL or IRIS GL™ books—to make the best use of IRIS Performer and this programming guide. Most of the other books listed here, however, delve into more advanced topics and are listed as further reading for those interested. Information is also provided on electronic access to Silicon Graphics' files containing answers to frequently asked IRIS Performer questions.

Computer Graphics

For a general treatment of a wide variety of graphics-related topics, see:

- Foley, J.D., A. van Dam, S.K. Feiner, and J.F. Hughes. *Computer Graphics: Principles and Practice*, 2nd Ed. Reading, Mass.: Addison-Wesley Publishing Company, Inc., 1990.
- Newman, W.M., and R.F. Sproull, *Principles of Interactive Computer Graphics*, 2nd Ed. New York: McGraw-Hill, Inc., 1979.

For specific topics of interest to developers using IRIS Performer, also see:

- Akeley, Kurt, "RealityEngine Graphics," *Computer Graphics Annual Conference Series (SIGGRAPH)*, 1993. pp. 309-318.
- Michael Jones, Sharon Clay, James Helman, John Rohlf, Andy Bigos, Philippe Tarbouriech, Wes Hoffman, Eric Johnston, Michael Limber, and Scott Watson, "Designing Real-Time 3D Graphics for Entertainment," *Course Notes of 1997 SIGGRAPH Course #6*.
- Willis, L. R., Jones, M. T., and Zhao, J. "A Method for Continuous Adaptive Terrain", *Proceedings of the 1996 Image Conference*. June 23-28, 1996, Scottsdale Arizona.
- John S. Montrym, Daniel R. Baum, David L. Dignam, Christopher J. Migdal, "InfiniteReality: A Real-Time Graphics System," *Computer Graphics Annual Conference Series (SIGGRAPH)*, 1997. pp. 293-302.
- Rohlf, John and James Helman, "IRIS Performer: A High Performance Multiprocessing Toolkit for Real-Time 3D Graphics," *Computer Graphics Proceedings, Annual Conference Series (SIGGRAPH)*, 1994, pp. 381-394.
- Shoemake, Ken. "Animating Rotation with Quaternion Curves," *SIGGRAPH '85 Conference Proceedings Vol 19, Number 3, 1985*. The IRIS GL and OpenGL Graphics Libraries

For information about IRIS GL, see these Silicon Graphics publications:

- *Graphics Library Programming Guide*, Volumes I and II
- *Graphics Library Programming Tools and Techniques*

To order all three of the above manuals, call 1-800-800-SGI1 (in the U.S. and Canada) and specify part number M4-GLGT-5.2. Outside the U.S. and Canada, please contact your local sales office or distributor.

For information about OpenGL, see:

- Neider, Jackie, Tom Davis, and Mason Woo, *OpenGL Programming Guide*. Reading, Mass.: Addison-Wesley Publishing Company, Inc., 1993. A comprehensive guide to learning OpenGL.
- OpenGL Architecture Review Board, *OpenGL Reference Manual*. Reading, Mass.: Addison-Wesley Publishing Company, Inc., 1993. A compilation of OpenGL reference pages.
- *The OpenGL Porting Guide*, a Silicon Graphics publication shipped in IRIS InSight-viewable on-line format. Provides information on updating IRIS GL-based software to use OpenGL.

X, Xt, IRIS IM, and Window Systems

In conjunction with OpenGL, you may wish to learn about the X window system, the Xt Toolkit Intrinsic library, and IRIS IM (though note that if you use IRIS Performer's pfWindow routines, windows are handled for you; in that case you don't need to know about any of these topics). For information on X, Xt, and Motif, see the O'Reilly X Window System Series, Volumes 1, 2, 4, and 5 (usually referred to simply as "O'Reilly" with a volume number):

- Nye, Adrian, Volume One: Xlib Programming Manual. Sebastopol, California: O'Reilly & Associates, Inc., 1991.
- Volume Two: Xlib Reference Manual, published by O'Reilly & Associates, Inc., Sebastopol, California.
- Volume Four: X Toolkit Intrinsic Programming Manual, by Adrian Nye and Tim O'Reilly, published by O'Reilly & Associates, Inc., Sebastopol, California.
- Volume Five: X Toolkit Intrinsic Reference Manual, published by O'Reilly & Associates, Inc., Sebastopol, California.

For information on IRIS IM, Silicon Graphics' port of OSF/Motif™, and on making your application interact well with the Silicon Graphics desktop, see these Silicon Graphics publications:

- *IRIS IM Programming Guide (007-1472-nnn)*
- *Indigo Magic User Interface Guidelines (007-2167-nnn)*
- *Indigo Magic Desktop Integration Guide (007-2006-nnn)*

All three of these books are shipped in IRIS InSight™-viewable on-line format.

Visual Simulation

For information about visual simulation and the use of simulation systems in training and research, see:

- Rolfe, J.M., and K.J. Staples, eds. *Flight Simulation*. Cambridge: Cambridge University Press, 1986. Provides a comprehensive overview of visual simulation from the basic equations of motion to the design of simulator cabs, optical and display systems, motion bases, and instructor/operator stations. Also includes a historical overview and an extensive bibliography of visual simulation and aerodynamic simulation references.
- Rougelot, Rodney S. "The General Electric Computer Color TV Display," in Faiman, M., and J. Nievergelt, eds. *Pertinent Concepts in Computer Graphics*. Urbana, Ill.: University of Illinois Press, 1969, pp. 261-281. This extensive report gives an excellent overview of the origins of visual simulation. It shows many screen images of the original systems developed for various NASA programs and includes the first real-time textured image. This article provides the basis for understanding the historical development of computer image generation and real-time graphics.
- Schacter, Bruce J., ed. *Computer Image Generation*. New York: John Wiley & Sons, Inc., 1983. Reviews the computer image generation process and provides a detailed analysis of early approaches to system design and implementation. The bibliography refers to early papers by the designers of the first image-generation systems.

Mathematics of Flight Simulation

Stevens, Brian L., and Frank L. Lewis. *Aircraft Control and Simulation*. New York: John Wiley & Sons, Inc., 1992. This book describes the complete implementation of a flight-dynamics model for the F-16 fighter aircraft. It provides the basic equations of motion and explains how the more complex issues are handled in practice. Some source code, in FORTRAN, is included.

Virtual Reality

Kalawsky, Roy S. *Science of Virtual Reality and Virtual Environments*. Reading, Mass.: Addison-Wesley Publishing Company, Inc., 1993.

Geometric Reasoning

These two books address geometric reasoning in general, rather than any specifically computer-related or Performer-specific topics:

- Abbott, Edwin A. *Flatland: A Romance of Many Dimensions*, 6th Ed. New York: Dover Publications, Inc., 1952. The story of A. Square and his journeys among the dimensions.
- Polya, George. *How to Solve It: A New Aspect of Mathematical Method*, 2nd Ed. Princeton, NJ: Princeton University Press, 1973.

Conference Proceedings

The proceedings of the I/ITSEC (Interservice/Industry Training, Simulation, and Education Conference) are a primary source of published visual simulation experience. In the past this conference has been known as the National Training Equipment Center/Industry Conference (NTEC/IC) and the Interservice/Industry Training Equipment Conference (I/ITEC). Proceedings are available from the National Technical Information Service (NTIS). Here are NTIS order numbers for several of the older proceedings:

- Seventh N/IC, November 1974: AD-A000-970 NTEC
- Eighth N/IC, November 1975: AD-A028-885 NTEC
- Ninth N/IC, November 1976: AD-A031-447 NTEC
- Tenth N/IC, November 1977: AD-A047-905 NTEC
- Eleventh N/IC, November 1978: AD-A061-381 NTEC
- First I/ITEC, November 1979: AD-A077-656 NTEC
- Third I/ITEC, November 1981: AD-A109-443 NTEC

The IMAGE Society is dedicated solely to the advancement of visual simulation technology and its applications. It holds conferences and workshops, the proceedings of which are an excellent source of advice and guidance for visual simulation developers. The society can be reached through electronic mail at image@acvax.inre.asu.edu. Some of the IMAGE proceedings published by the Air Force Human Resources Lab AFHRL at Williams AFB prior to the formation of the IMAGE Society are also available from the NTIS. Order numbers are:

- IMAGE, May, 1977: AD-A044-582 AFHRL
- IMAGE II (closing), July, 1981: AD-A104-676 AFHRL
- IMAGE II (proceedings), November, 1981: AD-A110-226 AFHRL

The Society of Photo-Optical Instrumentation Engineers (SPIE) also has articles of interest to visual simulation developers in their conference proceedings. Some of the interesting publications are:

- Vol. 17, *Photo-Optical Techniques in Simulators*, April, 1969
- Vol. 59, *Simulators & Simulation*, March, 1975
- Vol. 162, *Visual Simulation & Image Realism*, August, 1978

Survey Articles in Magazines

- *Aviation Week & Space Technology*, January 17, 1983. Special issue on visual simulation.
- Fischetti, Mark A., and Carol Truxal. "Simulating the Right Stuff." *IEEE Spectrum*, March, 1985, pp. 38-47.
- Schacter, Bruce. "Computer Image Generation for Flight Simulation." *IEEE Computer Graphics & Applications*, October, 1981, pp. 29-68.
- Schacter, Bruce, and Narendra Ahuja. "A History of Visual Flight Simulation." *Computer Graphics World*, May, 1980, pp. 16-31.
- Tucker, Jonathan B., "Visual Simulation Takes Flight." *High Technology Magazine*, December, 1984, pp. 34-47.

“IRIS Performer Programming Interface”

This chapter describes the fundamental ideas behind the IRIS Performer programming interface.

IRIS Performer Programming Interface

This chapter describes the fundamental ideas behind the IRIS Performer programming interface in the following sections:

- “General Naming Conventions” on page 3
- “Class API” on page 5
- “Base Classes” on page 8.

General Naming Conventions

The IRIS Performer API uses naming conventions to help you understand what a given command will do and even predict the appropriate names of routines for desired functionality. Following similar naming practices in the software that you develop will make it easier for you and others on your team to understand and debug your code.

The API is largely object-oriented; it contains classes of objects comprised of methods that:

- Configure their parent objects.
- Apply associated operations, based on the current configuration of the object.

Both C and C++ bindings are provided for IRIS Performer. In addition, naming conventions provide a consistent and predictable API and indicate the kind of operations performed by a given command.

Prefixes

The prefix of the command tells you in which library a C command or C++ class is found. All exposed IRIS Performer C commands and C++ classes begin with ``pf``. The utility libraries use an additional prefix letter, such as ``pfu`` for the `libpfutil` general utility library, ``pfi`` for the `libpfui` input handling library, and ``pfd`` for the `libpfdu` database utility library. `Libpr` level commands still have the ``pf`` prefix as they are still in the main `libpf` library.

Header Files

Each IRIS Performer library contains a main header file in `/usr/include/Performer` that contains type and class definitions, the C API for that library, and global routines that are part of the C and C++ API. *Libpf* is broken into two distinct pieces: the low-level rendering layer, *libpr*, and the application layer, *libpf*, and each has their own main header file: *pr.h* and *pf.h*. Since *libpf* is considered to include *libpr*, *pf.h* includes *pr.h*. C++ class header files are found under `/usr/include/Performer/{pf, pr, ...}`. Each class has its own C++ header file and that header must be included to use that class.

```
#include <Performer/pf.h>
#include <Performer/pf/pfGroup.h>
.....
pfGroup *group;
```

Naming in C and C++

All C++ class method names have an expanded C counterpart. Typically, the C routine will include the class name in the routine, whereas the C++ method will not.

```
C: pfGetPipeScreen();
C++: pipe->getScreen();
```

For some very general routines on the most abstract classes, the class name is omitted. This is the case with the child API on `pfNodes`:

```
C: pfAddChild(node, child);
C++: node->addChild(child);
```

Command and type names are mixed case where the first letter of a new word in a name is capitalized. C++ method names always start with a lower case letter.

```
pfTexture *texture;
texture->loadFile();
```

Abbreviations

Type names do not use abbreviations. The C API acting on that type will often use abbreviations for the type names, as will the associated tokens and enums.

In procedure names, a name will always be abbreviated or never, and the same abbreviation will always be used and will be in the `pfNew*` C command. For example: the `pfTexture` object uses 'Tex' in its API, such as `pfNewTex()`. If a type name has multiple words, the abbreviation will use the first letter of the first words and then the first syllable of the last word.

```
pfPipeWindow *pwin = pfNewPWin();
pfPipeVideoChannel *pvchan = pfNewPVChan();
pfTexLOD *tlod = pfNewTLOD();
```

Macros, Tokens, and Enums

Macros, tokens, and enums all use full upper-case. Token names associated with a class and methods of a class start with the abbreviated name for that class, such as texture to "tex" in `PFTEX_SHARPEN`.

Class API

The API of a given class, such as `pfTexture`, is comprised of:

- API to create an instance of the object
- API to set parameters on the object
- API to get those parameter settings
- API to perform actions on the configured object

Object Creation

Objects are always created with

```
C: pfThing *thing = pfNewThing();
C++: pfThing *thing = new pfThing;
```

Libpf objects are automatically created out of the shared memory arena. Libpr objects take as an argument an arena pointer which, if `NULL`, will cause allocation off the heap.

Set Routines

A set routine has the form:

```
C: pfThingParam(thing, ... ) (note no 'Set' in the name)
C++: thing->setParam()
```

Set routines are usually very fast and are not order dependent. Work required to process the settings happens once when the object is first used after settings have changed. If particularly expensive options must be done, there will be a pfConfigThing routine or method to explicitly force this work that must be called before the object is to be used.

Get Routines

For every 'set' there is a matching 'get' routine to get back the value that was set.

```
C: pfGetThingParam(thing, ... )
C++: thing->getParam()
```

If the set/get is for a single value, that value is usually the return value of the routine. If there are multiple values together, the 'get' routine will then take as arguments pointers to result variables.

Getting Current In-Use Values

Get routine return values that have been previously set by the user, or default values if no settings have been made. Sometimes a value other than the user-specified value is currently in use and that is the value that you would like to get. For these cases, there is a separate 'getCur' routine to get the current in-use value.

```
C: pfGetCurThingParam()
C++: thing->getcurParam()
```

These 'cur' routines may only be able to give reasonable values in the process which associated operations are happening. Example: to get the current texture (**pfGetCurTex()**), you need to be in the draw process since that is the only process that has a current texture.

Action Routines

An action routine has the form:

```
C: pfVerbThing(), such as pfApplyTex()
C++: thing->verb(), such as tex->apply()
```

Action routines can have parameter scope and apply only to that parameter. These routines have the form

```
C: pfVerbThingParam(), such as pfApplyTexMinLOD()
C++: thing->verbParam(), such as tex->applyMinLOD()
```

Apply and Draw Routines

The Apply and Draw action routines do graphics operations and so must happen either in the draw process or in display list mode.

```
C: pfApplypfGeoState()
pfDrawGSet()
C++: gstate->apply()
gset->draw()
```

Enable and Disable of Modes

Features that can be enabled and disabled are done so with **pfEnable()** and **pfDisable()**, respectively.

pfGetEnable() takes PFEN_* tokens naming the graphics state operation to enable or disable. A **GetEnable()** is used to query enable status and will return 1 or 0 if the given mode is enabled or disabled, respectively.

```
ex: pfEnable(PFEN_TEXTURE), pfDisable(PFEN_TEXTURE),
pfGetEnable(PFEN_TEXTURE);
```

Mode, Attribute, or Value

Classes instances are configured by having their internal fields set. These fields may be simple modes or complex attribute structures. Mode values are ints or tokens, attributes are typically pointers to objects, and values are floats.

```
pfGStateMode(gstate, PFSTATE_DECAL, PFDECAL_LAYER)
pfGStateAttr(gstate, PFSTATE_TEXTURE, texPtr)
pfGStateVal(gstate, PFSTATE_ALPHAREF, 0.5)
```

Base Classes

IRIS Performer provides an object-oriented programming interface to most of its data structures. Only IRIS Performer functions can change the values of elements of these data structures; for instance, you must call **pfMtlColor()** to set the color of a **pfMaterial** structure rather than modifying the structure directly.

For a more transparent type of memory, IRIS Performer provides **pfMemory**. All object classes are derived from **pfMemory**. **pfMemory** instances must be explicitly allocated with the **new** operator and cannot be allocated statically, on the stack, or included directly in other object definitions. **pfMemory** is managed memory; it includes special fields, such as **size**, **arena**, and **ref count**, that are initialized by the **pfMemory new()** function.

Some very simple and unmanaged data types are not encapsulated for speed and easy access. Examples include **pfMatrix**, **pfSphere** and **pfVec3**. These data types are referred to as public structures and are inherited from **pfStruct**.

Unlike **pfMemory**, **pfStructs** can be:

- Allocated statically.
- Allocated on the stack.
- Included directly in other structure and object definitions.

pfStructs allocated off the stack or allocated statically are not in the shared memory arena and thus are not safe for multiprocessed use. Also, **pfStructs** allocated off the stack in a procedure do not exist after the procedure exits so they should not be given to persistent objects, such as a **pfVec3** array of vertices for a **pfGeoSet**.

In order to allow some functions to apply to multiple data types, IRIS Performer uses the concept of class inheritance. Class inheritance takes advantage of the fact that different data types (classes) often share attributes. For example, a **pfGroup** is a node which can have children. A **pfDCS** (Dynamic Coordinate System) has the same basic structure as a **pfGroup**, but also defines a transformation to apply to its children—in other words, the **pfDCS** data type inherits the attributes of the **pfGroup** and adds new attributes of its own. This means that all functions that accept a **pfGroup*** argument will alternatively accept a **pfDCS*** argument.

For example, **pfAddChild()** takes a `pfGroup*` argument, but

```
pfDCS *dcs = pfNewDCS();  
pfAddChild(dcs, child);
```

appends *child* to the list of children belonging to *dcs*.

Because the C language does not directly express the notion of classes and inheritance, arguments to functions must be cast before being passed, for example,

```
pfAddChild((pfGroup*)dcs, (pfNode*)child);
```

In the example above, no such casting is required because IRIS Performer provides macros that perform the casting when compiling with ANSI C, for example:

```
#define pfAddChild(g, c) pfAddchild((pfGroup*)g, (pfNode*)c)
```

Note: Using automatic casting eliminates type checking—the macros will cast anything to the desired type. If you make a mistake and pass an unintended data type to a casting macro, the results may be unexpected.

No such trickery is required when using the C++ API. Full type checking is always available at compile time.

Inheritance Graph

The relations between classes can be arranged in a directed acyclic inheritance graph in which each child inherits all of its parent's attributes, as illustrated in Figure 1-1. IRIS Performer does not use multiple inheritance, so each class has only one parent in the graph.

Note: It's important to remember that an inheritance graph is different from a scene graph. The inheritance graph shows the inheritance of data elements and member functions among user-defined data types; the scene graph shows the relationship among instances of nodes in a hierarchical scene definition.

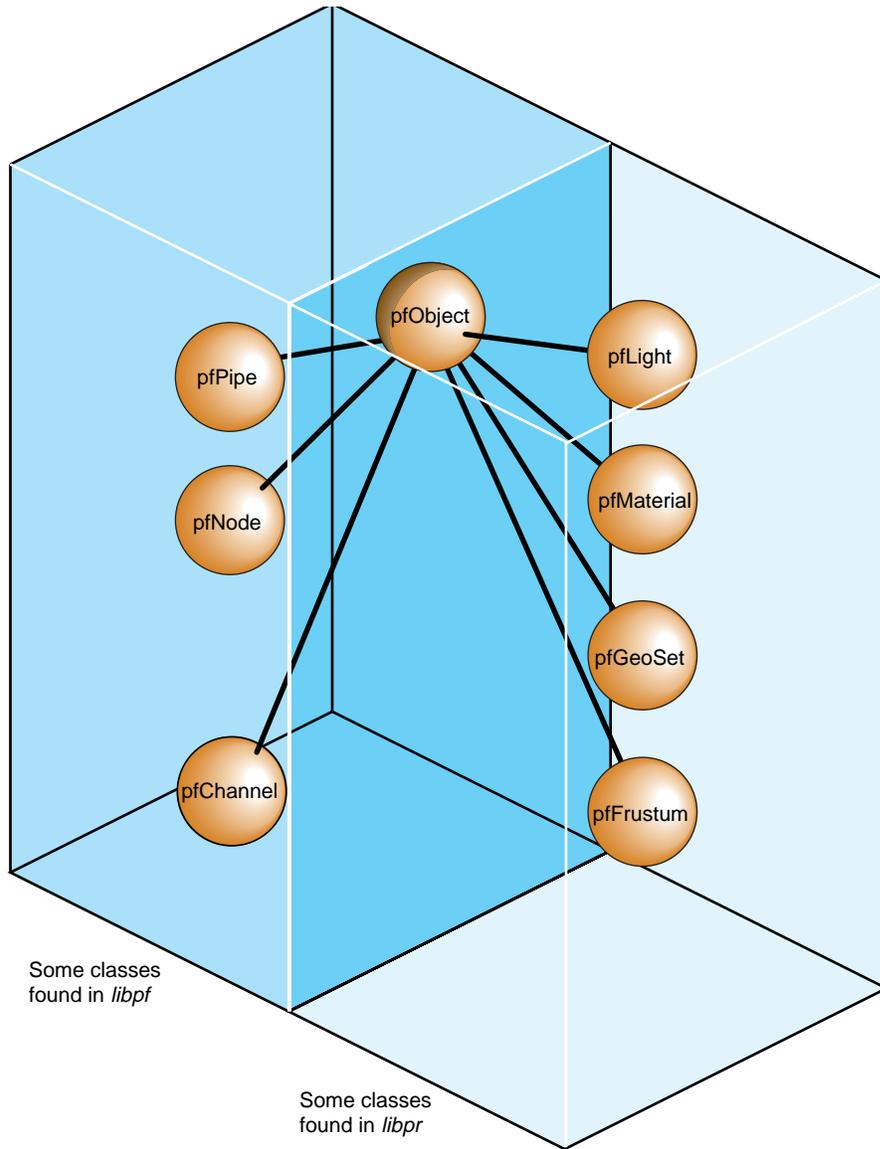


Figure 1-1 Partial Inheritance Graph of IRIS Performer Data Types

IRIS Performer objects are divided into two groups: those found in the *libpf* library and those found in the *libpr* library. These two groups of objects have some common attributes, but also differ in some respects.

While IRIS Performer only uses single inheritance, some objects encapsulate others, hiding the encapsulated object but also providing a functional interface that mimics its original one. For example a `pfChannel` has a `pfFrustum`, a `pfFrameStats` has a `pfStats`, a `pfPipeWindow` has a `pfWindow`, and a `pfPipeVideoChannel` has a `pfVideoChannel`. In these cases, the first object in each pair provides functions corresponding to those of the second. For example, `pfFrustum` has a routine,

```
pfMakeSimpleFrust(frust, 45.0f);
```

and `pfChannel` has a corresponding routine,

```
pfMakeSimpleChan(channel, 45.0f);
```

***Libpr* and *Libpf* Objects**

All of the major classes in IRIS Performer are derived from the `pfObject` class. This common, base class unifies the data types by providing common attributes and functions. *Libpf* objects are further derived from `pfUpdatable`. The `pfUpdatable` abstract class provides support for automatic multi-buffering for multiprocessing. `pfObjects` have no special support for multiprocessing and so all processes share the same copy of the `pfObject` in the shared arena. *libpr* objects allocated from the heap are only visible in the process in which they are created or in child processes created after the object. Changes made to such an object in one process are not visible in any other process.

Explicit multi-buffering of `pfObjects` is available through the `pfFlux` class. In general, *libpr* provides lightweight and low-level modular pieces of functionality that are then enhanced by more powerful *libpf* objects.

User Data

The primary attribute defined by the `pfObject` class is the custom data a user gets to define on any `pfObject` called “user data.” `pfUserDataSlot` attaches the user-supplied data pointer to user data. `pfUserData` attaches the user-supplied data pointer to user data slot. Example 1-1 shows how to use user data.

Example 1-1 How to Use User Data

```
typedef struct
{
    float coeffFriction;
    float density;
    float *dataPoints;
}
myMaterial;

myMaterial    *granite;

granite = (myMaterial *)pfMalloc(sizeof(myMaterial), NULL);
granite->coeffFriction = 0.5f;
granite->density = 3.0f;
granite->dataPoints = (float *)pfMalloc(sizeof(float)*8, NULL);
graniteMtl = pfNewMtl(NULL);

pfUserData(graniteMtl, granite);
```

pfDelete() and Reference Counting

Most kinds of data objects in IRIS Performer can be placed in a hierarchical scene graph, using instancing when an object is referenced multiple times. Scene graphs can become quite complex, which can cause problems if you're not careful. Deleting objects can be a particularly dangerous operation, for example, if you delete an object that another object still references.

Reference counting provides a bookkeeping mechanism that makes object deletion safe: an object is never deleted if its reference count is greater than zero.

All *libpr* objects (such as `pfGeoState` and `pfMaterial`) have a reference count that specifies how many other objects refer to it. A reference is made whenever an object is attached to another using the IRIS Performer routines shown in Table 1-1.

Table 1-1 Routines that Modify *libpr* Object Reference Counts

Routine	Action
pfGSetGState	Attaches a pfGeoState to a pfGeoSet
pfGStateAttr	Attaches a state structure (such as a pfMaterial) to a pfGeoState
pfGSetHlight	Attaches a pfHighlight to a pfGeoSet
pfTexDetail	Attaches a detail pfTexture to a base pfTexture
pfGSetAttr	Attaches attribute and index arrays to a pfGeoSet
pfTexImage	Attaches an image array to a pfTexture
pfAddGSet, pfReplaceGSet, pfInsertGSet	Modify pfGeoSet/pfGeode association

When object A is attached to object B, the reference count of A is incremented. Additionally, if A replaces a previously referenced object C, then the reference count of C is decremented. Example 1-2 demonstrates how reference counts are incremented and decremented.

Example 1-2 Objects and Reference Counts

```

pfGeoState *gstateA, *gstateC;
pfGeoSet *gsetB;

/* Attach gstateC to gsetB. Reference count of gstateC
 * is incremented. */
pfGSetGState(gsetB, gstateC);

/* Attach gstateA to gsetB, replacing gstateC. Reference
 * count of gstateC is decremented and that of gstateA
 * is incremented. */
pfGSetGState(gsetB, gstateA);

```

This automatic reference counting done by IRIS Performer routines is usually all you'll ever need. However, the routines **pfRef()**, **pfUnref()**, and **pfGetRef()** allow you to increment, decrement, and retrieve the reference count of a *libpr* object should you wish to do so. (These routines also work with objects allocated by **pfMalloc()**; see the *IRIS Performer Programmer's Guide* for more information).

An object whose reference count is equal to 0 can be deleted with **pfDelete()**. **pfDelete()** works for all *libpr* objects and all *pfNodes* but not for other *libpr* objects like *pfPipe* and *pfChannel*. **pfDelete()** first checks the reference count of an object. If the reference count is non-positive, **pfDelete()** decrements the reference count of all objects that the current object references, then it deletes the current object. **pfDelete()** doesn't stop here but continues down all reference chains, deleting objects until it finds one whose count is greater than zero. Once all reference chains have been explored, **pfDelete** returns a boolean indicating whether it successfully deleted the first object or not. Example 1-3 illustrates the use of **pfDelete()** with *libpr*.

Example 1-3 Using **pfDelete()** with *libpr* Objects

```
pfGeoState *gstate0, *gstate1;
pfMaterial *mtl;
pfGeoSet *gset;

gstate0 = pfNewGState(arena); /* initial ref count is 0 */
gset = pfNewGSet(arena); /* initial ref count is 0 */
mtl = pfNewMtl(arena); /* initial ref count is 0 */

/* Attach mtl to gstate0. Reference count of mtl is
 * incremented. */
pfGStateAttr(gstate0, PFSTATE_FRONTMTL, mtl);

/* Attach mtl to gstate1. Reference count of mtl is
 * incremented. */
pfGStateAttr(gstate1, PFSTATE_FRONTMTL, mtl);

/* Attach gstate0 to gset. Reference count of gstate0 is
 * incremented. */
pfGSetGState(gset, gstate0);

/* This deletes gset, gstate0, but not mtl since gstate1 is
 * still referencing it. */
pfDelete(gset);
```

Example 1-4 illustrates the use of **pfDelete()** with *libpf*.

Example 1-4 Using **pfDelete()** with *libpf* Objects

```
pfGroup *group;
pfGeode *geode;
pfGeoSet *gset;

group = pfNewGroup(); /* initial parent count is 0 */
geode = pfNewGeode(); /* initial parent count is 0 */
gset = pfNewGSet(arena); /* initial ref count is 0 */

/* Attach geode to group. Parent count of geode is
 * incremented. */
pfAddChild(group, geode);

/* Attach gset to geode. Reference count of gset is
 * incremented. */
pfAddGSet(geode, gset);

/* This has no effect since the parent count of geode is 1.*/
pfDelete(geode);

/* This deletes group, geode, and gset */
pfDelete(group);
```

Some notes about reference counting and **pfDelete()**:

- All reference count modifications are locked so that they guarantee mutual exclusion when multiprocessing.
- Objects added to a **pfDispList** don't have their counts incremented due to performance considerations.
- In the multiprocessing environment of *libpf*, the successful deletion of a **pfNode** doesn't have immediate effect but is delayed one or more frames until all processes in all processing pipelines are through with the node. This accounts for the fact that **pfDispLists** don't reference-count their objects.

- **pfUnrefDelete(obj)** is shorthand for

```
if(pfUnref(obj) ==0)
    pfDelete(obj);
```

This is true when **pfUnrefGetRef** is atomic.

- Objects whose count reaches zero are not automatically deleted by IRIS Performer. You must specifically request that an object be deleted with **pfDelete()** or **pfUnrefDelete()**.

Copying Objects with pfCopy()

pfCopy() is currently implemented for *libpr* (and **pfMalloc()**) objects only. Object references are copied and reference counts are modified appropriately, as illustrated in Example 1-5.

Example 1-5 Using pfCopy()

```
pfGeoState *gstate0, *gstate1;
pfMaterial *mtlA, *mtlB;

gstate0 = pfNewGState(arena);
gstate1 = pfNewGState(arena);
mtlA = pfNewMtl(arena); /* initial ref count is 0 */
mtlB = pfNewMtl(arena); /* initial ref count is 0 */

/* Attach mtlA to gstate0. Reference count of mtlA is
 * incremented. */
pfGStateAttr(gstate0, PFSTATE_FRONTMTL, mtlA);

/* Attach mtlB to gstate1. Reference count of mtlB is
 * incremented. */
pfGStateAttr(gstate1, PFSTATE_FRONTMTL, mtlB);

/* gstate1 = gstate0. The reference counts of mtlA and mtlB
 * are 2 and 0 respectively. Note that mtlB is NOT deleted
 * even though its reference count is 0. */
pfCopy(gstate1, gstate0);
```

pfMalloc and the related routines provide a consistent method to allocate memory, either from the user's heap (using the C-library malloc function) or from a shared memory arena (using the IRIX malloc function).

Printing Objects with pfPrint()

pfPrint() can print many different kinds of objects to a file, for example, you can print nodes and geosets. To do so, you specify in the argument of the function the object to print, the level of verbosity, and the destination file. An additional argument, *which*, specifies different data according to the type of object being printed.

The different levels of verbosity include:

- PFPRINT_VB_OFF—no printing.
- PFPRINT_VB_ON—minimal printing (default).
- PFPRINT_VB_NOTICE—minimal printing (default).
- PFPRINT_VB_INFO—considerable printing.
- PFPRINT_VB_DEBUG—exhaustive printing.

If the object to print is a type of pfNode, *which* specifies whether the print traversal should only traverse the current node (PFTRAV_SELF) or the entire scene graph where the node specified in the argument is the root node (PFTRAV_SELF | PFTRAV_DESCEND). For example, to print an entire scene graph, in which *scene* is the root node, to the file, *fp*, with default verbosity, use the following line of code.

```
file = fopen ("scene.out", "w");
pfPrint(scene, PFTRAV_SELF | PFTRAV_DESCEND, PFPRINT_VB_ON, fp);
fclose(file);
```

If the object to print is a pfFrameStats, *which* should specify a bitmask of the frame statistics classes that you want printed. The values for the bitmask include:

- PFSTATS_ON Enables the specified classes.
- PFSTATS_OFF Disables the specified classes.
- PFSTATS_DEFAULT Sets the specified classes to their default values.
- PFSTATS_SET Sets the class enable mask to enmask.

For example, to print select classes of a pfFrameStats structure, *stats*, to stderr, use the following line of code.

```
pfPrint(stats, PFSTATS_ENGFX | PFFSTATS_ENDB | PFFSTATS_ENCULL,
        PFSTATS_ON, NULL);
```

If the object to print is a `pfGeoSet`, *which* is ignored and information about that `pfGeoSet` is printed according to the verbosity indicator. The output contains the types, names, and bounding volumes of the nodes and `pfGeoSets` in the hierarchy. For example, to print the contents of a `pfGeoSet`, *gset*, to `stderr`, use the following line of code.

```
pfPrint(gset, NULL, PFPRINT_VB_DEBUG, NULL);
```

Note: When the last argument, *file*, is set to `NULL`, the object is printed to `stderr`.

Determining Object Type

Sometimes you have a pointer to a `pfObject` but you don't know what it really is—is it a `pfGeoSet`, a `pfChannel`, or something else? `pfGetType()` returns a `pfType` which specifies the type of a `pfObject`. This `pfType` can be used to determine the class ancestry of the object. Another set of routines, one for each class, returns the `pfType` corresponding to that class, e.g. `pfGetGroupClassType()` returns the `pfType` corresponding to `pfGroup`.

`pfIsOfType()` tells whether an object is derived from a specified type, as opposed to being the exact type.

With these functions you can test for class type as shown in Example 1-6.

Example 1-6 General-Purpose Scene Graph Traverser

```
void
travGraph(pfNode *node)
{
    if (pfIsOfType(node, pfGetDCSClassType()))
        doSomethingTransforming(node);

    /* If 'node' is derived from pfGroup then recursively
     * traverse its children */
    if (pfIsOfType(node, pfGetGroupClassType()))
        for (i = 0; i < pfGetNumChildren(node); i++)
            travGraph(pfGetChild(node, i));
}
```

Because IRIS Performer allows subclassing of built-in types, when decisions are made based on the type of an object, it is usually better to use `pfIsOfType()` to test the type of an object rather than to test for the strict equality of the `pfTypes`. Otherwise the code will not have reasonable default behavior with file loaders or applications which use subclassing.

The `pfType` returned from `pfGetType()` is useful for programs but it is not in a readable form for you. Calling `pfGetTypeName()` on a `pfType` returns a null-terminated ASCII string that identifies an object's type. For a `pfDCS`, for example, `pfGetTypeName()` returns the string, "pfDCS." The type returned by `pfGetType()` can then be compared to a class type using `pfIsOfType()`. Class types can be returned by methods such as `pfGetGroupClassType()`.

“Setting Up the Display Environment”

This chapter describes how to create a display environment by configuring rendering pipelines, channels, and viewpoints.

Setting Up the Display Environment

libpf is a visual-database processing and rendering system. The visual database has at its root a *pfScene* (as described in Chapter 3 and Chapter 4). The chain of events in leading from the scene graph to the display includes:

1. A *pfScene* is viewed by a *pfChannel*.
2. The *pfChannel* view of the *pfScene* is rendered by a *pfPipe* into a frame buffer.
3. A *pfPipeWindow* manages the frame buffer.
4. The images in the frame buffer are transmitted to a display system which is managed by a *pfPipeVideoChannel*.

Figure 2-1 shows this chain of events.

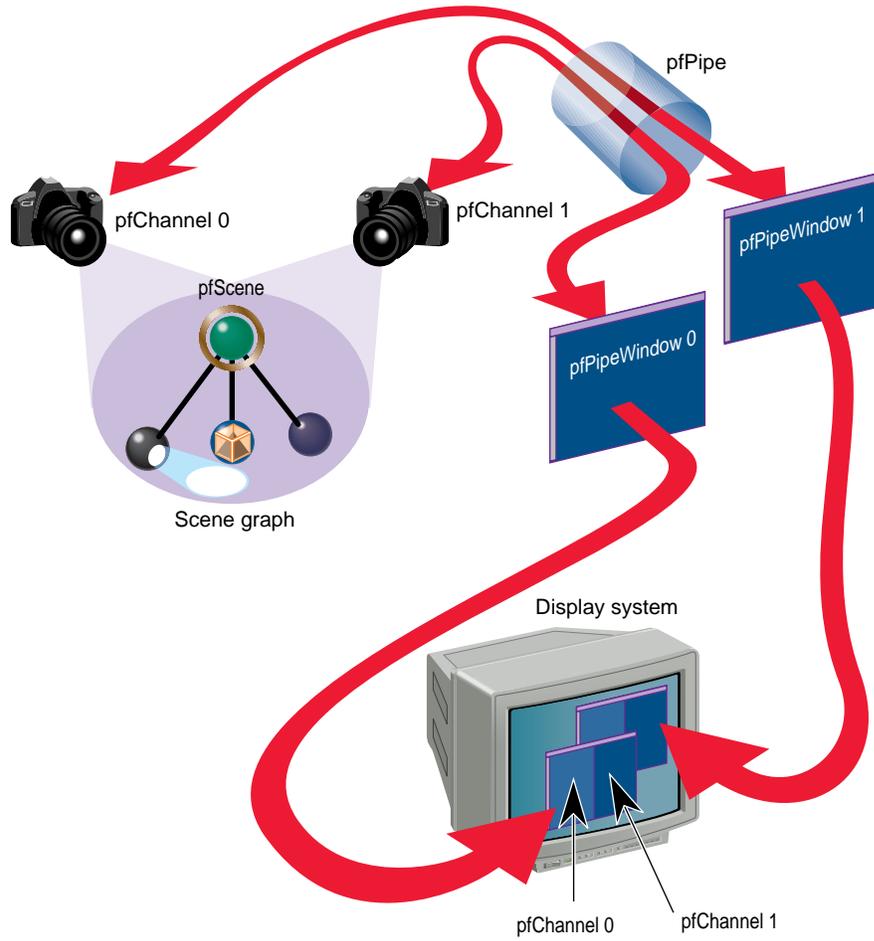


Figure 2-1 From Scene Graph to Visual Display

This chapter describes how to implement this chain of events using pfPipes, pfPipeWindows, and pfChannels.

Using Pipes

This section describes *rendering pipelines* (pfPipes) and their implementation in IRIS Performer. Each rendering pipeline draws into one or more windows (pfPipeWindows) associated with a single Geometry Pipeline. A minimum of one rendering pipeline is required, although it is possible to have more than one.

The Functional Stages of a Pipeline

This rendering pipeline comprises three primary functional stages:

APP	Simulation processing, which includes reading input from control devices, simulating the vehicle dynamics of moving models, updating the visual database, and interacting with other networked simulation stations.
CULL	Traverses the visual database and determines which portions of it are potentially visible (a procedure known as <i>culling</i>), selects a <i>level of detail</i> for each model, sorts objects and optimizes state management, and generates a display list for the draw function.
DRAW	Traverses the display list and issues graphics library commands to a Geometry Pipeline in order to create an image for subsequent display.

Figure 2-2 shows the process flow for a single-pipe system. The application constructs and modifies the scene definition (a pfScene) associated with a channel. The traversal process associated with that channel's pfPipe then traverses the scene graph, building an IRIS Performer *libpr* display list. As shown in the figure, this display list is used as input to the draw process that performs the actual graphics library actions required to draw the image.

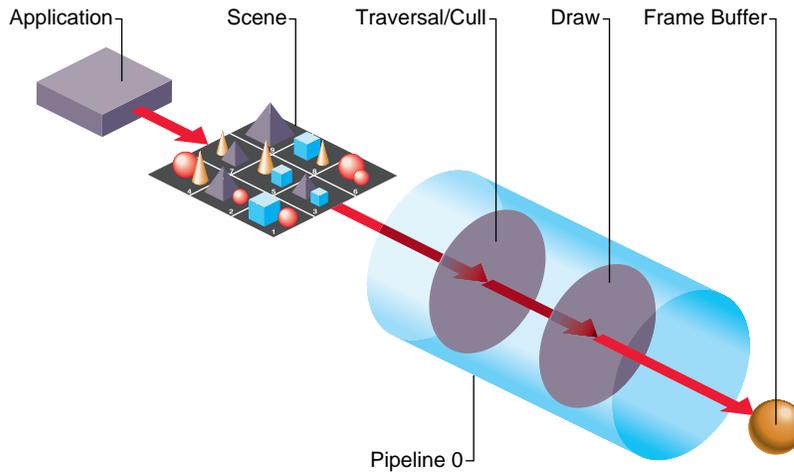


Figure 2-2 Single Graphics Pipeline

IRIS Performer also provides additional processes for application processing tasks, such as database loading and intersection traversals, but these processes are per-application and are asynchronous to the software rendering pipeline(s).

An IRIS Performer application renders images using one or more pfPipes. Each pfPipe represents an independent software-rendering pipeline. Most IRIS systems contain only one Geometry Pipeline™, so a single pfPipe is usually appropriate. This single pipeline is often associated with a window that occupies the entire display surface.

Alternative configurations include Onyx2™ systems with InfiniteReality graphics (allowing up to eight Geometry Pipelines). Applications can render into multiple windows, each of which is connected to a single Geometry Pipeline through a pfPipe rendering pipeline.

Figure 2-3 shows the process flow for a dual-pipe system. Notice both the differences and similarities between these two figures. Each pipeline (pfPipe) is independent in multiple-pipe configurations; the traversal and draw tasks are separate, as are the *libpr* display lists that link them. In contrast, these pfPipes are controlled by the same application process, and in many situations access the same shared scene definition.

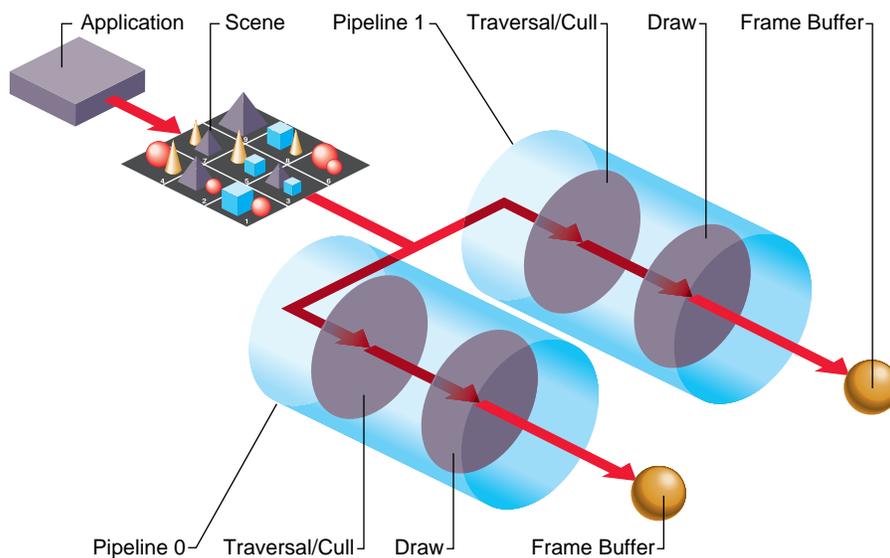


Figure 2-3 Dual Graphics Pipeline

Each of these stages can be combined into a single IRIX process or split into multiple processes (`pfMultiprocess`) for enhanced performance on multiple CPU systems. Multiprocessing and multiple pipes are advanced topics that are discussed in “Successful Multiprocessing With IRIS Performer” in Chapter 5.

Creating and Configuring a pfPipe

`pfPipes` and their associated processes are created when `pfConfig()` is called. They exist for the duration of the application. After `pfConfig()`, the application can get handles to the created `pfPipes` using `pfGetPipe()`. The argument to `pfGetPipe()` indicates which `pfPipe` to return and is an integer between 0 and `numPipes-1`, inclusive. The `pfPipe` handle is then used for further configuration of the `pfPipe`.

`pfMultipipe()` specifies the number of `pfPipes` desired. `pfMultiprocess()` specifies the multiprocessing mode used by all `pfPipes`; the default is one. These two routines are discussed further in “Successful Multiprocessing With IRIS Performer” in Chapter 5.

A key part of pfPipe initialization is the determination of the graphics hardware pipeline (or screen) and the creation of a window on that screen. The screen of a pfPipe can be set explicitly using **pfPipeScreen()**. Under single pipe operation, pfPipes can also inherit the screen of their first opened window. Under multipipe operation, the screen of all pfPipes must be determined before the pipes are configured by **pfConfigStage()** or the first call to **pfFrame()**. There may be other operations that require pre-set knowledge of the screen even under single pipes, such as custom configuration of video channels, discussed in “Creating and Configuring a pfChannel” on page 31.

Once the screen of a pfPipe has been set, it cannot be changed. All windows of a pfPipe must be opened on the same screen. A graphics window is associated with a pfPipe through the pfPipeWindow mechanism. If you do not create a pfPipeWindow, IRIS Performer will automatically create and open a full screen window with a default configuration for your pfPipe.

Once you create and initialize a pfPipe, you can query information about its configuration parameters. **pfGetPipeScreen()** returns the index number of the hardware pipeline for the pfPipe, starting from zero. On single-pipe systems the return value will be zero. If no screen has been set, the return value will be (-1). **pfGetPipeSize()** returns the full screen size, in pixels, of the rendering area associated with a pfPipe.

You may have application states associated with pfPipe stages and processes that need special initialization. For this purpose, you may provide a stage configuration callback for each pfPipe stage using **pfStageConfigFunc(pipe, stageMask, configFunc)** and specify the pfPipe, the stage bitmask (including one or more of PFPROC_APP, PFPROC_CULL, and PFPROC_DRAW), and your stage configuration callback routine. At any time, you may call the function **pfConfigStage()** from the application process to trigger the execution of your stage configuration callback in the process associated with that pfPipe’s stage. The stage configuration callback will be invoked at the start of that stage within the current frame (the current frame in the application process, and subsequent frames through the cull and draw phases of the software rendering pipeline). Use a **pfStageConfigFunc()** callback function to configure performer processes not associated with pfPipes, such as the database process, PFPROC_DBASE, and the intersection process, PFPROC_ISECT. A common process initialization task for real-time applications is the selection and/or specification of a CPU on which to run.

Example of pfPipe Use

The sample source code shipped with IRIS Performer includes several simple examples of pfPipe use in both C and C++. Specifically, look at the following examples under the C and C++ directories in */usr/share/Performer/src/pguide/libpf/*, such as *hello.c*, *simple.c*, and *multipte.c*.

Example 2-1 illustrates the basics of using pipes. The code in this example is adapted from IRIS Performer sample programs.

Example 2-1 pfPipes in Action

```
main()
{
    int i;

    /* Initialize IRIS Performer */
    pfInit();
    /* Set number of pfPipes desired -- THIS MUST BE DONE
     * BEFORE CALLING pfConfig().
     */
    pfMultipipe(NumPipes);
    /* set multiprocessing mode */
    pfMultiprocess(ProcSplit);
    ...
    /* Configure IRIS Performer and fork extra processes if
     * configured for multiprocessing.
     */
    pfConfig();
    ...

    /* Optional custom mapping of pipes to screens.
     * This is actually the reverse as the default.
     */
    for (i=0; i < NumPipes; i++)
        pfPipeScreen(pfGetPipe(i), NumPipes-(i+1));
    {
        /* set up optional DRAW pipe stage config callback */
        pfStageConfigFunc(-1 /* selects all pipes */,
            PFPROC_DRAW /* stage bitmask */,
            ConfigPipeDraw /* config callback */);
        /* Config func should be done next pfFrame */
        pfConfigStage(i, PFPROC_DRAW);
    }
}
```

```
    InitChannels();
    ...
    /* trigger the configuration and opening of pfPipes
     * and pfWindows
     */
    pfFrame();

    /* Application's simulation loop */
    while(!SimDone())
    {
        ...
    }
}

/* CALLBACK FUNCTIONS FOR PIPE STAGE INITIALIZATION */
void
ConfigPipeDraw(int pipe, uint stage)
{
    /* Application state for the draw process can be initialized
     * here. This is also a good place to do real-time
     * configuration for the drawing process, if there is one.
     * There is no graphics state or pfState at this point so no
     * rendering calls or pfApply*() calls can be made.
     */
    pfPipe *p = pfGetPipe(pipe);
    pfNotify(PFNFY_INFO, PFNFY_PRINT,
            "Initializing stage 0x%x of pipe %d", stage, pipe);
}
```

Using Channels

This section describes how to use pfChannels. A pfChannel is a view of a scene. A pfChannel is a required element for an IRIS Performer application because it establishes the visual frame of reference for what is rendered in the drawing process.

Creating and Configuring a pfChannel

When you create a new pfChannel, it is attached to a pfPipe for the duration of the application. The pfPipe renders the pfScene viewed by the pfChannel into a pfPipeWindow that is managed by that pipe. Use **pfNewChan()** to create a new pfChannel and assign it to a pfPipe. pfChannels are automatically assigned to the first pfPipeWindow of the pfPipe. In the sample program, the following statement creates a new channel and assigns it to pipe *p*.

```
chan = pfNewChan(p);
```

The pfChannel is automatically placed in the first pfPipeWindow of the pfPipe. A pfPipeWindow is created automatically if one is not explicitly created with **pfNewPWin()**.

The simplest configuration uses one pipe, one channel, and one window. You can use multiple channels in a single pfPipeWindow on a pfPipe, thereby allowing channels to share hardware resources. Using multiple channels is an advanced topic that is discussed in the section of this chapter on “Using Multiple Channels.” For now, focus your attention on understanding the concepts of setting up and using a single channel.

The primary function of a pfChannel is to define the view of a scene. A view is fully characterized by a *viewport*, a *viewing frustum*, and a *viewpoint*. The following sections describe how to set up the scene and view for a pfChannel.

Setting Up a Scene

A pfChannel draws the pfScene set by **pfChanScene()**. A channel can draw only one scene per frame but can change scenes from frame to frame. Other pfChannel attributes such as LOD modifications, described in “pfLOD Nodes” in Chapter 3, affect the scene.

A pfChannel also renders an environmental model known as pfEarthSky. A pfEarthSky defines the method for clearing the channel viewport before rendering the pfScene and also provides environmental effects, including ground and sky geometry and fog and haze. A pfEarthSky is attached to a pfChannel by **pfChanESky()**.

Setting Up a Viewport

A pfChannel is rendered by a pfPipe into its pfPipeWindow. The screen area that displays a pfChannel's view is determined by the origin and size of the window and the channel viewport specified by pfChanViewport. The channel viewport is relative to the lower left corner of the window and ranges from 0 to 1. By default, a pfChannel viewport covers the entire window.

Suppose that you want to establish a viewport that is one-quarter of the size of the window, located in the lower left corner of the window. Use **pfChanViewport(chan, 0.0, 0.25, 0.0, 0.25)** to set up the one-quarter window viewport for the channel *chan*.

You can then set up other channels to render to the other three-quarters of the window. For example, you can use four channels to create a four-way view for an architectural or CAD application. See "Using Multiple Channels" on page 40 to learn more about multiple channels.

Setting Up a Viewing Frustum

A viewing frustum is a truncated pyramid that defines a viewing volume. Everything outside this volume is clipped, while everything inside is projected onto the viewing plane for display. A frustum is defined by

- field-of-view (FOV) in the horizontal and vertical dimensions
- near and far *clipping planes*

A viewing frustum is created by the intersections of the near and far clipping planes with the top, bottom, left, and right sides of the infinite viewing volume formed by the FOV and aspect ratio settings. The aspect ratio is the ratio of the vertical and horizontal dimensions of the FOV.

Figure 2-4 shows the parameters that define a symmetric viewing frustum. To establish asymmetric frusta refer to the pfChannel(3pf) or pfFrustum(3pf) reference pages for further details.

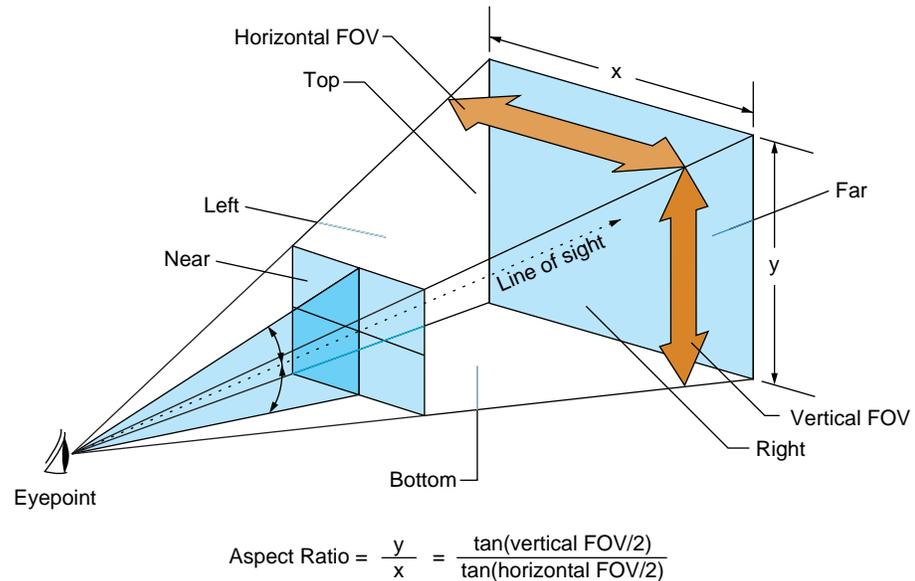


Figure 2-4 Symmetric Viewing Frustum

The viewing frustum is called *symmetric* when the vertical half-angles are equal and the horizontal half-angles are equal.

Field-of-View

The FOV is the angular width of view. Use **pfChanFOV(chan, horiz, vert)** to set up viewing angles in IRIS Performer. The quantities *horiz* and *vert* are the total horizontal and vertical fields of view in degrees; usually you specify one and let IRIS Performer compute the other. If you're specifying one angle, pass any amount less than or equal to zero, or greater than or equal to 180, as the other angle. IRIS Performer automatically computes the unspecified FOV angle to fit the pfChannel viewport using the aspect-ratio preserving relationship

$$\tan(\text{vert}/2) / \tan(\text{horiz}/2) = \text{aspect ratio}$$

That is, the ratio of the tangents of the vertical and horizontal half-angles is equal to the aspect ratio. For example, if *horiz* is 45 degrees and the channel viewport is twice as wide as it is high (so the aspect ratio is 0.5), then the vertical field-of-view angle, *vert*, is computed to be 23.4018 degrees. If both angles are unspecified, **pfChanFOV()** assumes a default value of 45 degrees for *horiz* and computes the value of *vert* as described.

Clipping Planes

Clipping planes define the near and far boundaries of the viewing volume. These distances describe the extent of the visual range in the view, because geometry outside these boundaries is *clipped*, meaning that it isn't drawn.

Use **pfChanNearFar(chan, near, far)** to specify the distance along the line of sight from the viewpoint to the *near* and *far* planes that bound the viewing volume. These clipping planes are perpendicular to the line of sight. For the best visual acuity, choose these distances so that *near* is as far away as possible from the viewpoint and *far* is as close as possible to the viewpoint. Minimizing the range between *near* and *far* provides more resolution for distance comparisons and fog computations.

Setting Up a Viewpoint

A viewpoint describes the position and orientation of the viewer. It is the origin of the viewing location, the direction of the line of sight from the viewer to the scene being viewed, and an up direction. The default viewpoint is at the origin (0, 0, 0) looking along the +Y axis, with +Z up and +X to the right.

Use **pfChanView(chan, point, dir)** to define the viewpoint for the pfChannel identified by *chan*. Specify the view origin for *point* in *x*, *y*, *z* world coordinates. Specify the view direction for *dir* in degrees by giving the degree measures of the three *Euler angles*: *heading*, *pitch*, and *roll*.

Heading is a rotation about the *z* axis, pitch is a rotation about the *x* axis, and roll is a rotation about the *y* axis. The value of *dir* is the product of the rotations $ROTy(roll) * ROTx(pitch) * ROTz(heading)$, where $ROTa(angle)$ is a rotation matrix about axis *a* of *angle* degrees.

Angles have not only a degree value, but also a *sense*, + or -, indicating whether the direction of rotation is clockwise or counterclockwise. Because different systems follow different conventions, it is very important to understand the sense of the Euler angles as they are defined by IRIS Performer. IRIS Performer follows the *right-hand rule*. According to the right-hand rule, counterclockwise rotations are positive. This means that a rotation about the x axis by +90 degrees shifts the +Y axis to the +Z axis, a rotation about the y axis by +90 degrees shifts the +Z axis to the +X axis, and a rotation about the z axis by +90 degrees shifts the +X axis to the +Y axis.

Figure 2-5 shows a toy plane (somewhat reminiscent of the Ryan S-T) at the origin of a coordinate system with the angles of rotation labeled for heading, pitch, and roll. The arrows show the direction of positive rotation for each angle.

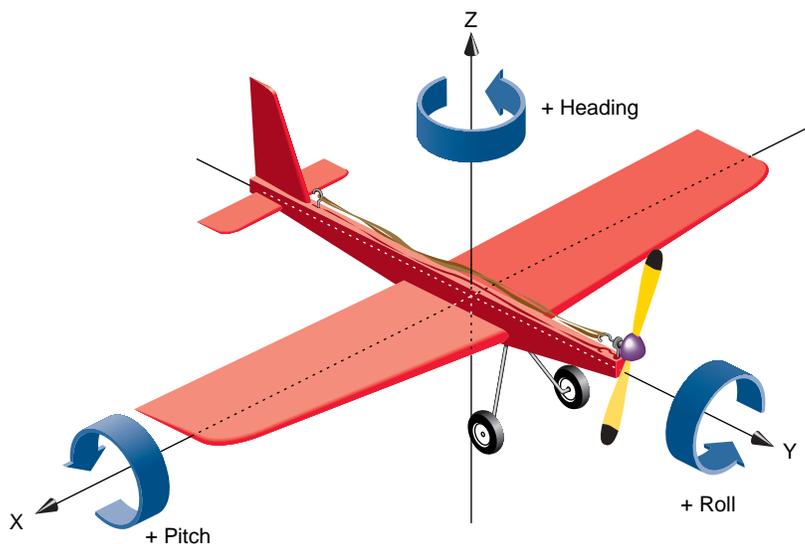


Figure 2-5 Heading, Pitch, and Roll Angles

A roll motion tips the wings from side to side. A pitch motion tips the nose up or down. A yaw motion steers the plane, changing its heading. Accurate readings of these angles are critical information for a pilot during a flight, and a thorough understanding of how the angles function together is required for creation of an accurate flight simulation visual with IRIS Performer. The same is also true of marine and other vehicle simulations.

Alternatively, you can use **pfChanViewMat(chan, mat)** to create a 4x4 homogeneous matrix *mat* that defines the view coordinate system for channel *chan*. The upper left 3x3 submatrix defines the coordinate system axes, and the bottom row vector defines the origin of the coordinate system. The matrix must be orthonormal, or the results will be undefined. You can construct matrices using tools in the *libpr* library.

The origin and heading, pitch, and roll angles, or the view matrix, create a complete view specification. The view specification can locate the eyepoint frame-of-reference origin at any point in world coordinates. The *gaze vector*, the eye's +Y axis, can point in any direction. The *up vector*, the eye's +Z axis, can point in any direction perpendicular to the gaze vector.

You can query the system for the view and eyepoint-direction values with **pfGetChanView()**, or obtain the view matrix directly with **pfGetChanViewMat()**.

The view direction can be modified by one or more offsets, relative to the eyepoint frame-of-reference. View offsets are useful in situations where several channels render the same scene into adjacent displays for a wider field-of-view or higher resolution. Offsets are also used for multiple viewer perspectives, such as pilot and copilot views.

Use **pfChanViewOffsets(chan, xyz, hpr)** to specify additional translation and rotation offsets for the viewpoint and direction; *xyz* specifies a translation vector and *hpr* specifies a heading/pitch/roll rotation vector. Viewing offsets are automatically added each frame to the view direction specified by **pfChanView()** or **pfChanViewMat()**.

For example, to create three different perspectives of the same scene as displayed by three windows in an airplane cockpit, use azimuth offsets of 45, 0, and -45 for left, middle, and right views. To create vertical view groups such as might be seen through the windscreen of a helicopter, use both azimuth and elevation offsets. Once the view offsets have been set up, you need only set the view once per frame. View offsets are applied after the eyepoint position and gaze direction have been established. As with the other angles, be aware that the conventions for measuring azimuth and elevation angles vary between graphics systems, so you should verify that the sense of the angles is correct.

Example of Channel Use

Example 2-2 shows how to use various pfChannel-related functions. The code is derived from IRIS Performer sample programs.

Example 2-2 Using pfChannels

```
main()
{
    pfInit();
    ...
    pfConfig();
    ...
    InitScene();
    InitPipe();
    InitChannel();

    /* Application main loop */
    while(!SimDone())
    {
        ...
    }
}

void InitChannel(void)
{
    pfChannel *chan;
    chan = pfNewChan(pfGetPipe(0));

    /* Set the callback routines for the pfChannel */
    pfChanTravFunc(chan, PFTRAV_CULL, CullFunc);
    pfChanTravFunc(chan, PFTRAV_DRAW, DrawFunc);

    /* Attach the visual database to the channel */
    pfChanScene(chan, ViewState->scene);

    /* Attach the EarthSky model to the channel */
    pfChanESky(chan, ViewState->eSky);

    /* Initialize the near and far clipping planes */
    pfChanNearFar(chan, ViewState->near, ViewState->far);

    /* Vertical FOV is matched to window aspect ratio. */
    pfChanFOV(chan, 45.0f/NumChans, -1.0f);

    /* Initialize the viewing position and direction */
    pfChanView(chan, ViewState->initView.xyz,
               ViewState->initView.hpr);
}
```

```

/* CULL PROCESS CALLBACK FOR CHANNEL*/
/* The cull function callback. Any work that needs to be
 * done in the cull process should happen in this function.
 */
void
CullFunc(pfChannel * chan, void *data)
{
    static long first = 1;

    if (first)
    {
        if ((pfGetMultiprocess() & PFMP_FORK_CULL) &&
            (ViewState->procLock & PFMP_FORK_CULL))
            pfuLockDownCull(pfGetChanPipe(chan));
        first = 0;
    }
    PreCull(chan, data);

    pfCull();          /* Cull to the viewing frustum */

    PostCull(chan, data);
}

/* DRAW PROCESS CALLBACK FOR CHANNEL*/
/* The draw function callback. Any graphics functionality
 * outside IRIS Performer must be done here. I/O with pure * IRIS GL
 devices must happen here.
 */
void
DrawFunc(pfChannel *chan, void *data)
{
    PreDraw(chan, data);    /* Clear the viewport, etc. */

    pfDraw();              /* Render the frame */

    /* draw HUD, read IRIS GL devices, or whatever else needs
     * to be done post-draw.
     */
    PostDraw(chan, data);
}

```

Controlling the Video Output

You use `pfPipeVideoChannel` to query and control the configuration of a hardware video channel. The methods allow you to, for example, query or specify the origin and size of the video output and scale the display.

By default, all `pfVideoChannels` on a `pfPipe` use the first entire video channel on the screen selected by the `pfPipe`. Each `pfPipeWindow` initially has a default `pfPipeVideoChannel` already assigned to it. When `pfChannels` are added to `pfPipeWindows`, they will be using, by default, this first `pfPipeVideoChannel`. You can get a `pfPipeVideoChannel` of a `pfPipeWindow` with `pfGetPWinPVChan()` and specifying the index of the `pfPipeVideoChannel` on the `pfPipeWindow`; the initial default one will be at index 0. You can then reconfigure this `pfPipeVideoChannel` to select a different video channel or change the attributes of the selected video channel. You can create a `pfPipeVideoChannel` with `pfNewPVChan()`. To use this for a given `pfChannel`, you must add it to a `pfPipeWindow` that will cover the screen area of the desired video channel. When a `pfPipeVideoChannel` is added to a `pfPipeWindow` with `pfAddPWinPVChan()`, the index into the `pfPipeWindow` list of video channels is returned and by default the `pfPipeVideoChannel` will get the next active hardware video channel after the previous `pfPipeVideoChannel` on that `pfPipeWindow`. You can explicitly select the hardware video channel with `pfPVChanId()`. The `pfChannel` will then reference this `pfPipeVideoChannel` through the index that you got back from `pfAddPWinPVChan()` and assign to the `pfChannel` with `pfChanPWinPVChanIndex()`.

```
pvc = pfNewPVChan(p);
pvcIndex = pfPWinAddPVChan(pw, pvc);
pfChanPWinPVChanIndex(chan, pvcIndex);
```

Note that the screen of the `pfPipe` must be known to fully specify the desired video channel. Queries on the `pfPipeVideoChannel` will return values indicating unknown configuration until the screen is known. The screen can be determined by IRIS Performer when the window is opened in the DRAW process but you can also explicitly set the screen of the `pfPipe` with `pfPipeScreen()`.

You can also get to the hardware video channel structure, `pfVideoChannelInfo()`, for more configuration options, such as reading gamma data or even a specific video format. For more information on `pfPipeWindows` and `pfPipeVideoChannels`, see Chapter 12, “`pfPipeWindows` and `pfPipeVideoChannels`.”

Using Multiple Channels

Each rendering pipeline can render multiple channels with multiple `pfPipeVideoChannels` to a single `pfPipeWindows`. Multiple `pfPipeWindows` can also be used but at the cost of some additional processing overhead. The `pfChannel` is assigned to the proper `pfPipeWindow` and selects its `pfPipeVideoChannel` from that `pfPipeWindow`. The `pfChannel` must also have a viewport, set with `pfChanViewport()`, that covers the proper window area to match that of the desired `pfPipeVideoChannel`.

Each channel represents an independent viewpoint into either a shared or an independent visual database. Different types of application can have vastly different pipeline-window-channel configurations. This section describes two extremes: visual simulation applications where there is typically one window per pipeline, and highly interactive uses that require dynamic window and channel configuration.

One Window per Pipe, Multiple Channels per Window

Often there will be a single channel associated with each pipeline, as shown in the top half of Figure 2-6. This section describes two important uses for multiple-channel support—multiple pipelines per system and multiple windows per pipeline—the second of which is illustrated in the bottom half of Figure 2-6.

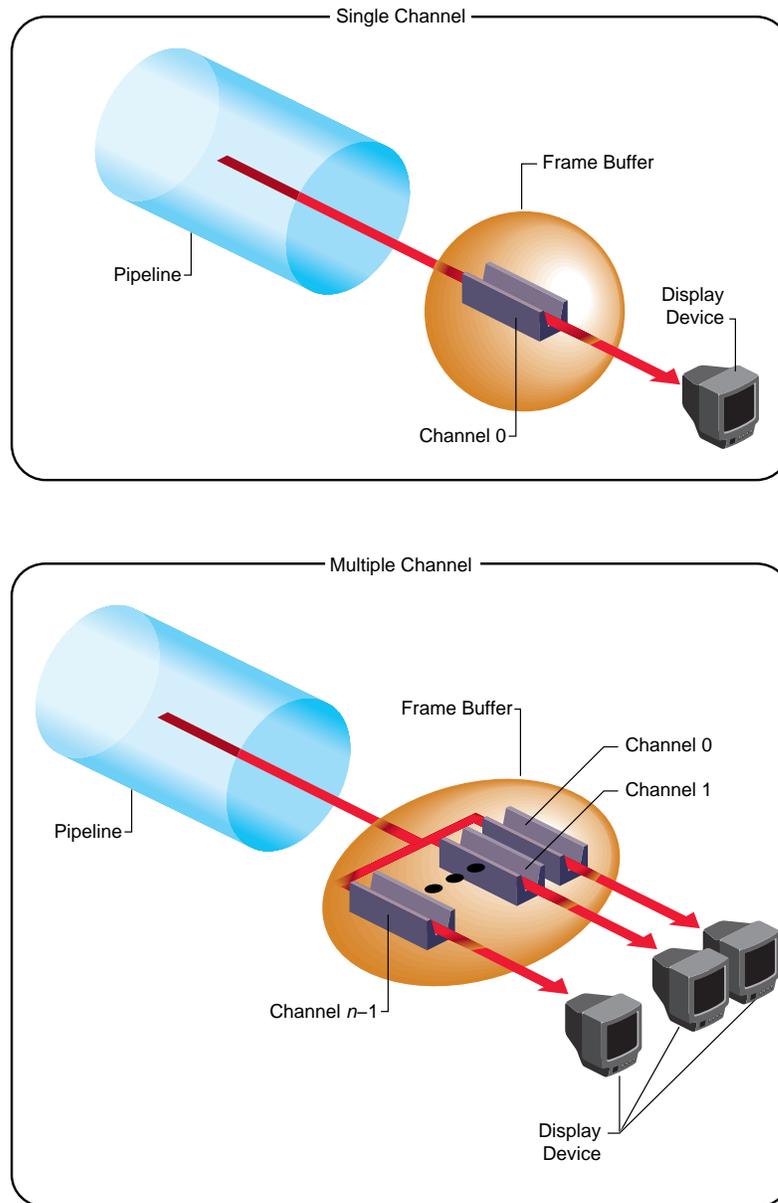


Figure 2-6 Single-Channel and Multiple-Channel Display

One situation that requires multiple channels occurs when inset views must appear within an image. A simple example of this application is a driving simulator in which the screen image represents the view out the windshield. If a rear-view mirror is to be drawn, it must overlay the main forward view to provide a separate view of the same database within the borders of the simulated mirror's frame.

Channels are physically rendered in the order that they are assigned to a `pfPipeWindow` on their parent `pfPipe`. Channels, upon creation, are assigned to the end of the channel list of the first window of their `pfPipe`. In the driving simulator example, creating pipes and channels with the following structure creates two channels on a single shared pipeline:

```
pipeline = pfGetPipe(0);
frontView = pfNewChan(pipeline);
rearView = pfNewChan(pipeline);
```

In this case, IRIS Performer's actual drawing order becomes:

1. Clear *frontView*.
2. Draw *frontView*.
3. Clear *rearView*.
4. Draw *rearView*.

This default ordering results in the rear-view mirror image always overlaying the front-view image, as desired. You can control and re-order the drawing of channels within a `pfPipeWindow` with the `pfInsertChan(pwin, where, chan)` and `pfMoveChan(pwin, where, chan)` routines. More details about multiple channels and multiple window are discussed in the next section.

When the host has multiple Geometry Pipelines, as supported on Onyx RealityEngine² systems, you can create a `pfPipe` and `pfChannel` pair for each hardware pipeline. The following code fragment illustrates a two-channel, two-pipeline configuration:

```
leftPipe = pfGetPipe(0);
leftView = pfNewChan(leftPipe);
rightPipe = pfGetPipe(1);
rightView = pfNewChan(rightPipe);
```

This configuration forms the basis for a high-performance stereo display system, since there is a hardware pipeline dedicated to each eye and rendering occurs in parallel.

The two-channel stereo-view application described in this example and the inset-view application described in the previous example can be combined to provide stereo views for a driving simulator with an inset rear-view mirror. The correct management of each eye's viewpoint and the mirror reflection helps provide a convincing sense of physical presence within the vehicle.

The third common multiple-channel situation involves support for multiple video outputs per pipeline. To do this, first associate each pipeline with a set of nonoverlapping channels, one for each desired view. Next, use one of the following video-splitting methods:

- Use the multi-channel hardware options, available from Silicon Graphics, for systems such as the 8 channel Display Generator(DG) for Onyx2 InfiniteReality, where you can create up to eight independent video outputs from a single Graphics Pipeline, with each video output corresponding to one of the tiled channels. The OCTANE video option supports four video outputs and the RealityEngine² Multi-Channel Option supports six video channels per Graphics Pipeline.
- Connect multiple video monitors in series to a single pipeline's video output. Because each monitor receives the same display image, a masking *bezel* is used to obscure all but the relevant portion of each display surface.

The three multiple-channel concepts described here can be used in combination. For example, use of three InfiniteReality pipelines, each equipped with the 8 channel DG, allows creation of up to 24 independent video displays. The channel-tiling method can also be used for some or all of these displays.

Example 2-3 shows how to use multiple channels on separate pipes.

Example 2-3 Multiple Channels, One Channel per Pipe

```
pfChannel *Chan[MAX_CHANS];

void InitChannel(int NumChans)
{
    /* Initialize each channel on a separate pipe */
    for (i=0; i< NumChans; i++)
        Chan[i] = pfNewChan(pfGetPipe(i));

    ...

    /* Make channel n/2 the master channel (can be any
     * channel).
     */
}
```

```
ViewState->masterChan = Chan[NumChans/2];

{
    long share;

    /* Get the default channel-sharing mask */
    share = pfGetChanShare(ViewState->masterChan);

    /* Add in the viewport share bit */
    share |= PFCHAN_VIEWPORT;

    if (GangDraw)
    {
        /* add GangDraw to channel share mask */
        share |= PFCHAN_SWAPBUFFERS_HW;
    }
    pfChanShare(ViewState->masterChan, share);
}

/* Attach channels */
for (i=0; i< NumChans; i++)
    if (Chan[i] != ViewState->masterChan)
        pfAttachChan(ViewState->masterChan, Chan[i]);

...
/* Continue with channel initialization */
}
```

Using Channel Groups

In many multiple-channel situations, including the examples described in the previous section, it is useful for channels to share certain attributes. For the three-channel cockpit scenario, each `pfChannel` shares the same eyepoint while the left and right views are offset using `pfChanViewOffsets()`. IRIS Performer supports the notion of *channel groups*, which facilitate attribute sharing between channels.

`pfChannels` can be gathered into channel groups that share like attributes. A channel group is created by attaching one `pfChannel` to another, or to an existing channel group. Use `pfAttachChan()` to create a channel group from two channels or to add a channel to an existing channel group. Use `pfDetachChan()` to remove a `pfChannel` from a channel group.

A *channel share mask* defines shared attributes for a channel group. The attribute tokens listed in Table 2-1 are bitwise OR-ed to create the share mask.

Table 2-1 Attributes in the Share Mask of a Channel Group

Token	Shared Attributes
PFCHAN_FOV	Horizontal and vertical fields of view
PFCHAN_VIEW	View position and orientation
PFCHAN_VIEW_OFFSETS	(<i>x, y, z</i>) and (<i>heading, pitch, roll</i>) offsets of the view direction
PFCHAN_NEARFAR	Near and far clipping planes
PFCHAN_SCENE	All channels display the same scene
PFCHAN_EARTHSKY	All channels display the same earth/sky model
PFCHAN_STRESS	All channels use the same stress filter
PFCHAN_LOD	All channels use the same LOD modifiers
PFCHAN_SWAPBUFFERS	All channels swap buffers at the same time
PFCHAN_SWAPBUFFERS_HW	Synchronize swap buffers for channels on different graphics pipelines

Use **pfChanShare()** to set the share mask for a channel group. By default, channels share all attributes except PFCHAN_VIEW_OFFSETS. When you add a pfChannel to a channel group, it inherits the share mask of that group.

A change to any shared attribute is applied to all channels in a group. For example, if you change the viewpoint of a pfChannel that shares PFCHAN_VIEW with its group, all other pfChannels in the group will acquire the same viewpoint.

Two attributes are particularly important to share in adjacent-display multiple-channel simulations: PFCHAN_SWAPBUFFERS and PFCHAN_LOD. PFCHAN_LOD ensures that geometry that straddles displays is drawn the same way in each channel. In this case, all channels will use the same LOD modifier when rendering their scenes so that LOD behavior is consistent across channels. PFCHAN_SWAPBUFFERS ensures that channels refresh the display with a new frame at the same time. pfChannels in different pfPipes that share PFCHAN_SWAPBUFFERS_HW will frame-lock the graphics pipelines together.

Example 2-4 illustrates the use of multiple channels and channel-sharing.

Example 2-4 Channel-Sharing

```
pfChannel *Chan[MAX_CHANS];

main()
{
    pfInit();
    ...
    /* Set number of pfPipes desired. THIS MUST BE DONE
     * BEFORE CALLING pfConfig().
     */
    pfMultipipe(NumPipes);
    ...
    pfConfig();
    ...
    InitScene();

    InitChannels();

    pfFrame();

    /* Application main loop */
    while(!SimDone())
    {
        ...
    }
}

void InitChannel(int NumChans)
{
    /* Initialize all channels on pipe 0 */
    for (i=0; i< NumChans; i++)
        Chan[i] = pfNewChan(pfGetPipe(0));

    ...

    /* Make channel n/2 the master channel (can be any
     * channel).
     */
    ViewState->masterChan = Chan[NumChans/2];

    ...
}
```

```
/* Attach all Channels as slaves to the master channel */
for (i=0; i< NumChans; i++)
    if (Chan[i] != ViewState->masterChan)
        pfAttachChan(ViewState->masterChan, Chan[i]);

pfSetVec3(xyz, 0.0f, 0.0f, 0.0f);
/* Set each channel's viewing offset. In this case use
 * many channels to create one multichannel contiguous
 * frustum with a 45° field of view.
 */
for (i=0; i < NumChans; i++)
{
    float fov = 45.0f/NumChans;

    pfSetVec3(hpr, (((NumChans - 1) * 0.5f) - i) * fov,
              0.0f, 0.0f);
    pfChanViewOffsets(Chan[i], xyz, hpr);
}

...

/* Now, just configure the master channel and all of the
 * other channels will share those attributes.
 */

chan = ViewState->masterChan;
pfChanTravFunc(chan, PFTRAV_CULL, CullFunc);
pfChanTravFunc(chan, PFTRAV_DRAW, DrawFunc);
pfChanScene(chan, ViewState->scene);
pfChanESky(chan, ViewState->eSky);
pfChanNearFar(chan, ViewState->near, ViewState->far);
pfChanFOV(chan, 45.0f/NumChans, -1.0f);
pfChanView(chan, ViewState->initView.xyz,
           ViewState->initView.hpr);

...
}
```

Multiple Channels and Multiple Windows

For some interactive applications, you may want to be able to dynamically control the configuration of Channels and Windows. IRIS Performer allows you to dynamically create, open, and close windows. You can also move channels amongst the windows of the shared parent pfPipe, and re-order channels within a pfPipeWindow. Channels can be appended to the end of a pfPipeWindow channel list with **pfAddChan()** and removed with **pfRemoveChan()**. A channel can only be attached to one pfPipeWindow — no instancing of pfChannels is allowed. When a pfChannel is put on a pfPipeWindow, it is automatically deleted from its previous pfPipeWindow. A channel that is not assigned to a pfPipeWindow is not drawn (though it may still be culled).

You can control and re-order the drawing of channels within a pfPipeWindow with the **pfInsertChan(pwin, where, chan)** and **pfMoveChan(pwin, where, chan)** routines. Both of these routines do a type of insertion: **pfInsertChan()** will add *chan* to *pwin*'s channel list in front of the channel in the list at location *where*. **pfMoveChan()** will delete *chan* from its old location and move it to *where* in *pwin*'s channel list.

If you have pfChannels in different pfPipeWindows or pfPipes that are supposed to combine to form a continuous scene, you will want to ensure that both the vertical retrace and doublebuffering of these windows is synchronized. This is required for both reasonable performance and visual quality. Use the genlock(7) system video feature to ensure that the vertical retraces of different graphics pipelines are synchronized. To synchronize double buffering, you want to either specify PFCHAN_SWAPBUFFERS_HW in the share mask of the pfChannels and put the pfChannels in a share group, or else create a pfPipeWindow swap group, discussed in Chapter 12, "pfPipeWindows and pfPipeVideoChannels."

“Nodes and Node Types”

This chapter describes the structure of IRIS Performer’s scene-definition databases and component data types.

Nodes and Node Types

A scene graph holds the data that defines a virtual world. The scene graph includes low-level descriptions of object geometry and their appearance, as well as higher-level, spatial information, such as specifying the positions, animations, and transformations of objects, as well as additional application-specific data.

Scene graph data is encapsulated in many different types of nodes. One node might contain the geometric data of an object; another node might contain the transformation for that object to orient and position it in the virtual world. The nodes are associated in a hierarchy that is an adirected, acyclic graph. IRIS Performer and your application can act on the scene graph to perform various complex operations efficiently, such as database intersection and rendering scenes.

This chapter focuses on the data types themselves rather than instances of those types. Chapter 4, “Database Traversal,” discusses traversing sample scene graphs in terms of actual objects rather than abstract data types.

Nodes

A scene is represented by a graph of nodes. A node is a subclass of `pfNode`. Only nodes can be in scene graphs and have child nodes. In general, nodes either contain descriptive information about scene graph geometry, or they create groups and hierarchies of nodes. Many classes, such as `pfEngine` and `pfFlux`, that are not nodes can interact with nodes.

Attribute Inheritance

The basic element of a scene hierarchy is the node. While IRIS Performer supplies many specific types of nodes, it also uses a concept called *class inheritance*, which allows different node types to share attributes. An attribute is a descriptive element of geometry or its appearance.

pfNode

IRIS Performer's node hierarchy begins with the pfNode class, as shown in Figure 3-1.

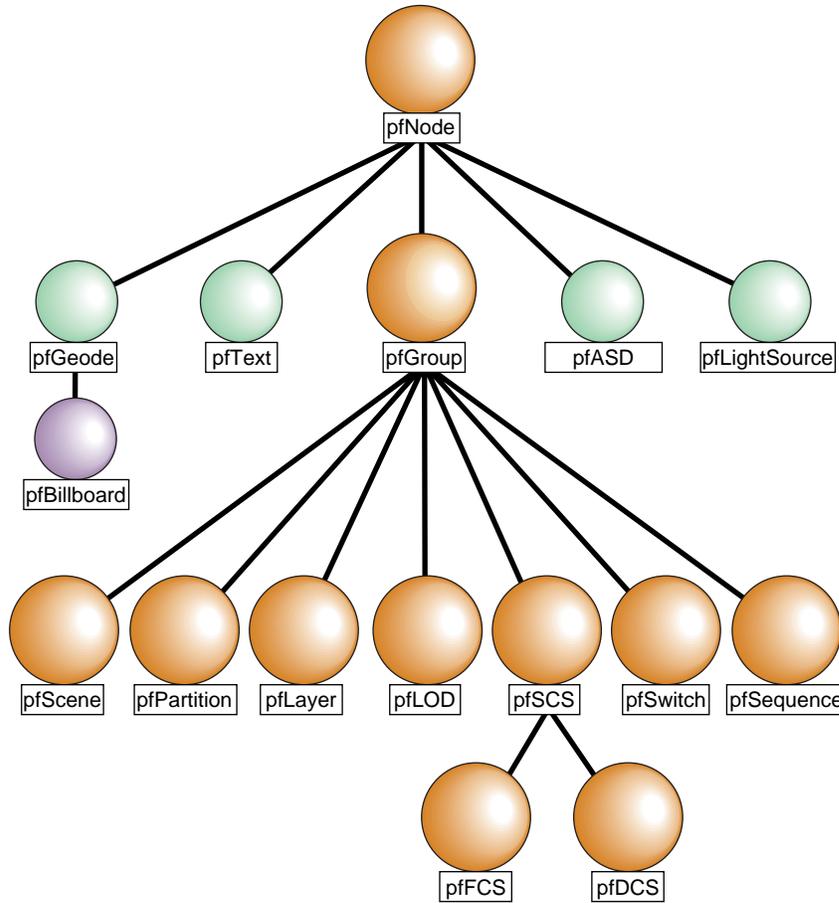


Figure 3-1 Nodes in the IRIS Performer Hierarchy

All node types are derived from pfNode; they inherit pfNode's attributes and the *libpf* routines for setting and getting attributes. In general, a node type inherits the attributes and routines of all its parent nodes in the type hierarchy.

Table 3-1 lists the basic node class and gives a simple description for each node type.

Table 3-1 IRIS Performer Node Types

Node Type	Node Class	Description
pfNode	Abstract	Basic node type
pfGroup	Branch	Groups zero or more children
pfScene	Root	Parent of the visual database
pfSCS	Branch	Static Coordinate System
pfDCS	Branch	Dynamic Coordinate System
pfFCS	Branch	Flux Coordinate System
pfSwitch	Branch	Selects among multiple children
pfSequence	Branch	Sequences through its children
pfLOD	Branch	Level-of-detail node
pfLayer	Branch	Renders coplanar geometry
pfLightSource	Leaf	Contains specifications for a light source
pfGeode	Leaf	Contains geometric specifications
pfBillboard	Leaf	Rotates geometry to face the eyepoint
pfPartition	Branch	Partitions geometry for efficient intersections
pfText	Leaf	Renders 2D and 3D text
pfASD	Leaf	Controls transition between LOD levels.

pfNode

As shown in Figure 3-1, all *libpf* nodes are arranged in a type hierarchy, which defines the inheritance of functionality. A pfNode is an abstract class, meaning that a pfNode can never be explicitly created by an application, and all other nodes inherit the functionality of pfNode.. Its purpose is to provide a root to the type hierarchy and to define the attributes that are common to all node types.

pfNode Attributes

The following pfNode attributes are inherited by all other *libpf* node types:

- Node name
- Parent list
- Bounding geometry
- Intersection and traversal masks
- Callback functions and data
- User data

Bounding geometry, intersection masks, user data, and callbacks are advanced topics that are discussed in Chapter 4, “Database Traversal.”

The routines that set, get, and otherwise manipulate these attributes can be used by all *libpf* node types, as indicated by the keyword ‘Node’ in the routine names. Nodes used as arguments to pfNode routines must be cast to pfNode* to match parameter prototypes, as shown in this example:

```
pfNodeName((pfNode*) dcs, "rotor_rotation");
```

However, you usually don’t need to do this casting explicitly. When you use the C API and compile with the `-ansi` flag (which is the usual way to compile IRIS Performer applications), *libpf* provides macro wrappers around pfNode routines that automatically perform argument casting for you. When you use the C++ API, such type casting is not necessary.

pfNode Operations

In addition to sharing attributes, certain basic operations are provided for all node types. They include:

New	Create and return a handle to a new node.
Get	Get node attributes.
Set	Set node attributes.
Find	Find a node based on its name.
Print	Print node data.

Copy	Copy node data.
Delete	Delete a node.

The Set operation is implied in the node attribute name. The names of the attribute-getting functions contain the string “Get”.

An Example of Scene Creation

Example 3-1 illustrates the creation of a scene that includes two different kinds of pfNodes. (For information about pfScene nodes, see “pfScene Nodes” on page 63; for information about pfDCS nodes, see “pfDCS Nodes” on page 64.)

Example 3-1 Making a Scene

```

pfScene *scene;
pfDCS *dcs1, *dcs2;

scene = pfNewScene();           /* Create a new scene node */
dcs1 = pfNewDCS();             /* Create a new DCS node */
dcs2 = pfNewDCS();             /* Create a new DCS node */
pfCopy(dcs2, dcs1);            /* Copy all node attributes */
                                /*      from dcs1 to dcs2 */
pfNodeName(scene, "Scene_Graph_Root"); /* Name scene node */
pfNodeName(dcs1, "DCS_1");      /* Name dcs1 */
pfNodeName(dcs2, "DCS_2");      /* Name dcs2 */
...
/* Use a pfGet*() routine to determine node name */
printf("Name of first DCS node is %s.", pfGetNodeName(dcs1));
...
/* Recursively free this node if it's no longer referenced */
pfDelete(scene);
...

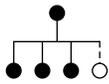
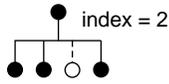
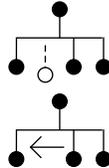
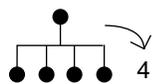
```

pfGroup

In addition to inheriting the pfNode attributes described in the “pfNode” section of this chapter, a pfGroup also maintains a list of zero or more child nodes that are accessed and manipulated using group operators. Children of a pfGroup can be either branch or leaf nodes. Traversals process the children of a pfGroup in left-to-right order.

Table 3-2 lists the pfGroup functions, with a description and a visual interpretation of each.

Table 3-2 pfGroup Functions

Function Name	Description	Diagram
pfAddChild(group, child)	Appends <i>child</i> to the list for <i>group</i> .	
pfInsertChild(group, index, child)	Inserts <i>child</i> before the child whose place in the list is <i>index</i> .	
pfRemoveChild(group, child)	Detaches <i>child</i> from the list and shifts the list to fill the vacant spot. Returns 1 if <i>child</i> was removed. Returns 0 if <i>child</i> was not found in the list. Note that the “removed” node is only detached, not deleted.	
pfGetNumChildren(group)	Returns the number of children in <i>group</i> .	

pfGroup nodes can organize a database hierarchy either logically or spatially. For example, if your database contains a model of a town, a logical organization might be to group all house models under a single pfGroup. However, this kind of organization is less efficient than a spatial organization, which arranges geometry by location. A spatial organization improves culling and intersection performance; in the example of the town, spatial organization would consist of grouping houses with their local terrain geometry instead of with each other. Chapter 4 describes how to spatially organize your database for best performance.

The code fragment in Example 3-2 illustrates building a hierarchy using pfGroup nodes.

Example 3-2 Hierarchy Construction Using Group Nodes

```

scene = pfNewScene();

/* The following loop constructs a sample hierarchy by
 * adding children to several different types of group
 * nodes. Notice that in this case the terrain was broken
 * up spatially into a 4x4 grid, and a switch node is used
 * to cause only one vehicle per terrain node to be
 * traversed.
 */

for(j = 0; j < 4; j++)
  for(i = 0; i < 4; i++)
  {
    pfGroup *spatial_terrain_block = pfNewGroup();
    pfSCS *house_offset = pfNewSCS();
    pfSCS *terrain_block_offset = pfNewSCS();
    pfDCS *car_position = pfNewDCS();
    pfDCS *tank_position = pfNewDCS();
    pfDCS *heli_position = pfNewDCS();
    pfSwitch *current_vehicle_type;
    pfGeode *heli, *car, *tank;

    pfAddChild(scene, spatial_terrain_block);
    pfAddChild(spatial_terrain_block,
               terrain_block_offset);
    pfAddChild(spatial_terrain_block, house_offset);
    pfAddChild(spatial_terrain_block,
               current_vehicle_type);
    pfAddChild(current_vehicle_type, car_position);
    pfAddChild(current_vehicle_type, tank_position);
    pfAddChild(current_vehicle_type, heli_position);
    pfAddChild(car_position, car);
    pfAddChild(tank_position, tank);
    pfAddChild(heli_position, heli);
  }

...

/* The following shows how one might use IRIS Performer to
 * manipulate the scene graph at run time by adding and
 * removing children from branch nodes in the scene graph.

```

```
*/  
  
for(j = 0; j < 4; j++)  
    for(i = 0; i < 4; i++)  
        {  
            pfGroup *this_terrain;  
            this_terrain = pfGetChild(scene, j*4 + i);  
            if (pfGetNumChildren(this_terrain) > 2)  
                this_tank = pfGetChild(this_terrain, 2);  
            if (is_tank_disable(this_tank))  
                {  
                    pfRemoveChild(this_terrain, this_tank);  
                    pfAddChild(disabled_tanks, this_tank);  
                }  
        }  
...  

```

Working With Nodes

This section describes the basic concepts involved in working with nodes. It explains how *shared instancing* can be used to create multiple copies of an object, and how changes made to a parent node propagate down to its children. A sample program that illustrates these concepts is presented at the end of the chapter.

Instancing

A scene graph is typically constructed at application initialization time by creating and adding new nodes to the graph. If a node is added to two or more parents it is termed *instanced* and is shared by all its parents. Instancing is a powerful mechanism that saves memory and makes modeling easier. *libpf* supports two kinds of instancing, which are described in the following sections.

Shared Instancing

Shared instancing is the result of simply adding a node to multiple parents. If an instanced node has children, then the entire subgraph rooted by the node is considered to be instanced. Each parent shares the node; thus, modifications to the instanced node or its subgraph are experienced by all parents. Shared instances can be nested—that is, an instance can itself instance other nodes.

In the following sample code, group0 and group1 share a node:

```
pfAddChild(group0, node);
pfAddChild(group1, node);
```

Figure 3-2 shows the structure created by this code. Before the instancing operation, the two groups and the node to be shared all exist independently, as shown in the left portion of the figure. After the two function calls shown above, the two groups both reference the same shared hierarchy. (If the original groups referenced other nodes, those nodes would remain unchanged.) Note that each of the group nodes considers the shared hierarchy to be its own child.

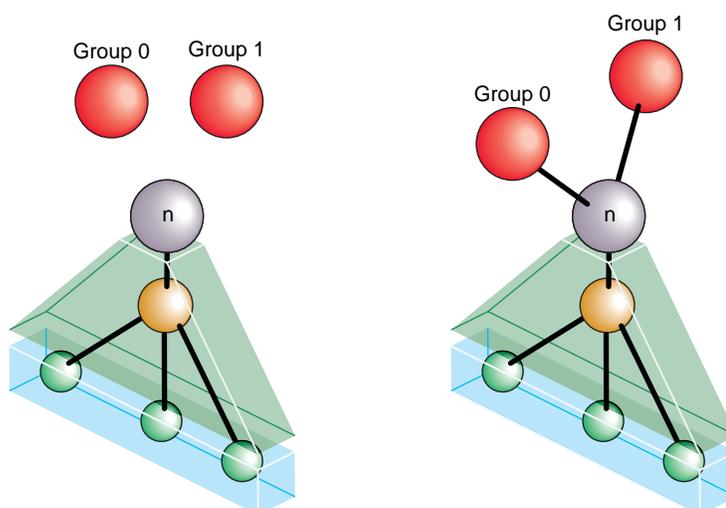


Figure 3-2 Shared Instances

Cloned Instancing

In many situations shared instancing isn't desirable. Consider a subgraph that represents a model of an airplane with articulations for ailerons, elevator, rudder, and landing gear. Shared instances of the model result in multiple planes that share the same articulations. Consequently, it's impossible for one plane to be flying with its landing gear retracted while another is on a runway with its landing gear down.

Cloned instancing provides the solution to this problem by *cloning*—creating new copies of variable nodes in the subgraph. Leaf nodes containing geometry are not cloned and are shared to save memory. Cloning the airplane model generates new articulation nodes, which can be modified independently of any other cloned instance. The cloning operation, `pfClone()`, is actually a traversal and is described in detail in Chapter 4.

Figure 3-3 shows the result of cloned instancing. As in the previous figure, the left half of the drawing represents the situation before the operation, and the right half shows the result of the operation.

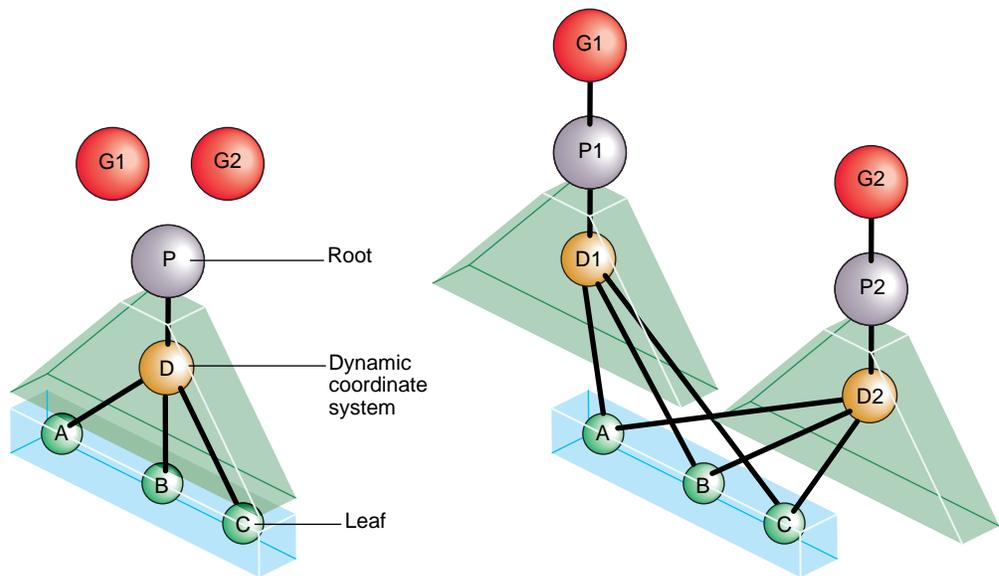


Figure 3-3 Cloned Instancing

The cloned instancing operation constructs new copies of each internal node of the shared hierarchy, but uses the same shared instance of all the leaf nodes. In use, this is an important distinction, because the number of internal nodes may be relatively few, while the number and content of geometry-containing leaf nodes is often quite extensive.

Nodes G1 and G2 in Figure 3-3 are the groups that form the root nodes after the *cloned instancing* operation is complete. Node P is the parent or root node of the instanced object, and D is a dynamic coordinate system contained within it. Nodes A, B, and C are the leaf geometry nodes; they are shared rather than copied.

The code in Example 3-3 shows how to create cloned instances.

Example 3-3 Creating Cloned Instances

```

pfGroup *g1, *g2, *p;
pfDCS *d;
pfGeode *a, *b, *c;

...
/* Create initial instance of scene hierarchy of p under
 * group g1: add a DCS to p, then add three pfGeode nodes
 * under the DCS.
 */
pfAddChild(g1,p);
pfAddChild(p,d);
pfAddChild(d,a);
pfAddChild(d,b);
pfAddChild(d,c);

...
/* Create cloned instance version of p under g2 */
pfAddChild(g2, pfClone(p,0));
/* Notice that pfGeodes are cloned by instancing rather than
 * copying. Also notice that the second argument to
 * pfClone() is 0; that argument is currently required by
 * IRIS Performer to be zero.
 */
...

```

Bounding Volumes

libpf uses bounding volumes for culling and to improve intersection performance. *libpf* computes bounding volumes for all nodes in a database hierarchy unless the bound is explicitly set by the application. The bounding volume of a branch node encompasses the spatial extent of all its children. *libpf* automatically recomputes bounds when children are modified.

By default, bounding volumes are *dynamic*; that is, *libpf* automatically recomputes them when children are modified. For instance, in Example 3-4 when the DCS is rotated nothing more needs to be done to update the bounding volume for *g1*.

Example 3-4 Automatically Updating a Bounding Volume

```
pfAddChild(g1,dcs);
pfAddChild(dcs, helicopter);

...

pfDCSRot(dcs, heading+10.0f, pitch,roll);
...
pfDCSRot(dcs, heading, pitch - 5.0f, roll + 2.0f);
```

In some cases, you may not want bounding volumes to be recomputed automatically. For example, in a merry-go-round with horses moving up and down, you know that the horses stay within a certain volume. Using **pfNodeBSphere()**, you can specify a bounding sphere within which the horse always remains and tell IRIS Performer that the bounding volume is “static”—not to be updated no matter what happens to the node’s children. You can always force an update by setting the bounding volume to NULL with **pfNodeBSphere()**, as follows:

```
pfNodeBSphere(node, NULL, NULL, PFBOUND_STATIC);
```

At the lowest level, within **pfGeoSets**, bounding volumes are maintained as axially-aligned boxes. When you add a **pfGeoSet** to a **pfGeode** or directly invoke **pfGetGSetBBox()** on the **pfGeoSet**, a bounding box is created for the **pfGeoSet**. Neither the bounding box of the **pfGeoSet** nor the bounding volume of the **pfGeode** is updated if the geometry changes inside the **pfGeoSet**. You can force an update by setting the **pfGeoSet** bounding box and then the **pfGeode** bounding volume to a NULL bounding box, as follows:

- Recompute the **pfGeoSet** bounding box from the internal geometry:

```
pfGSetBBox(gset, NULL);
```
- Recompute the **pfGeode** bounding volume from the bounding boxes of its **pfGeoSets**:

```
pfNodeBSphere(geode, NULL, PFBOUND_DYNAMIC);
```

Node Types

This section describes the node types and the functions for working with each node type.

For more information about `pfLPointState` and `pfLightSource`, see Chapter 6, “Creating Visual Effects.”

pfScene Nodes

A `pfScene` is a root node that is the parent of a visual database. Use `pfNewScene()` to create a new scene node. Before the scene can be drawn, you must call `pfChanScene(channel, scene)` to attach it to a `pfChannel`.

Any nodes that are within the graph that is parented by a `pfScene` are culled and drawn once the `pfScene` is attached to a `pfChannel`. Because `pfScene` is a group, it uses `pfGroup` routines; however, a `pfScene` cannot be the child of any other node. The following statement adds a `pfGroup` to a scene:

```
pfAddChild(scene, root);
```

In the simplest case, the `pfScene` is the only node you need to add. Once you have a `pfPipe`, `pfChannel`, and `pfScene`, you have all the necessary elements for generating graphics using IRIS Performer.

pfScene Default Rendering State

`pfScene` nodes may specify a global `pfGeoState` that all other `pfGeoStates` in nodes below the `pfScene` will inherit from. Specification of this scene `pfGeoState` is done via the function `pfSceneGState()`. This functionality allows for the subtle optimization of pushing the most frequently used `pfGeoState` attributes for a particular scene graph into a global state and having the individual states inherit these attributes rather than specify them. This can save IRIS Performer work during culling (by having to ‘unwrap’ fewer `pfGeoStates`) and thus possibly increase frame rate.

There are several database utility functions in *libpfd* designed to help with this optimization. `pfdMakeSceneGState()` returns an ‘optimal’ `pfGeoState` based on a list of `pfGeoStates`. `pfdOptimizeGStateList()` takes an existing global `pfGeoState`, a new global `pfGeoState`, and a list of `pfGeoState`’s that should be optimized and cause all attributes of `pfGeoStates` in the list of `pfGeoStates` to be inherited if they are the same as the attribute in the new global `pfGeoState`. Lastly `pfdMakeSharedScene()` will cause this

optimization to happen for all of the `pfGeoStates` under the `pfScene` that was passed into the function. For more information on `pfGeoStates` see Chapter 8, “Geometry,” which discusses *libpr* in more detail. For more information of the creation and optimization of databases see Chapter 7, “Importing Databases,” which discusses building database converters and *libpfd*.

pfSCS Nodes

A `pfSCS` is a branch node that represents a static coordinate system. A `pfSCS` node contains a fixed modeling transformation matrix that cannot be changed once it is created. `pfSCS` nodes are useful for positioning models within a database. For example, a house that is modeled at the origin should be placed in the world with a `pfSCS` because houses rarely move during program execution.

Use `pfNewSCS(matrix)` to create a new `pfSCS` using the transformation defined by *matrix*. To find out what matrix was used to create a given `pfSCS`, call `pfGetSCSMat()`.

For best graphics performance, matrices passed to `pfSCS` nodes (and the `pfDCS` node type described in the next section) should be orthonormal (translations, rotations, and uniform scales). Nonuniform scaling requires renormalization of normals in the graphics pipe. Projections and other non-affine transformations are not supported.

While `pfSCS` nodes are useful in modeling, using too many of them can reduce culling, rendering, and intersection performance. For this reason, *libpf* provides the `pfFlatten()` traversal. `pfFlatten()` will traverse a scene graph and apply static transformations directly to geometry to eliminate the overhead associated with managing the transformations. `pfFlatten()` is described in detail in Chapter 4, “Database Traversal.”

pfDCS Nodes

A `pfDCS` is a branch node that represents a dynamic coordinate system. Use a `pfDCS` when you want to apply an initial transformation to a node and also change the transformation during the application. Use a `pfDCS` to articulate moving parts and to show object motion.

Use `pfNewDCS()` to create a new `pfDCS`. The initial transformation of a `pfDCS` is the *identity matrix*. Subsequent transformations are set by specifying a new transformation matrix, or by replacing the rotation, scale, or translation in the current transformation matrix. The `pfDCS` transforms each child $C(i)$ to $C(i) * \text{Scale} * \text{Rotation} * \text{Translation}$.

Table 3-3 lists functions for manipulating a pfDCS, including rotating, scaling, and translating the children of the pfDCS.

Table 3-3 DCS Transformations

Function Name	Description
pfNewDCS	Create a new pfDCS node.
pfDCSTrans	Set the translation coordinates to x , y , z .
pfDCSRot	Set the rotation transformation to h , p , r .
pfDCSCoord	Rotate and translate by <i>coord</i> .
pfDCSScale	Scale by a uniform scale factor.
pfDCSMat	Use a matrix for transformations.
pfGetDCSMat	Retrieve the current matrix for a given pfDCS.

pfFCS Nodes

A pfFCS is a branch node that represents a flux coordinate system. The transformation matrix of a pfFCS is contained in the pfFlux which is linked to it. This linkage allows a pfEngine to animate the matrix of a pfFCS. The linkage also allows multiple pfFCSs to share the same transform.

Use **pfNewFCS(flux)** to create a new pfFCS linked to *flux*.

Table 3-4 lists functions for manipulating a pfFCS. pfFCS, pfFlux, and pfEngine are fully described in Chapter 14, “Dynamic Data.”

Table 3-4 FCS Functions

Function	Description
pfNewFCS	Create a new pfFCS node.
pfFCSFlux	Link a flux to a given pfFCS.
pfGetFCSFlux	Get a pointer to the flux linked to a given pfFCS.

Table 3-4 (continued) FCS Functions

Function	Description
pfGetFCSMat	Retrieve the current matrix for a given pfFCS.
pfGetFCSMatPtr	Get a pointer to the current matrix for a given pfFCS.

pfSwitch Nodes

A pfSwitch is a branch node that selects one, all, or none of its children. Use **pfNewSwitch()** to return a handle to a new pfSwitch. To select all the children, use the PFSWITCH_ON argument to **pfSwitchVal()**. Deselect all the children (turning the switch off) using PFSWITCH_OFF. To select a single child, give the index of the child from the child list. To find out the current value of a given switch, call **pfGetSwitchVal()**. Example 3-5 (in the “pfSequence Nodes” section) illustrates a use of pfSwitch nodes to control pfSequence nodes.

pfSequence Nodes

A pfSequence is a pfGroup that sequences through a range of its children, drawing each child for a specified duration. Each child in a sequence can be thought of as a frame in an animation. A sequence can consist of any number of children, and each child has its own duration. You can control whether an entire sequence repeats from start to end, repeats from end to start, or terminates.

Use **pfNewSeq()** to create and return a handle to a new pfSequence. Once the pfSequence has been created, use the group function **pfAddChild()** to add the children that you want to animate.

Table 3-5 describes the functions for working with pfSequences.

Table 3-5 pfSequence Functions

Function	Description
pfNewSeq	Create a new pfSequence node.
pfSeqTime	Set the length of time to display a frame.
pfGetSeqTime	Find out the time allotted for a given frame.

Table 3-5 (continued) pfSequence Functions

Function	Description
pfSeqInterval	Set the range of frames and sequence type.
pfGetSeqInterval	Find out interval parameters.
pfSeqDuration	Control the speed and number of repetitions of the entire sequence.
pfGetSeqDuration	Retrieve speed and repetition information for the sequence.
pfSeqMode	Start, stop, pause, and resume the sequence.
pfGetSeqMode	Find out the sequence's current mode.
pfGetSeqFrame	Get the current frame.

Example 3-5 demonstrates a possible use of both switches and sequences. First, sequences are set up to contain animation sequences for explosions, fire, and smoke; then a switch is used to control which sequences are currently active.

Example 3-5 Using pfSwitch and pfSequence Nodes

```

pfSwitch *s;
pfSequence *explosion1_seq, *explosion2_seq, *fire_seq,
           *smoke_seq;

...
s = pfNewSwitch();
explosion1_seq = pfNewSeq();
explosion2_seq = pfNewSeq();
fire_seq = pfNewSeq();
smoke_seq = pfNewSeq();

pfAddChild(s, explosion1_seq);
pfAddChild(s, explosion2_seq);
pfAddChild(s, fire_seq);
pfAddChild(s, smoke_seq);
pfSwitchVal(s, PFSWITCH_OFF);

...
if (direct_hit)
{
    pfSwitchVal(s, PFSWITCH_ON); /* Select all sequences */

    /* Set first explosion sequence to go double normal
       * speed and repeat 3 times. */

```

```
pfSeqMode(explosion1_seq, PFSEQ_START);
pfSeqDuration(explosion1_seq, 2.0f, 3);

/* Set second explosion sequence to display first child
 * of sequence for 2 seconds before continuing. */
pfSeqMode(explosion2_seq, PFSEQ_START);
pfSeqTime(explosion2, 0.0f, 2.0f);

/* Set fire to wait on first frame of sequence until .3
 * seconds after second explosion. */
pfSeqMode(fire_seq, PFSEQ_START);
pfSeqTime(fire_seq, 0.0f, 2.3f);

/* Set smoke to wait until .1 seconds after fire. */
pfSeqMode(smoke_seq, PFSEQ_START);
pfSeqTime(smoke_seq, 0.0f, 2.4f);
}
else if (explosion && (expl_type == 0))
{
    pfSeqMode(explosion1_seq, PFSEQ_START);
    pfSwitchVal(s, 0);
}
else if (explosion && (expl_type == 1))
{
    pfSeqMode(explosion2_seq, PFSEQ_START);
    pfSwitchVal(s, 1);
}
else if (fire_is_burning)
{
    pfSeqMode(fire_seq, PFSEQ_START);
    pfSwitchVal(s, 2);
}
else if (smoking)
{
    pfSeqMode(smoke_seq, PFSEQ_START);
    pfSwitchVal(s, 3);
}
else
    pfSwitchVal(s, PFSWITCH_OFF);
...
```

pfLOD Nodes

A pfLOD is a level-of-detail node. Level-of-detail switching is an advanced concept that is discussed in Chapter 5, “Frame and Load Control.” A level-of-detail node specifies how its children are to be displayed, based on the visual range from the channel’s viewpoint. Each child has a defined range, and the entire pfLOD has a defined center.

Table 3-6 describes the functions for working with pfLODs.

Table 3-6 pfLOD Functions

Function	Description
pfNewLOD	Create a level of detail node.
pfLODRange	Set a range at which to use a specified child node.
pfGetLODRange	Find out the range for a given node.
pfLODCenter	Set the pfLOD center.
pfGetLODCenter	Retrieve the pfLOD center.
pfLODTransition	Set the width of a specified transition.
pfGetLODTransition	Get the width of a specified transition.

pfASD Nodes

pfASD nodes handle dynamic generation and morphing of the visible part of a surface based on multiple LODs. pfASD nodes allow for the smooth LOD transition of large and complex surfaces, such as large area terrain. For information on pfASD nodes, see Chapter 15, “Active Surface Definition.”

pfLayer Nodes

A pfLayer is a leaf node that resolves the visual priority of coplanar geometry. A pfLayer allows the application to define a set of *base geometry* and a set of *layer geometry* (sometimes called *decal geometry*). The base geometry and the decal geometry should be coplanar, and the decal geometry must lie within the extent of the base polygons.

Table 3-7 describes the functions for working with pfLayers.

Table 3-7 pfLayer Functions

Function	Description
pfNewLayer	Create a pfLayer node.
pfLayerMode	Specify a hardware mode to use in drawing decals.
pfGetLayerMode	Get current mode.
pfLayerBase	Specify the child containing base geometry.
pfGetLayerBase	Find out which child contains base geometry.
pfLayerDecal	Specify the child containing decal geometry.
pfGetLayerDecal	Find out which child contains decal geometry.

pfLayer nodes can be used to overlay any sort of markings on a given polygon and are important to avoid *flimmering*. Example 3-6 demonstrates how to display runway markings as a decal above a coplanar runway. This example uses the performance mode PFDECAL_BASE_FAST for layering; as described in the pfLayer and pfDecal reference pages, other available modes are PFDECAL_BASE_HIGH_QUALITY, PFDECAL_BASE_DISPLACE, and PFDECAL_BASE_STENCIL.

Example 3-6 Marking a Runway With a pfLayer Node

```

pfLayer *layer;
pfGeode *runway, *runway_markings;

...
/* avoid flimmering of runway and runway_markings */
layer = pfNewLayer();
pfLayerBase(layer, runway);
pfLayerDecal(layer, runway_markings);
pfLayerMode(layer, PFDECAL_BASE_FAST);

```

pfGeode Nodes

pfGeode is short for *geometry node* and is the primary node for defining geometry in *libpf*. A pfGeode contains a list of geometry structures called pfGeoSets, which are part of the IRIS Performer *libpr* library. pfGeoSets encapsulate graphics state and geometry and are described in the “Geometry Sets” section of Chapter 8, “Geometry.” It is important to understand that pfGeoSets are not nodes but are simply elements of a pfGeode.

Table 3-8 describes the functions for working with pfGeodes.

Table 3-8 pfGeode Functions

Function	Description
pfNewGeode	Create a pfGeode.
pfAddGSet	Add a pfGeoSet.
pfRemoveGSet	Remove a pfGeoSet.
pfInsertGSet	Insert a pfGeoSet.
pfReplaceGSet	Replace a pfGeoSet.
pfGetGSet	Supply a pointer to the specified pfGeoSet.
pfGetNumGSets	Determine how many pfGeoSets are in the given pfGeode.

Example 3-7 shows how to attach several pfGeoSets to a pfGeode.

Example 3-7 Adding pfGeoSets to a pfGeode

```
pfGeode *car1;
pfGeoSet *muffler, *frame, *windows, *seats, *tires;

muffler = read_in_muffler_geometry();
frame = read_in_frame_geometry();
seats = read_in_seat_geometry();
tires = read_in_tire_geometry();

pfAddGSet(car1, muffler);
pfAddGSet(car1, frame);
pfAddGSet(car1, seats);
pfAddGSet(car1, tires);
...
```

pfText Nodes

A pfText node is *libpf* leaf node that contains a set of *libpr* pfStrings that should be rendered based on the libpf cull and draw traversals. In this sense a pfText is similar to a pfGeode except that it renders 3-dimensional text through the *libpr* pfString and pfFont mechanisms rather than rendering standard 3-dimensional geometry via *libpr* pfGeoSet and pfGeoState functionality. pfText nodes are useful for displaying 3-dimensional text and other collections of geometry from a fixed index list. Table 3-9 lists the major pfText functions.

Table 3-9 pfText Functions

Function	Description
pfNewText	Create a pfText.
pfAddString	Add a pfString.
pfRemoveString	Remove a pfString.
pfInsertString	Insert a pfString.
pfReplaceString	Replace a pfString.
pfGetString	Supply a pointer to the specified pfString.
pfGetNumStrings	Determine how many pfStrings are in the given pfText.

Using the pfText facility is easy. Example 3-8 shows how a pfFont is defined, how pfStrings are created that reference that font, and then how those pfStrings are added to a pfText node for display. See the description of pfStrings and pfFonts in Chapter 8, “Geometry,” for information on setting up individual strings to input into a pfText node

Example 3-8 Adding pfStrings to a pfText

```
int nStrings,i;
char tmpBuf[8192];
char fontName[128];
pfFont *fnt = NULL;
/* Create a new text node
pfText *txt = pfNewText();

/* Read in font using libpfdu utility function */
scanf("%s",fontName);
fnt = pfdLoadFont("type1",fontName,PFDFONT_EXTRUDED);
```

```
/* Cant render pfText or libpr pfString without a pfFont */
if (fnt == NULL)
    pfNotify(PFNFY_WARN, PFNFY_PRINT,
            "No Such Font - %s\n", fontName);

/* Read nStrings text strings from standard input and */
/* Attach them to a pfText */
scanf("%d", &nStrings);
for(i=0; i<nStrings; i++)
{
    char c;
    int j=0;
    int done = 0;
    pfString *curStr = NULL;

    while(done < 2) /* READ STRING - END on '|'|' */
    {
        c = getchar();
        if (c == '|')
            done++;
        else
            done = 0;
        tmpBuf[j++] = c;
    }
    tmpBuf[PF_MAX2(j-2, 0)] = '\0';

    /* Create new libpr pfString structure to attach to pfText */
    curStr = pfNewString(pfGetSharedArena());

    /* Set the font for the libpr pfString */
    pfStringFont(curStr, fnt);

    /* Assign the char string to the pfString */
    pfStringString(curStr, tmpBuf);

    /* Add this libpr pfString to the pfText node */
    /* Like adding a libpr pfGeoSet to a pfGeode */
    pfAddString(txt, curStr);
}
pfAddChild(SceneGroup, txt);
```

pfBillboard Nodes

A pfBillboard is a pfGeode that rotates its children’s geometry to follow the view direction or the eyepoint. Billboards are useful for portraying complex objects that are roughly symmetrical in one or more axes. The billboard rotates to always present the same image to the viewer using far fewer polygons than a solid model uses. In this way, billboards reduce both transformation and pixel fill demands on the graphics subsystem at the expense of some additional host processing. A classic example is a textured billboard of a single quadrilateral representing a tree.

Because a pfBillboard is also a pfGeode, you can pass a pfBillboard argument to any pfGeode routine. To add geometry, call **pfAddGSet()** (see “pfGeode Nodes” on page 71). Each pfGeoSet in the pfBillboard is treated as a separate piece of billboard geometry; each one turns so that it always faces the eye point.

pfBillboards can be either constrained to rotate about an axis, as is done for a tree or a lamp post, or constrained only by a point, as when simulating a cloud or a puff of smoke. Specify the rotation mode by calling **pfBboardMode()**; specify the rotational axis by calling **pfBboardAxis()**. Since rotating the geometry to the eyepoint doesn’t fully constrain the orientation of a point-rotating billboard, modes are available to use the additional degree of freedom to align the billboard in eye space or world space. Usually the normals of billboards are specified to be parallel to the rotational axis to avoid lighting anomalies.

pfFlatten() is highly recommended for billboards. If a billboard lies beneath a pfSCS or pfDCS, an additional transformation is done for each billboard. This can have a substantial performance impact on the cull process, where billboards are transformed.

Table 3-10 describes the functions for working with pfBillboards.

Table 3-10 pfBillboard Functions

Function	Description
pfNewBboard	Create a pfBillboard node.
pfBboardPos	Set a billboard’s position.
pfGetBboardPos	Find out a billboard’s position.
pfBboardAxis	Specify the rotation or alignment axis.
pfGetBboardAxis	Find out the rotation or alignment axis.

Table 3-10 (continued) pfBillboard Functions

Function	Description
pfBboardMode	Specify a billboard's rotation type.
pfGetBboardMode	Find out a billboard's rotation type.

Example 3-9 demonstrates the construction of a pfBillboard node. The code can be found in */usr/share/Performer/src/pguide/libpf/C/billboard.c*.

Example 3-9 Setting Up a pfBillboard

```
static pfVec2 BBTexCoords[] = {{0.0f, 0.0f},
                               {1.0f, 0.0f},
                               {1.0f, 1.0f},
                               {0.0f, 1.0f}};

static pfVec3 BBVertCoords[4] = /* XZ plane for pt bboards */
    {{-0.5f, 0.0f, 0.0f},
     { 0.5f, 0.0f, 0.0f},
     { 0.5f, 0.0f, 1.0f},
     {-0.5f, 0.0f, 1.0f}};

static pfVec3 BBAxes[4] = {{1.0f, 0.0f, 0.0f}, /* X */
                          {0.0f, 1.0f, 0.0f}, /* Y */
                          {0.0f, 0.0f, 1.0f}, /* Z */
                          {0.0f, 0.0f, 1.0f}}; /*world Zup*/

static int BBPrimLens[] = { 4 };

static pfVec4 BBColors[] = {{1.0, 1.0, 1.0, 1.0}};

/* Convert static data to pfMalloc'ed data */
static void*
memdup(void *mem, size_t bytes, void *arena)
{
    void *data = pfMalloc(bytes, arena);
    memcpy(data, mem, bytes);
    return data;
}

/* For pedagogical use only. Reasonable performance
 * requires more then one pfGeoSet per pfBillboard.
```

```
*/

pfBillboard*
MakeABill(pfVec3 pos, pfGeoState *gst, long bbType)
{
    pfGeoSet *gset;
    pfGeoState *gstate;
    pfBillboard *bill;
    void *arena = pfGetSharedArena();

    gset = pfNewGSet(arena);
    gstate = pfNewGState(arena);

    pfGStateMode(gstate, PFSTATE_ENLIGHTING, PF_OFF);
    pfGStateMode(gstate, PFSTATE_ENTEXTURE, PF_ON);
    /*... Create/load texture map for billboard... */
    pfGStateAttr(gstate, PFSTATE_TEXTURE, texture);
    pfGSetGState(gset, gstate);

    pfGSetAttr(gset, PFGS_COORD3, PFGS_PER_VERTEX,
        memdup(BBVertCoords, sizeof(BBVertCoords), arena),
        NULL);
    pfGSetAttr(gset, PFGS_TEXCOORD2, PFGS_PER_VERTEX,
        memdup(BBTexCoords, sizeof(BBTexCoords), arena),
        NULL);

    pfGSetAttr(gset, PFGS_COLOR4, PFGS_OVERALL,
        memdup(BBColors, sizeof(BBColors), arena),
        NULL);

    pfGSetPrimLengths(gset,
        (int*)memdup(BBPrimLens, sizeof(BBPrimLens), arena));
    pfGSetPrimType(gset, PFGS_QUADS);
    pfGSetNumPrims(gset, 1);
    pfGSetGState(gset, gst);

    bill = pfNewBboard();
    switch (bbType)
    {
    case PF_X: /* axial rotate */
    case PF_Y:
    case PF_Z:
        pfBboardAxis(bill, BBAxes[bbType]);
        pfBboardMode(bill, PFBB_ROT, PFBB_AXIAL_ROT);
        break;
    }
```

```
case 3: /* point rotate */
    pfBboardAxis(bill, BBAxes[bbType]);
    pfBboardMode(bill, PFBB_ROT, PFBB_POINT_ROT_WORLD);
    break;
}
pfAddGSet(bill, gset);
pfBboardPos(bill, 0, pos);

return bill;
}
```

pfPartition Nodes

A `pfPartition` is a `pfGroup` that organizes the scene graphs of its children into a static data structure that can be more efficient for intersections. Currently, partitions are only useful for data that lies more or less on an XY plane, such as terrain. A `pfPartition` would therefore be inappropriate for a skyscraper model.

Partition construction comes in two phases. After a piece of the scene graph has been placed under the `pfPartition`, **`pfBuildPart()`** examines the spatial arrangement of geometry beneath the `pfPartition` and determines an appropriate origin and spacing for the grid. Because the search is exhaustive, this examination can be time-consuming the first time through. Once a good partitioning is determined, the search space can be restricted for future database loads using the partition attributes.

The second phase is invoked by **`pfUpdatePart()`**, which distributes the `pfGeoSets` under the `pfPartition` into cells in the spatial partition created by **`pfBuildPart()`**. **`pfUpdatePart()`** needs to be called if any geometry under the `pfPartition` node changes.

During intersection traversal, the segments in a `pfSegSet` (see “Intersection Requests: `pfSegSets`” in Chapter 4) are scan-converted onto the grid, yielding faster access to those `pfGeoSets` that potentially intersect the segment. A `pfPartition` can be made to function as a normal `pfGroup` during intersection traversal by OR-ing `PFTRAV_IS_NO_PART` into the intersection traversal mode in the `pfSegSet`.

Table 3-11 describes the functions for working with pfPartitions.

Table 3-11 pfPartition Functions

Function	Description
pfNewPart	Create a pfPartition.
pfPartVal	Set the desired pfPartition value.
pfGetPartVal	Find out the attributes of specified value.
pfPartAttr	Set the desired pfPartition attribute.
pfGetPartAttr	Find out the attributes of specified attribute.
pfBuildPart	Construct a spatial partitioning based on the attributes.
pfUpdatePart	Traverse the partition's children and incorporate changes.
pfGetPartType	Determine what kind of partition is being used.

Example 3-10 demonstrates setting up and using a pfPartition node.

Example 3-10 Setting Up a Partition

```

pfGroup *terrain;
pfPartition *partition;
pfScene *scene;

...

terrain = read_in_grid_aligned_terrain();

...

/* create a default partitioning of a terrain grid */
partition = pfNewPart();
pfAddChild(scene, partition);
pfAddChild(partition, terrain);
pfBuildPart(partition);

...

```

```

/* use the partitions to perform efficient intersections
 * of sets of segments with the terrain */
for(i = 0; i < numVehicles; i++)
    pfNodeIsectSegs(partition, vehicle_segment_set[i],
                    hit_struct);
...

```

Sample Program

The sample program shown in Example 3-11 demonstrates scene graph construction, shared instancing, and transformation inheritance. The program uses IRIS Performer objects and functions that are described fully in later chapters.

This program reads the names of two objects from the command line, although defaults are supplied if file names are not given. These files are loaded and a second instance of each object is created. In each case, this instance is made to orbit the original object, and the second pair are also placed in orbit around the first. This program is “*inherit.c*” and is part of the suite of *IRIS Performer Programmer’s Guide* example programs.

Example 3-11 Inheritance Demonstration Program

```

/*
 * inherit.c - transform inheritance example
 */

#include <math.h>
#include <Performer/pf.h>
#include <Performer/pfdu.h>

int
main(int argc, char *argv[])
{
    pfPipe *pipe;
    pfPipeWindow *pw;
    pfScene *scene;
    pfChannel *chan;
    pfCoord view;
    float z, s, c;
    pfNode *model1, *model2;
    pfDCS *node1, *node2;
    pfDCS *dcs1, *dcs2, *dcs3, *dcs4;
    pfSphere sphere;

```

```
char *file1, *file2;

/* choose default objects of none specified */
file1 = (argc > 1) ? argv[1] : "blob.nff";
file2 = (argc > 1) ? argv[1] : "torus.nff";

/* Initialize Performer */
pfInit();

pfFilePath(
    "."
    "./data"
    "../data"
    "../../data"
    "../../../data"
    "../../../../data"
    "/usr/share/Performer/data");

/* Single thread for simplicity */
pfMultiprocess(PFMP_DEFAULT);

/* Load all loader DSO's before pfConfig() forks */
pfdInitConverter(file1);
pfdInitConverter(file2);

/* Configure */
pfConfig();

/* Load the files */
if ((modell = pfdLoadFile(file1)) == NULL)
{
    pfExit();
    exit(-1);
}
if ((model2 = pfdLoadFile(file2)) == NULL)
{
    pfExit();
    exit(-1);
}

/* scale models to unit size */
node1 = pfNewDCS();
pfAddChild(node1, modell);
pfGetNodeBSphere(modell, &sphere);
if (sphere.radius > 0.0f)
```

```
        pfDCSScale(node1, 1.0f/sphere.radius);

node2 = pfNewDCS();
pfAddChild(node2, model2);
pfGetNodeBSphere(model2, &sphere);
if (sphere.radius > 0.0f)
    pfDCSScale(node2, 1.0f/sphere.radius);

/* Create the hierarchy */
dcs4 = pfNewDCS();
pfAddChild(dcs4, node1);
pfDCSScale(dcs4, 0.5f);

dcs3 = pfNewDCS();
pfAddChild(dcs3, node1);
pfAddChild(dcs3, dcs4);

dcs1 = pfNewDCS();
pfAddChild(dcs1, node2);

dcs2 = pfNewDCS();
pfAddChild(dcs2, node2);
pfDCSScale(dcs2, 0.5f);
pfAddChild(dcs1, dcs2);

scene = pfNewScene();
pfAddChild(scene, dcs1);
pfAddChild(scene, dcs3);
pfAddChild(scene, pfNewLSource());

/* Configure and open GL window */
pipe = pfGetPipe(0);
pw = pfNewPWin(pipe);
pfPWinType(pw, PFPWIN_TYPE_X);
pfPWinName(pw, "IRIS Performer");
pfPWinOriginSize(pw, 0, 0, 500, 500);
pfOpenPWin(pw);

chan = pfNewChan(pipe);
pfChanScene(chan, scene);

pfSetVec3(view.xyz, 0.0f, 0.0f, 15.0f);
pfSetVec3(view.hpr, 0.0f, -90.0f, 0.0f);
pfChanView(chan, view.xyz, view.hpr);
```

```
/* Loop through various transformations of the DCS's */
for (z = 0.0f; z < 1084; z += 4.0f)
{
    pfDCSRot(dcs1,
        (z < 360) ? (int) z % 360 : 0.0f,
        (z > 360 && z < 720) ? (int) z % 360 : 0.0f,
        (z > 720) ? (int) z % 360 : 0.0f);

    pfSinCos(z, &s, &c);
    pfDCSTrans(dcs2, 1.0f * c, 1.0f * s, 0.0f);

    pfDCSRot(dcs3, z, 0, 0);
    pfDCSTrans(dcs3, 4.0f * c, 4.0f * s, 4.0f * s);
    pfDCSRot(dcs4, 0, 0, z);
    pfDCSTrans(dcs4, 1.0f * c, 1.0f * s, 0.0f);

    pfFrame();
}

/* show objects static for three seconds */
sleep(3);

pfExit();
exit(0);
}
```

Chapter 4

“Database Traversal”

This chapter explains how to manipulate, traverse, and examine a scene graph.

Database Traversal

Chapter 3, “Nodes and Node Types,” described the node types used by *libpf*. This chapter describes the operations that can be performed on the run-time database defined by a scene graph. These operations typically work with part or all of a scene graph and are known as *traversals* because they traverse the database hierarchy. IRIS Performer supports four major kinds of database traversals:

- Application
- Cull
- Draw
- Intersection

The application traversal updates the active elements in the scene graph for the next frame. This includes processing active nodes and invoking user supplied callbacks for animations or other embedded behaviors.

Visual processing consists of two basic traversals: culling and drawing. The cull traversal selects the visible portions of the database and puts them into a display list. The draw traversal then runs through that display list and sends rendering commands to the Geometry Pipeline. Once you have set up all the necessary elements, culling and drawing are automatic, although you can customize each traversal for special purposes.

The intersection traversal computes the intersection of one or more line segments with the database. The intersection traversal is user-directed. Intersections are used to determine

- height above terrain
- line-of-sight visibility
- collisions with database objects

Like other traversals, intersection traversals can be directed by the application through identification masks and function callbacks. Table 4-1 lists the routines and data types relevant to each of the major traversals; more information about the listed traversal attributes can be found later in this chapter and in the appropriate reference pages.

Table 4-1 Traversal Attributes for the Major Traversals

Traversal Attribute	Application PFTRAV_APP	Cull PFTRAV_CULL	Draw PFTRAV_DRAW	Intersection PFTRAV_ISECT
Controllers	pfChannel	pfChannel	pfChannel	pfSegSet
Global Activation	pfFrame() pfSync() pfAppFrame()	pfFrame()	pfFrame()	pfFrame() pfNodeIsect- Segs(), pfChan- NodeIsectSegs()
Global Callbacks	pfChanTrav- Func()	pfChanTrav- Func()	pfChanTrav- Func()	pfIsectFunc()
Activation within Callback	pfApp()	pfCull()	pfDraw()	pfFrame() pfNodeIsect- Segs(), pfChan- NodeIsectSegs()
Path Activation	NA	pfCullPath()	NA	NA
Modes	pfChanTrav- Mode()	pfChanTrav- Mode()	pfChanTrav- Mode()	pfSegSet (also discriminator callback)
Node Callbacks	pfNodeTrav- Funcs()	pfNodeTrav- Funcs()	pfNodeTrav- Funcs()	pfNodeTrav- Funcs()
Traverser Masks	pfChanTrav- Mask()	pfChanTrav- Mask()	pfChanTrav- Mask()	pfSegSet mask
Traverse Masks	pfNodeTrav- Mask()	pfNodeTrav- Mask()	pfNodeTrav- Mask()	pfNodeTrav- Mask() pfGSetIsect- Mask()

Scene Graph Hierarchy

A visual database, also known as a *scene*, contains state information and geometry. A scene is organized into a hierarchical structure known as a *graph*. The graph is composed of connected database units called nodes. Nodes that are attached below other nodes in the tree are called *children*. Children belong to their *parent* node. Nodes with the same parent are called *siblings*.

Database Traversals

The scene hierarchy supplies definitions of how items in the database relate to one another. It contains information about the logical and spatial organization of the database. The scene hierarchy is processed by visiting the nodes in depth-first order and operating on them. The process of visiting, or touching, the nodes is called *traversing* the hierarchy. The tree is traversed from top to bottom and from left to right. IRIS Performer implements several types of database traversals, including application, clone, cull, delete, draw, flatten, and intersect. These traversals are described in more detail later in this chapter.

The principal traversals (application, cull, draw and intersect) all use a similar traversal mechanism that employs traversal masks and callbacks to control the traversal. When a node is visited during the traversal, processing is performed in the following order:

1. Prune the node based on the bitwise AND of the traversal masks of the node and the pfChannel (or pfSegSet). If pruned, traversal continues with the nodes siblings.
2. Invoke the node's pre-traversal callback, if any, and either prune, continue, or terminate the traversal, depending on callback's return value.
3. Traverse, beginning again at step 1, the node's children or geometry (pfGeoSets). If the node is a pfSwitch, a pfSequence, or a pfLOD, the state of the node affects which children are traversed.
4. Invoke the node's post-traversal callback, if any.

State Inheritance

In addition to imposing a logical and spatial ordering of the database, the hierarchy also defines how state is inherited between parent and child nodes during scene graph traversals. For example, a parent node that represents a transformation causes the subsequent transformation of each of its children when it and they are traversed. In other words, the children inherit *state*, which includes the current coordinate transformation, from their parent node during database traversal.

A *transformation* is a 4x4 homogeneous matrix that defines a 3D transformation of geometry, which typically consist of scaling, rotation, and translation. The node types pfSCS and pfDCS both represent transformations. Transformations are inherited through the scene graph with each new transformation being concatenated onto the ones above it in the scene graph. This allows chained articulations and complex modeling hierarchies.

The effects of state are propagated downward only, not from left to right nor upward. This means that only parents can affect their children—siblings have no effect on each other nor on their parents. This behavior results in an easy-to-understand hierarchy that is well suited for high-performance traversals.

Graphics state such as textures and materials are not inherited by way of the scene graph, but are encapsulated in leaf geometry nodes called pfGeode nodes, which are described in the section “Node Types” in Chapter 3.

Database Organization

IRIS Performer uses the spatial organization of the database to increase the performance of certain operations such as drawing and intersections. It is therefore recommended that you consider the spatial arrangement of your database. What you might think of as a logical arrangement of items in the database may not match the spatial arrangement of those items in the visual environment, which can reduce IRIS Performer’s ability to optimize operations on the database. See “Organizing a Database for Efficient Culling” on page 94 for more information about spatial organization in a visual database and the efficiency of database operations.

Application Traversal

The application traversal is the first traversal that occurs during the processing of the scene graph in preparation for rendering a frame. It is initiated by calling **pfAppFrame()**. If **pfAppFrame()** is not explicitly called, the traversal is automatically invoked by **pfSync()** or **pfFrame()**. An application traversal can be invoked for each channel, but usually channels share the same application traversal (see **pfChanShare()**).

The application traversal updates dynamic elements in the scene graph, such as geometric morphing. The application traversal is also often used for implementing animations or other custom processing when it is desirable to have those behaviors embedded in the scene graph and invoked by IRIS Performer rather than requiring application code to invoke them every frame.

The traversal proceeds as described in “Database Traversals”. The selection of which children to traverse is also affected by the application traversal mode of the channel, in particular the choice of all, none or one of the children of **pfLOD**, **pfSequence** and **pfSwitch** nodes is possible. By default, the traversal obeys the current selection dictated by these nodes.

The following example (this loader reads both Open Inventor and VRML files) shows a simple callback changing the transformation on a **pfDCS** every frame.

Example 4-1 Application Callback to Make a Pendulum

```
int
AttachPendulum(pfDCS *dcs, PendulumData *pd)
{
    pfNodeTravFuncs(dcs, PFTRAV_APP, PendulumFunc, NULL);
    pfNodeTravData(dcs, PFTRAV_APP, pd);
}

int
PendulumFunc(pfTraverser *trav, void *userData)
{
    PendulumData *pd = (PendulumData*)userData;
    pfDCS *dcs = (pfDCS*)pfGetTravNode(trav);

    if (pd->on)
    {
        pfMatrix mat;
        double now = pfGetFrameTimeStamp();
        float frac, dummy;
```

```
pd->lastAngle += (now - pd->lastTime)*360.0f*pd->frequency;
if (pd->lastAngle > 360.0f)
    pd->lastAngle -= 360.0f;

// using sinusoidally generated angle
pfSinCos(pd->lastAngle, &frac, &dummy);
frac = 0.5f + 0.5f * frac;
frac = (1.0f - frac)*pd->angle0 + frac*pd->angle1;

pfMakeRotMat(mat,
    frac, pd->axis[0], pd->axis[1], pd->axis[2]);
pfDCSMat(dcs, mat);
pd->lastTime = now;
}

return PFTRAV_CONT;
}
```

Cull Traversal

The cull traversal occurs in the cull phase of the *libpf* rendering pipeline and is initiated by calling **pfFrame()**. A cull traversal is performed for each **pfChannel** and determines the portion of the scene to be rendered. The traversal processes the subgraphs of the scene that are both visible and selected by nodes in the scene graph that control traversal (e.g. **pfLOD**, **pfSequence**, **pfSwitch**). The visibility culling itself is performed by testing bounding volumes in the scene graph against the channel's viewing frustum.

For customizing the cull traversal, *libpf* provides traversal masks and function callbacks for each node in the database, as well as a function callback in which the application can do its own culling of custom data structures.

Traversal Order

The cull is a depth-first, left-to-right traversal of the database hierarchy beginning at a **pfScene**, which is the hierarchy's root node. For each node, a series of tests is made to determine whether the traversal should *prune* the node—that is, eliminate it from further consideration—or continue on to that node's children. The cull traversal processing is much as described earlier, in particular the draw traversal masks are compared and the node is checked for visibility before the traversal continues on to the nodes children:

1. Prune the node, based on the channel's draw traversal mask and the node's draw mask.
2. Invoke the node's pre-cull callback and either prune, continue, or terminate the traversal, depending on callback's return value.
3. Prune the node if its bounding volume is completely outside the viewing frustum.
4. Traverse, beginning again at step 1, the node's children or geometry (pfGeoSets) if the node is completely or partially in the viewing frustum. If the node is a pfSwitch, a pfSequence, or a pfLOD, the state of the node affects which children are traversed.
5. Invoke the node's post-cull callback.

The following sections discuss these steps in more detail.

Visibility Culling

Culling determines whether a node is within a pfChannel's viewing frustum for the current frame. Nodes that are not visible are pruned—omitted from the list of objects to be drawn—so that the Geometry Pipeline doesn't waste time processing primitives that couldn't possibly appear in the final image.

Hierarchical Bounding Volumes

Testing a node for visibility compares the *bounding volume* of each object in the scene against a viewing frustum that is bounded by the near and far clip planes and the four sides of the viewing pyramid. Both nodes (see Chapter 3, "Nodes and Node Types"), and pfGeoSets (see Chapter 8, "Geometry"), have bounding volumes that surround the geometry that they contain. Bounding volumes are simple geometric shapes whose centers and edges are easy to locate. Bounding volumes are organized hierarchically so that the bounding volume of a parent encloses the bounding volumes of all its children. You can specify bounding volumes or let IRIS Performer generate them for you (see "Bounding Volumes" in Chapter 3).

Figure 4-1 shows a frustum and three objects surrounded by bounding boxes. Two of the objects are outside the frustum; one is within it. One of the objects outside the frustum has a bounding box whose edges intersect the frustum, as shown by the shaded area. The visibility test for this object returns TRUE, because its bounding box does intersect the view frustum even though the object itself doesn't.

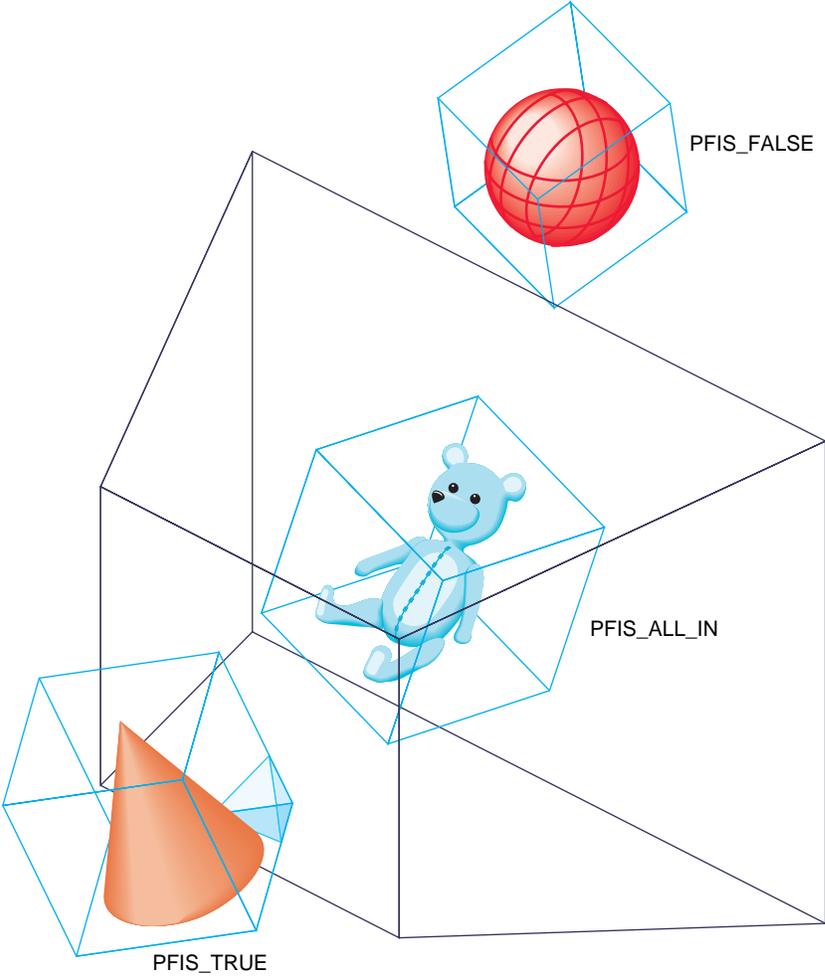


Figure 4-1 Culling to the Frustum

Visibility Testing

The cull traversal begins at the root node of a channel's scene graph (the `pfScene` node) and continues downward, directed by the results of the cull test at each node. At each node the cull test determines the relationship of the node's bounding volume to the viewing frustum. Possible results are that the bounding volume is entirely outside, is entirely within, is partially within, or completely contains the viewing frustum.

If the intersection test indicates that the bounding volume is entirely outside the frustum, the traversal prunes that node—that is, it doesn't consider the children of that node and continues with the node's next sibling.

If the intersection test indicates that the bounding volume is entirely inside the frustum, the node's children are not cull tested because the hierarchical nature of bounding volumes implies that the children must also be entirely within the frustum.

If the intersection test indicates that the bounding volume is partially within the frustum, or that the bounding volume completely contains the frustum, the testing process continues with the children of that node. Because a bounding volume is larger than the object it surrounds, it is possible for a bounding volume to be partially within a frustum even when none of its enclosed geometry is visible.

By default, IRIS Performer tests bounding volumes all the way down to the `pfGeoSet` level (see Chapter 8, "Geometry") to provide fine-grained culling. However, if your application is spending too much time culling, you can stop culling at the `pfGeode` level by calling `pfChanTravMode()`. Then if part of a `pfGeode` is potentially visible, all geometry in that `pfGeode` is drawn without cull-testing it first.

Visibility Culling Example

Figure 4-2 portrays a simple database that contains a toy block, train, and car. The block is outside the frustum, the bounding volume of the car is partially inside the frustum, and the train is completely inside the frustum.

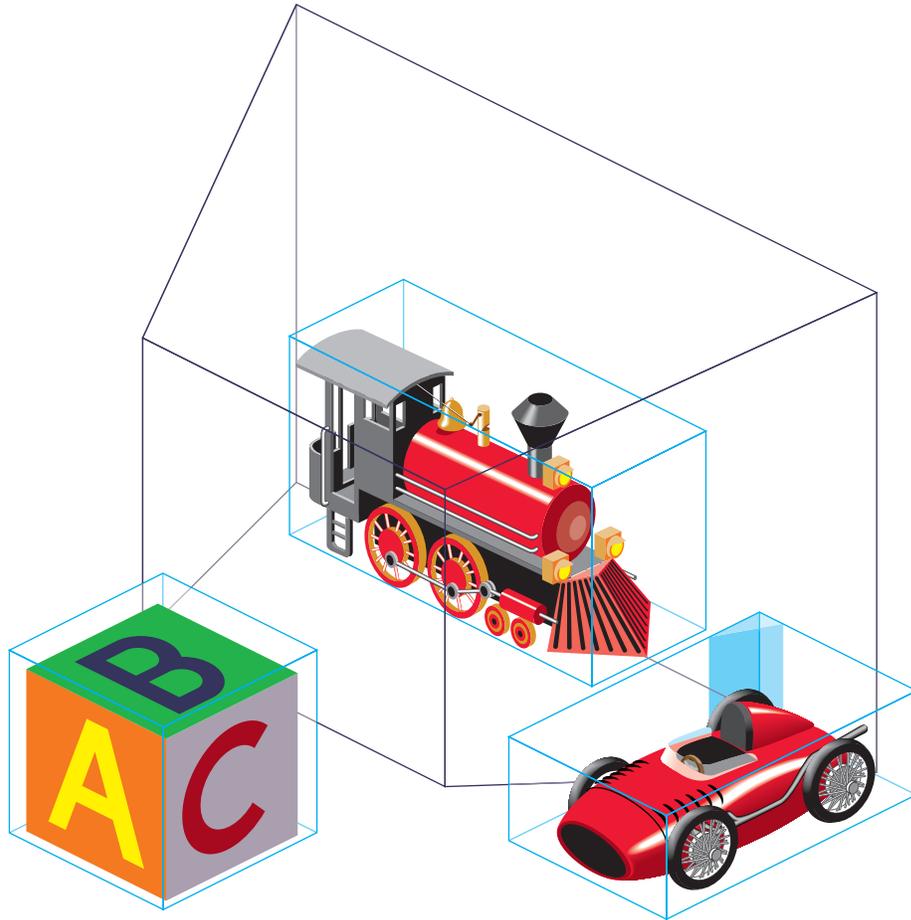


Figure 4-2 Sample Database Objects and Bounding Volumes

Organizing a Database for Efficient Culling

Efficient culling depends on having a database whose hierarchy is organized spatially. A good technique is to partition the database into regions, called *tiles*. Tiling is also required for *database paging*. Instead of culling the entire database, only the tiles that are within the view frustum need to be traversed.

The worst case for the cull traversal performance is to have a very flat hierarchy—that is, a pfScene with all the pfGeodes directly under it and many pfGeoSets in each pfGeode—or a hierarchy that is organized by object type (for example, having all trees in the database grouped under one pine tree node, rather than arranged spatially).

Figure 4-3 shows a sample database represented by cubes, cones, pyramids, and spheres. Organizing this database spatially, rather than by object type, promotes efficient culling. This type of spatial organization is the most effective control you have over efficient traversal.

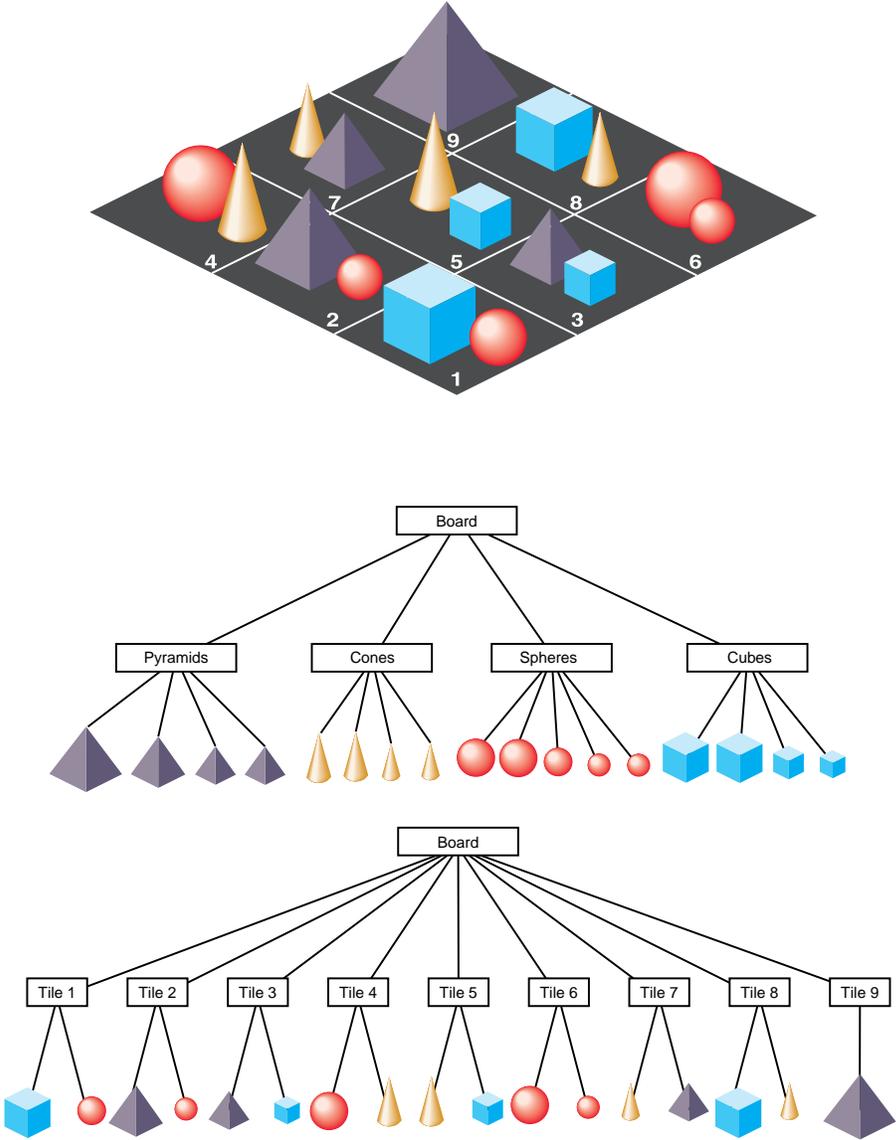


Figure 4-3 How to Partition a Database for Maximum Efficiency

When modeling a database, you should consider other trade-offs as well. Small amounts of geometry in each culling unit, whether pfGeode or pfGeoSet, provide better culling resolution and result in sending less non-visible geometry to the pipeline. Small pieces also improve the performance of line-segment intersection inquiries (see “Database Concerns” in Chapter 19). However, using many small pieces of geometry can increase the traversal time and can also reduce drawing performance. The optimal amount of geometry to place in each pfGeoSet depends on the application, database, system CPU, and graphics hardware.

Custom Visibility Culling

Existence within the frustum isn’t the only criterion that determines an object’s visibility. The item may be too distant to be seen from the viewpoint, or it may be obscured by other objects between it and the viewer, such as a wall or a hill. Atmospheric conditions can also affect object visibility. An object that is normally visible at a certain distance may not be visible at that same distance in dense fog.

Implementing more sophisticated culling requires knowledge of visibility conditions and control over the cull traversal. The cull traversal can be controlled through traversal masks, which are described in the section titled “Controlling and Customizing Traversals.”

Knowing whether an object is visible requires either prior information about the spatial organization of a database, such as cell-to-cell visibilities, or run-time testing such as computing line-of-sight visibility (LOS). You can compute simple LOS visibility by intersecting line segments that start at the eyepoint with the database. See the “Intersection Traversal” section of this chapter.

Sorting the Scene

During the cull traversal, a pfChannel can rearrange the order in which pfGeoSets are rendered for improved performance and image quality. It does this by *binning* and *sorting*. Binning is the act of placing pfGeoSets into specific *bins* which are rendered in a specific order. IRIS Performer provides two default bins: one for opaque geometry and one for blended, transparent geometry. The opaque bin is drawn before the transparent bin so transparent surfaces are properly blended with the background scene. Applications are free to add new bins and specify arbitrary bin orderings.

Sorting is done on a per-bin basis. `pfGeoSets` within a given bin are sorted by a specific criterion. Two useful criteria provided by IRIS Performer are sorting by graphics state and sorting by range. When sorting by state, `pfGeoSets` are sorted first by their `pfGeoState`, then by an application-specified hierarchy of state modes, values, and attributes which are identified by `PFSTATE_*` tokens and are described in the *libpr* chapter. State sorting can offer a huge performance advantage since it greatly reduces the number of mode changes carried out by the Geometry Pipeline. State sorting is the default sorting configuration for the opaque bin.

Range sorting is required for proper rendering of blended, transparent surfaces which must be rendered in back-to-front order so that each surface is properly blended with the current background color. Front-to-back sorting is also supported. The default sorting for the transparent bin is back-to-front sorting (Note that the sorting granularity is per-`pfGeoSet`, not per-triangle so transparency sorting is not perfect).

`pfChannel` bins are given rendering order and sorting configuration with `pfChanBinOrder()` and `pfChanBinSort()` respectively. A bin's order is simply an integer identifying its place in the list of bins. An order less than 0 or `PFSORT_NO_ORDER` means that `pfGeoSets` which fall into the bin are drawn immediately without any ordering or sorting. Multiple bins may have the same order but the rendering precedence among these bins is undefined.

A bin's sorting configuration is given as a token identifying the major sorting criterion and then an optional list of tokens, terminated with the `PFSORT_END` token, that defines a state sorting hierarchy.

`PFSORT_BY_STATE`

`pfGeoSets` are sorted first by `pfGeoState` then by the state elements found between the `PFSORT_STATE_BGN` and `PFSORT_STATE_END` tokens, for example.

`PFSORT_FRONT_TO_BACK`

`pfGeoSets` are sorted by nearest to farthest range from the eyepoint. Range is computed from eyepoint to the center of the `pfGeoSet`'s bounding volume.

PFSORT_BACK_TO_FRONT

pfGeoSets are sorted by farthest to nearest range from the eyepoint. Range is computed from eyepoint to the center of the pfGeoSet's bounding volume.

PFSORT_QUICK

A special, low-cost sorting technique. pfGeoSets must fall into a bin whose order is 0 in which case they will be sorted by pfGeoState and drawn immediately. This is the default sorting mode for the PFSORT_OPAQUE_BIN bin.

For example, the specification:

```
static int sort[] = {PFSORT_STATE_BGN,
                   PFSORT_STATE_TEXTURE, PFSORT_STATE_FRONTMTL,
                   PFSORT_STATE_END, PFSORT_END};
pfChanBinSort(chan, PFSORT_OPAQUE_BIN, PFSORT_BY_STATE,
              sort);
```

will sort the opaque bin by pfGeoState, then by pfTexture, then by pfMaterial.

A pfGeoSet's draw bin may be set directly by the application with **pfGSetDrawBin()**. Otherwise IRIS Performer automatically determines if the pfGeoSet belongs in the default opaque or transparent bins.

Paths Through the Scene Graph

You can define a chain, or *path*, of nodes in a scene graph using the pfPath data structure. (Note that a pfPath has nothing to do with filesystem paths as specified with the PFPATH environment variable or with specifying a path for a user to travel through a scene.) Once you've specified a pfPath with a call to **pfNewPath()**, you can traverse and cull that path as a subset of the entire scene graph using **pfCullPath()**. The function **pfCullPath()** must only be called from the cull callback function set by **pfChanTravFunc()**—see "Process Callbacks" on page 105 for details. For more information about the pfPath structure, see the pfPath(3pf) and pfList(3pf) reference pages.

When IRIS Performer looks for intersections, it can return a pfPath to the node containing the intersection. This feature is particularly useful when you're using instancing, in which case you can't use **pfGetParent()** to find out where in the scene graph the given node is. Finding out the pfPath to a given node is also useful in implementing picking.

Draw Traversal

The cull traversal generates a *libpr* display list of geometry and state commands (see “Display Lists” in Chapter 9), which describes the scene that is visible from a `pfChannel`. The draw traversal simply traverses the display list and sends commands to the Geometry Pipeline to generate the image.

Traversing a `pfDispList` is much faster than traversing the database hierarchy because the `pfDispList` *flattens* the hierarchy into a simple, efficient structure. In this way, the cull traversal removes much of the processing burden from the draw traversal; throughput greatly increases when both traversals are running in parallel.

Controlling and Customizing Traversals

The result of the cull traversal is a display list of geometry to be rendered by the draw traversal. What gets placed in the display list is determined by both visibility and by other user-specified modes and tests.

pfChannel Traversal Modes

The `PFTRAV_CULL` argument to `pfChanTravMode()` modifies the culling traversal. The cull mode is a bitmask that specifies the modes to enable, it is formed by the logical OR of one or more of these tokens:

- `PFCULL_VIEW`
- `PFCULL_GSET`
- `PFCULL_SORT`
- `PFCULL_IGNORE_LSOURCES`

Culling to the view frustum is enabled by `PFCULL_VIEW`. Culling to the `pfGeoSet`-level is enabled by `PFCULL_GSET` and can produce a tighter cull that improves rendering performance at the expense of culling time.

`PFCULL_SORT` causes the cull to sort geometry by state—for example, by texture or by material, in order to optimize rendering performance. It also causes transparent geometry to be drawn after opaque geometry for proper transparency effects.

By default, the enabled culling modes are `PFCULL_VIEW | PFCULL_GSET | PFCULL_SORT`. It is recommended that these modes be enabled unless the cull traversal becomes a significant bottleneck in the processing pipeline. In this case, try disabling `PFCULL_GSET` first, then `PFCULL_SORT`.

Normally, a `pfChannel`'s cull traversal pre-traverses the scene, following all paths from the scene to all `pfLightSources` in the scene so that light sources can be set up before the normal scene traversal. If you wish to disable this pre-traversal, set the `PFCULL_IGNORE_LSOURCES` cull enable bit but your `pfLightSources` will not illuminate the scene.

The `PFTRAV_DRAW` argument to `pfChanTravMode()` modifies the draw traversal. A mode of `PFDRAW_ON` is the default and will cause the `pfChannel` to be rendered. A mode of `PFDRAW_OFF` indicates that the `pfChannel` should not be drawn and essentially turns off the `pfChannel`.

pfNode Draw Mask

Each node in the database hierarchy can be assigned a mask that dictates whether the node is added to the display list and thereby whether it is drawn. This mask is called the *draw mask* (even though it is evaluated in the cull traversal) because it tells the cull process whether the node is drawable or not.

The draw mask of a node is set with `pfNodeTravMask()`. The channel also has a draw mask, which you set with `pfChanTravMask()`. By default, the masks are all 1s, or `0xffffffff`.

Before testing a node for visibility, the cull traversal ANDs the two masks together. If the result is zero, the cull prunes the node. If the result is nonzero, the cull proceeds normally. Mask testing occurs before all visibility testing and function callbacks.

Masks allow you to draw different subgraphs of the scene on different channels, to turn portions of the scene graph on and off, or to ignore hidden portions of the scene graph while drawing but make them active during intersection testing.

pfNode Cull and Draw Callbacks

One of the primary mechanisms for extending IRIS Performer is through the use of function callbacks, which can be specified on a per-node basis. IRIS Performer allows separate cull and draw callbacks, which are invoked both before and after node processing. Node callbacks are set with **pfNodeTravFuncs()**.

Cull callbacks can direct the cull traversal, while draw callbacks are added to the display list and later executed in the draw traversal for custom rendering. There are pre-cull and pre-draw callbacks, invoked before a node is processed, and post-cull and post-draw callbacks, invoked after the node is processed.

The cull callbacks return a value indicating how the cull traversal should proceed, as shown in Table 4-2.

Table 4-2 Cull Callback Return Values

Value	Action
PFTRAV_CONT	Continue and traverse the children of this node.
PFTRAV_PRUNE	Skip the subgraph rooted at this node and continue.
PFTRAV_TERM	Terminate the entire traversal.

Callbacks are processed by the cull traversal in the following order:

1. If a pre-cull callback is defined, then call the pre-cull callback to get a cull result and find out whether traversal should continue. Possible return values are listed in Table 4-2.
2. If the pre-cull callback returns PFTRAV_PRUNE, the traversal returns to the parent and continues with the node's siblings, if any. If the callback returns PFTRAV_TERM, the traversal terminates immediately. Otherwise, cull processing continues.
3. If the pre-cull callback doesn't set the cull result using **pfCullResult()**, and view-frustum culling is enabled, then perform the standard node-within-frustum test and set the cull result accordingly.
4. If the cull result is PFIS_FALSE, skip the traversal of children. The post-cull callback is invoked and traversal returns so that the parent node can traverse any siblings.

5. If a pre-draw callback is defined, then place a *libpr* display-list packet in the display list so that the node's pre-draw callback will be called by the draw process. If running a combined CULLDRAW traversal, invoke the pre-draw callback directly instead.
6. Process the node, continuing the cull traversal with each of the node's children or adding the node's geometry to a display list (for *pfGeodes*). If the cull result was `PFIS_ALL_IN`, view-frustum culling is disabled during the traversal of the children.
7. If a post-draw callback is defined, then place a *libpr* display-list packet in the display list so that the node's post-draw callback will be called by the draw process. If running a combined CULLDRAW traversal, invoke the post-draw callback directly instead.
8. If a post-cull callback is defined, then call the post-cull callback.

Draw callbacks are commonly used to place tags or change state while a subgraph is rendered. Note that if the pre-draw callback is called, the post-draw callback is guaranteed to be invoked. This way the callback can restore any state modified by the pre-draw callback. This is useful for state changes such as **`pfPushMatrix()`** and **`pfPopMatrix()`**, as shown in the environment-mapping code that's part of Example 4-2.

For doing customized culling, the pre-cull callback can determine whether a `PFIS_ALL_IN` has already turned off view-frustum culling using **`pfGetParentCullResult()`**, in which case it may not wish to do its own cull testing. It can also find out the result of the standard cull test by calling **`pfGetCullResult()`**.

Cull callbacks can also be used to render geometry (*pfGeoSets*) or change graphics state. Any *libpr* drawing commands are captured in a display list and are later executed during the draw traversal (see "Display Lists" in Chapter 9). However, direct graphics library calls can be made safely only in draw function callbacks, because only the draw process of multiprocess IRIS Performer configurations is known to be associated with a window.

Example 4-2 shows some sample node callbacks.

Example 4-2 *pfNode* Draw Callbacks

```
void
LoadScene(char *filename)
{
    pfScene *scene = pfNewScene();
    pfGroup *root = pfNewGroup();
    pfGroup *reflectiveGeodes = NULL;
```

```
root = pfdLoadFile(filename);
...
reflectiveGeodes =
    ReturnListOfGeodesWithReflectiveMaterials(root);

/* Use a node callback in the Draw process to turn on
 * and off graphics library environment mapping before
 * and after drawing all of the pfGeodes that have
 * pfGeoStates with reflective materials.
 */
pfNodeTravFuncs(reflectiveGeodes, PFTRAV_DRAW,
    pfdPreDrawReflMap, pfdPostDrawReflMap);
}

/* This callback turns on graphics library environment
 * mapping. Because it changes graphics state it must be a
 * Draw process node callback. */
long
pfdPreDrawReflMap(pfTraverser *trav, void *data)
{
    texgen(TX_S, TG_SPHEREMAP, 0);
    texgen(TX_T, TG_SPHEREMAP, 0);
    texgen(TX_S, TG_ON, NULL);
    texgen(TX_T, TG_ON, NULL);
    return NULL;
}

/* This callback turns off graphics library environment
 * mapping. Because it also changes graphics state it also
 * must be a Draw process node callback. Also notice that
 * it is important to return the graphics library's state to
 * the state at which it was in before the preNode callback
 * was even made.
 */
long
pfdPostDrawReflMap(pfTraverser *trav, void *data)
{
    texgen(TX_S, TG_OFF, NULL);
    texgen(TX_T, TG_OFF, NULL);
    return NULL;
}
```

Process Callbacks

libpf processes a visual database with a software-rendering pipeline composed of application, cull, and draw stages. The system of *process callbacks* allows you to insert your own custom culling and drawing functions into the rendering pipeline. Furthermore, these callbacks are invoked by the proper process when your IRIS Performer application is configured for multiprocessing.

By default, IRIS Performer culls and draws all active pfChannels when **pfFrame()** is called. However, you can specify cull and draw function callbacks so that **pfFrame()** will cause IRIS Performer to call your custom functions instead. These functions have the option of using the default IRIS Performer processing in addition to their own custom processing.

When multiprocessing is used, the rendering pipeline works on multiple frames at once. For example, when the draw process is rendering frame n , the cull process is working on frame $n+1$, and the application process is working on frame $n+2$. This situation requires careful management of data so that data generated by the application is propagated to the cull process and then to the draw process at the right time. IRIS Performer manages data that is passed to the process callbacks to ensure that the data is frame-coherent and isn't corrupted.

Example 4-3 illustrates the use of a cull-process callback.

Example 4-3 Cull-Process Callbacks

```
InitChannels()
{
    ...
    /* create and configure all channels*/
    ...
    /* define callbacks for cull and draw processes */
    pfChanTravFunc(chan, PFTRAV_CULL, CullFunc);
    pfChanTravFunc(chan, PFTRAV_DRAW, DrawFunc);
    ...
}

/* The Cull callback. Any work that needs to be done in the
 * Cull process should happen in this function.
 */
void
CullFunc(pfChannel * chan, void *data)
{
```

```
static long first = 1;

/* Lock down whatever processor the cull is using when
 * the cull callback is first called.
 */
if (first)
{
    if ((pfGetMultiprocess() & PFMP_FORK_CULL) &&
        (ViewState->procLock & PFMP_FORK_CULL))
        pfuLockDownCull(pfGetChanPipe(chan));
    first = 0;
}

/* User-defined pre-cull processing. Application-
 * specific cull knowledge might be used to provide
 * things like line-of-sight culling.
 */
PreCull(chan, data);

/* standard Performer culling to the viewing frustum */
pfCull();

/* User-defined post-cull processing; this routine might
 * be used to do things like record cull state from this
 * cull to be used in future culls.
 */
PostCull(chan, data);
}

/* The draw function callback. I/O with IRIS GL devices must
 * happen here. Any graphics library functionality outside
 * IRIS Performer must be done here.
 */
void
DrawFunc(pfChannel *chan, void *data)
{
    /* pre-Draw tasks like clearing the viewport */
    PreDraw(chan, data);

    pfDraw();          /* render the frame */

    /* draw HUD, read IRIS GL devices, and so on */
    PostDraw(chan, data);
}
```

Process Callbacks and Passthrough Data

Cull and draw callbacks are specified on a per-pfChannel basis using the functions **pfChanTravFunc()** with PFTRAV_CULL and PFTRAV_DRAW, respectively. **pfAllocChanData()** allocates *passthrough data*, data which is passed down the rendering pipeline to the callbacks.

In the cull phase of the rendering pipeline, IRIS Performer invokes the cull callback with a pointer to the pfChannel that is being culled and a pointer to the pfChannel's passthrough data buffer. The cull callback may modify data in the buffer. The potentially modified buffer is then copied and passed to the user's draw callback.

Default IRIS Performer processing is triggered by **pfCull()** and **pfDraw()**. By default, **pfFrame()** calls **pfCull()** first, then calls **pfDraw()**. If process callbacks are defined, however, **pfCull()** and **pfDraw()** are not invoked automatically and must be called by the callbacks to use IRIS Performer's default processing. **pfCull()** should be called only in the cull callback; it causes IRIS Performer to cull the current channel and to generate a display list suitable for rendering.

Channels culled by **pfCull()** may be drawn in the draw callback by **pfDraw()**. It is legal for the draw callback to call **pfDraw()** more than once. Multi-pass renderings performed with multiple calls to **pfDraw()** are typical when you use accumulation buffer techniques.

When the draw callback is invoked, the window will have already been properly configured for drawing the pfChannel. Specifically, the viewport, perspective, and viewing matrices are set to their correct values. User modifications of these values are not reset by **pfDraw()**. If a draw callback is specified, IRIS Performer doesn't automatically clear the viewport; it leaves that responsibility to the application. **pfClearChan()** can be called from the draw callback to clear the channel viewport. If *chan* has a **pfEarthSky()**, then the **pfEarthSky()** is drawn. Otherwise, the viewport is cleared to black and the z-buffer is cleared to its maximum value.

You should call **pfPassChanData()** to indicate that user data should be passed through the rendering pipeline, which propagate the data downstream to cull and draw callbacks. The next call to **pfFrame()** copies the channel buffer into internal buffers, so that the application is then free to modify data in the buffer without fear of corruption. The **pfPassChanData()** function should be called only when necessary, since calling it imposes some buffer-copying overhead. In addition, passthrough data should be as small as possible to reduce the time spent copying data.

The code fragment in Example 4-4 is an example of cull and draw callbacks and the passthrough data that is used to communicate with them.

Example 4-4 Using Passthrough Data to Communicate With Callback Routines

```
typedef struct
{
    long val;
} PassData;

void cullFunc(pfChannel *chan, void *data);
void drawFunc(pfChannel *chan, void *data);

int main()
{
    PassData *pd;

    /* allocate passthrough data */
    pd = (PassData*)pfAllocChanData(chan, sizeof(PassData));

    /* initialize channel callbacks */
    pfChanTravFunc(chan, PFTRAV_CULL, cullFunc);
    pfChanTravFunc(chan, PFTRAV_DRAW, drawFunc);

    /* main simulation loop */
    while (1)
    {
        pfSync();
        pd->val = 0;
        pfPassChanData(chan);
        pfFrame();
    }
}

void
cullFunc(pfChannel *chan, void *data)
{
    PassData *pd = (PassData*)data;

    pd->val++;
    pfCull();
}

void
drawFunc(pfChannel *chan, void *data)
```

```
{
    PassData *pd = (PassData*)data;
    fprintf(stderr, "%ld\n", pd->val);
    pfClearChan(chan);
    pfDraw();
}
```

This example would, regardless of the multiprocessing mode, have the values 0, 1, and 1 for *pd->val* at the points where **pfFrame()**, **pfCull()**, and **pfDraw()** are called. In this way, control data can be sent down the pipeline from the application, through the cull, and on to the draw process with frame synchronization without regard to the active multiprocessing mode.

When configured as a process separate from the draw, the cull callback should not attempt to send graphics commands to an IRIS Performer window because only the draw process is attached to the window. Callbacks should not modify the IRIS Performer database, but they can use **pfGet()** routines to inquire about database information. The draw callback should not call **swapbuffers()** (or an equivalent function when using OpenGL) because IRIS Performer must control buffer swapping in order to manage the necessary frame and channel synchronization. However, if you need special control over buffer swapping, use **pfPipeSwapFunc()** to register a function as the given pipe's buffer-swapping function. Once your function is registered, it will be called instead of **swapbuffers()** and may then invoke either of these functions.

Intersection Traversal

You can make spatial inquiries in IRIS Performer by testing the intersection of line segments with geometry in the database. For example, a single line segment pointing straight down from the eyepoint can determine your height above terrain, four such segments can simulate the four tires of a car, and segments swept out by points on a moving object can determine collisions with other objects.

Testing Line Segment Intersections

The testing of each line segment or group of spatially grouped segments requires a traversal of part or all of a scene graph. You make these inquiries using **pfNodeIsectSegs()**, which intersects the specified group of segments with the subgraph rooted at the specified node. **pfChanNodeIsectSegs()** functions similarly, but includes a channel so that the traversal can make decisions based on the level-of-detail specified by pfLOD nodes.

Intersection Requests: pfSegSets

A pfSegSet is a structure that embodies an intersection request.

```
typedef struct _pfSegSet
{
    long    mode;
    void*   userData;
    pfSeg   segs[PFIS_MAX_SEGS];
    ulong   activeMask;
    ulong   isectMask;
    void*   bound;
    long    (*discFunc)(pfHit*);
} pfSegSet;
```

The *segs* field is an array of line segments making up the query. You tell **pfNodeIsectSegs()** which segments to test with by setting the corresponding bit in the *activeMask* field. If your pfSegSet contains many closely-grouped line segments, you can specify a bounding volume using the data structure's *bound* field. **pfNodeIsectSegs()** can use that bounding volume to more quickly test the request against bounding volumes in the scene graph. The *userData* field is a pointer with which you can point to other information about the request that you might want access to in a callback. The other fields are described below. The pfSegSet isn't modified during the traversal.

Intersection Return Data: pfHit Objects

Intersection information is returned in pfHit objects. These can be queried using **pfQueryHit()** and **pfMQueryHit()**. Table 4-3 lists the items that can be queried from a pfHit object.

Table 4-3 Intersection-Query Token Names

Query Token	Description
PFQHIT_FLAGS	Status and validity information
PFQHIT_SEGNUM	Index of the segment in pfSegSet request
PFQHIT_SEG	Line segment as currently clipped
PFQHIT_POINT	Intersection point in object coordinates
PFQHIT_NORM	Geometric normal of an intersected triangle
PFQHIT_VERTS	Vertices of an intersected triangle
PFQHIT_TRI	Index of an intersected triangle
PFQHIT_PRIM	Index of an intersected primitive in pfGeoSet
PFQHIT_GSET	pfGeoSet of an intersection
PFQHIT_NODE	pfGeode of an intersection
PFQHIT_NAME	Name of pfGeode
PFQHIT_XFORM	Current transformation matrix
PFQHIT_PATH	Path in scene graph of intersection

The PFQHIT_FLAGS field is bit vector with bits that indicate whether an intersection occurred and whether the point, normal, primitive and transformation information is valid. For some types of intersections only some of the information has meaning; for instance, for a pfSegSet bounding volume intersecting a pfNode bounding sphere, the point information may not be valid.

Queries can be performed singly by calling **pfQueryHit()** with a single query token, or several at a time by using **pfMQueryHit()** with an array of tokens. In the latter case, the return information is placed in the specified order into a return array.

Intersection Masks

Before using `pfNodeIsectSegs()` to intersect the geometry in the scene graph, you must set intersection masks for the nodes in the scene graph and correspondingly in your search request.

Setting the Intersection Mask

`pfNodeTravMask()` sets the intersection masks in a subgraph of the scene down through GeoSets. For example:

```
pfNodeTravMask(root, PFTRAV_ISECT, 0x01,  
                PFTRAV_SELF | PFTRAV_DESCEND, PF_SET)
```

sets the intersection mask of all nodes and GeoSets in the scene graph to 0x01. A subsequent intersection request would then use 0x01 as the mask in `pfNodeIsectSegs()`. A description of how to use this mask follows.

Specifying Different Classes of Geometry

Databases can contain different classes of objects, and only some of those may be relevant for a particular intersection request. For example, the wheels on a truck follow the ground, even through a small pond; therefore, you only want to test for intersection with the ground and not with the water. For a boat, on the other hand, intersections with both water and the lake bottom have significance.

To accommodate distinctions between classes of objects, each node and GeoSet in a scene graph has an intersection mask. This mask allows traversals, such as intersections, to either consider or ignore geometry by class.

For example, you could use four classes of geometry to control tests for collision detection of a moving ship, collision detection for a falling bowling ball, and line-of-sight visibility. Table 4-4 matches database classes with the `pfNodeTravMask` and `pfGSetIsectMask` values used to support the traversal tests listed above.

Table 4-4 Database Classes and Corresponding Node Masks

Database Class	Node Mask
Water	0x01
Ground	0x02
Pier	0x04
Clouds	0x08

Once the mask values at nodes in the database have been set, intersection traversals can be directed by them. For example, the line segments for ship collision detection should be sensitive to the water, ground, and pier, while a those for a bowling ball would ignore intersections with water and the clouds, testing only against the ground and pier. Line-of-sight ranging should be sensitive to all the geometry in the scene. Table 4-5 lists the traversal mask values and mask representations that would achieve the proper intersection tests.

Table 4-5 Representing Traversal Mask Values

Intersection Class	Mask Value	Mask Representation
Ship	0x07	(Water Ground Pier)
Bowling ball	0x06	(Ground Pier)
Line-of-sight ranging	0x0f	(Water Ground Pier Clouds)

The intersection traversal prunes a node as soon as it gets a zero result from doing a bitwise AND of the node intersection mask and the traversal mask specified by the `pfSegSet`'s `isectMask` field. Thus, all nodes in the scene graph should normally be set to be the bitwise OR of the masks of their children. After setting the class-specific masks for different subgraphs of the scene, this can be accomplished by calling

```
pfNodeTravMask(root, PFSET_OR, PFTRAV_SET_FROM_CHILD, 0x0);
```

which sets each node's mask by OR-ing 0x0 with the current mask and the masks of the node's children.

Note that this traversal, like that used to update node bounding volumes, is unusual in that it propagates information up the graph from leaf nodes to root.

Discriminator Callbacks

If you need to make a more sophisticated discrimination than node masks allow about when an intersection is valid, IRIS Performer can issue a callback on each successful intersection and let you decide whether the intersection is valid in the current context.

If a callback is specified in `pfNodeIsectSegs()`, then at each level where an intersection occurs—for example, with bounding volumes of *libpf* `pfGeodes` (mode `PFTRAV_IS_GEODE`), *libpr* `GeoSets` (mode `PFTRAV_IS_GSET`), or individual geometric primitives (mode `PFTRAV_IS_PRIM`)—IRIS Performer invokes the callback, giving it information about the candidate intersection. The value you return from the callback determines whether the intersection should be ignored and how the intersection traversal should proceed.

If the return value includes the bit `PFTRAV_IS_IGNORE`, the intersection is ignored. The intersection traversal itself can also be influenced by the callback. The traversal is subject to three possible fates, as detailed in Table 4-6.

Table 4-6 Possible Traversal Results

Set Bits	Meaning
<code>PFTRAV_CONT</code>	Continue the traversal inside this subgraph or GeoSet.
<code>PFTRAV_PRUNE</code>	Continue the traversal but skip the rest of this subgraph or GeoSet.
<code>PFTRAV_TERM</code>	Terminate the traversal here.

Line Segment Clipping

Usually, the intersection point of most interest is the one that is nearest to the beginning of the segment. By default, after each successful intersection, the end of the segment is clipped so that the segment now ends at the intersection point. Upon the final return from the traversal, it contains the closest intersection point.

However, if you want to examine all intersections along a segment you can use a discriminator callback to tell IRIS Performer not to clip segments—simply leave out the PFTRAV_IS_CLIP_END bit in the return value. If you want the farthest intersection point, you can use PFTRAV_IS_CLIP_START so that after each intersection the new segment starts at the intersection point and extends outward.

Traversing Special Nodes

Level-of-detail nodes are intersected against the model for range zero, which is typically the highest level-of-detail. If you want to select a different model, you can turn off the intersection mask for the LOD node and place a switch node in parallel (having the same parent and children as the LOD) and set it to the desired model.

Sequences and switches intersect using the currently active child or children. Billboards are not intersected, since no eyepoint is defined for intersection traversals.

Picking

pfChanPick() provides a simple interface for intersection testing by enabling the user to move a mouse to select one or more geometries. The method uses **pfNodeIssectSegs()** and uses the high bit, PFIS_PICK_MASK, of the intersection mask in the scene graph. Setting up picking with **pfNodePickSetup()** sets this bit in the intersection mask throughout the specified subgraph, but does not enable caching inside pfGeoSets. See “Performance” on page 115.

pfChanPick() has an extra feature: it can either return the closest intersection (PFPK_M_NEAREST) or return all pfHits along the picking ray (PFPK_M_ALL).

Performance

The intersection traversal uses the hierarchical bounding volumes in the scene graph to allow culling of the database and then processes candidate GeoSets by testing against their internal geometry. For this reason, the hierarchy should reflect the spatial organization of the database. High-performance culling has similar requirements (see Chapter 19, “Performance Tuning and Debugging”).

Performance Trade-offs

IRIS Performer currently retains no information about spatial organization of data within GeoSets, so each triangle in the GeoSet must be tested. Although large GeoSets are good for rendering performance in the absence of culling, spatially localized GeoSets are best for culling (since a GeoSet is the smallest culling unit), and spatially localized GeoSets with few primitives are best for intersections.

Front Face/Back Face

One way to speed up intersection testing is to turn on `PFTRAV_IS_CULL_BACK`. When this flag is enabled, only front-facing geometry is tested.

Enabling Caching

Precomputing information about normals and projections speeds up intersections inside GeoSets. For the best performance, you should enable caching in GeoSets when you set the intersection masks with `pfNodeTravMask()`.

If the geometry within a GeoSet is dynamic, such as waves on a lake, caching can cause incorrect results. However, for geometry that changes only rarely, you can use `pfGSetIsectMask()` to recompute the cache as needed.

Intersection Methods for Segments

Normally, when intersecting down to the primitive level each line segment is separately tested against each bounding volume in the scene graph, and after passing those tests is intersected against the `pfGeoSet` bounding box. Segments that intersect the bounding box are eventually tested against actual geometry.

When a `pfSegSet` has a spatially localized group of at least several line segments, you can speed up the traversal by providing a bounding volume. You can use `pfCylAroundSegs()` to create a bounding cylinder for the segments, and place a pointer to the resulting cylinder in the `pfSegSet`'s *bound* field; then OR the `PFTRAV_IS_BCYL` bit into the `pfSegSet`'s *mode* field.

If only a rough volume-volume intersection is required, you can specify a bounding cylinder in the `pfSegSet` without any line segments at all and request discriminator callbacks at the `PFTRAV_IS_NODE` or `PFTRAV_IS_GSET` level.

Figure 4-4 illustrates some aspects of this process. The portion of the figure labeled A represents a single segment; B is a collection of nonparallel segments, not suitable for tightly bounding with a cylinder; and C shows parallel segments surrounded by a bounding cylinder. In the bottom portion of the figure, the bounding cylinder around the segments intersects the bounding box around the object; each segment in the cylinder thus must be tested individually to see if any of them intersect.

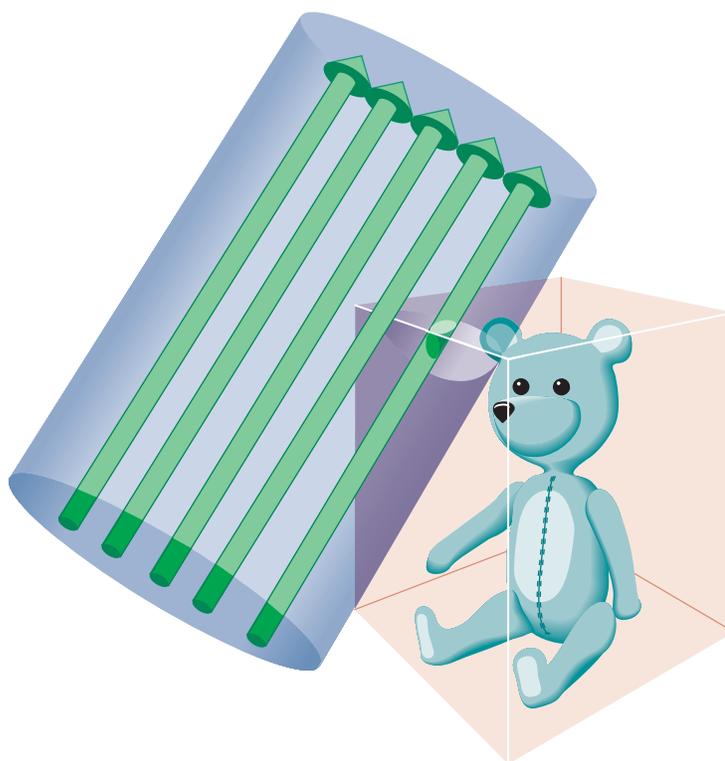


Figure 4-4 Intersection Methods

“Frame and Load Control”

This chapter explains how to control frame rate, synchronization, and dynamic load management.

Frame and Load Control

This chapter describes how to manage the display operations of a visual simulation application to maintain the desired frame rate and visual performance level. In addition, this chapter covers advanced topics including multiprocessing and shared memory management.

Frame-Rate Management

A *frame* is the period of time in which all processing must be completed before updating the display with a new image, for example, a frame rate of 60Hz means the display is updated 60 times per second and the time extent of a frame is 16.7ms. The ability to fit all processing within a frame depends on several variables, some of which are:

- the number of pixels being filled
- the number of transformations and modal changes being made
- the amount of processing required to create a display list for a single frame
- the quantity of information being sent to the graphics subsystem

Through intelligent management of Silicon Graphics CPU and graphics hardware, IRIS Performer minimizes the above variables in order to achieve the desired frame rate. However, in some cases, peak frame rate is less important than a *fixed frame rate*. Fixed frame rate means that the display is updated at a consistent, unvarying rate. While a simple step towards achieving a fixed frame rate is to reduce the maximum frame rate to an easily achievable level, we shall explore other (less Draconian) mechanisms in this chapter that do not adversely impact frame rates.

As discussed in the following sections, IRIS Performer lets you select the frame rate and has built-in functionality to maintain that frame rate and control overload situations when the draw time exceeds or grows uncomfortably close to a frame time. While these methods can be effective, they do require some cooperation from the run-time database. In particular, databases should be modeled with levels-of-detail and be spatially arranged.

Selecting the Frame Rate

IRIS Performer is designed to run at the fixed frame rate as specified by `pfFrameRate()`. Selecting a fixed frame rate does not in itself guarantee that each frame can be completed within the desired time. It is possible that some frames might require more computation time than is allotted by the frame rate. By taking too long, these frames cause *dropped* or *skipped* frames. A situation in which frames are dropped is called an *overload* or *overrun* situation. A system that is close to dropping frames is said to be in *stress*.

Achieving the Frame Rate

The first step towards achieving a frame rate is to make sure that the scene can be processed in less than a frame's time—hopefully *much* less than a frame's time. Although minimizing the processing time of a frame is a huge effort, rife with tricks and black magic, certain techniques stand out as IRIS Performer's main weapons against slothful performance:

- **Multiprocessing.** The use of multiple processes on multi-CPU systems can drastically increase throughput.
- **View culling.** By trivially rejecting portions of the database outside the viewing volume, performance can be increased by orders of magnitude.
- **State sorting.** Many graphics pipelines are sensitive to graphics mode changes. Sorting a scene by graphics state greatly reduces mode changes, increasing the efficiency of the hardware.
- **Level-of-detail.** Objects that are far away project to a relatively small area of the display so fewer polygons can be used to render the object without substantial loss of image quality. The overall result is fewer polygons to draw and improved performance.

Multiprocessing and level-of-detail is discussed in this chapter while view culling and state sorting are discussed in Chapter 4, "Database Traversal." More information on sorting in the context of performance tuning can be found in Chapter 19, "Performance Tuning and Debugging."

Fixing the Frame Rate

Frame intervals are fixed periods of time but frame processing is variable in nature. Because things change in a scene, such as when objects come into the field of view, frame processing cannot be fixed. In order to maintain a fixed frame rate, the average frame processing time must be less than the frame time so that fluctuations don't exceed the selected frame time. Alternately, the scene complexity can be automatically reduced or increased so that the frame rate stays within a user-defined "sweet spot". This mechanism requires that the scene be modeled with levels-of-detail (pFLOD nodes).

Each frame, IRIS Performer calculates the system *load* for each frame. Load is calculated as the percentage of the frame period it took to process the frame. Then if the default IRIS Performer fixed frame rate mechanisms are enabled, load is used to calculate system *stress*, which is in turn used to adjust the level of detail (LOD) of visible models. LOD management is IRIS Performer's primary method of managing system load.

Table 5-1 shows the IRIS Performer functions for controlling frame processing.

Table 5-1 Frame Control Functions

Function	Description
pfFrameRate	Set the desired frame rate.
pfSync	Synchronize processing to frame boundaries.
pfFrame	Initiate frame processing.
pfPhase	Control frame boundaries.
pfChanStressFilter	Control how stress is applied to LOD ranges.
pfChanStress	Manually control the stress value.
pfGetChanLoad	Determine the current system load.
pfChanLODAttr	Control how LOD is performed, including global LOD adjustment and blending (fade).

Figure 5-1 shows a frame-timing diagram that illustrates what occurs when frame computations are not completed within the required interval. The solid vertical lines in Figure 5-1 represent frame-display intervals. The dashed vertical lines represent video refresh intervals.

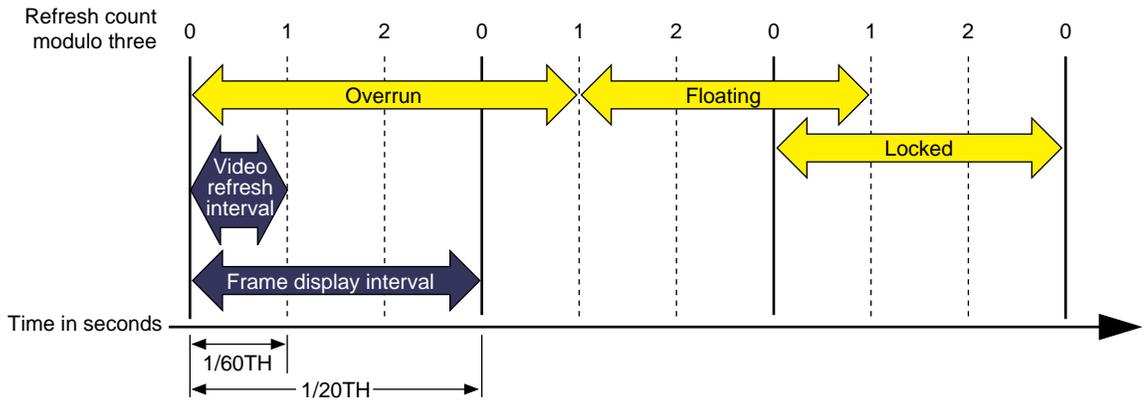


Figure 5-1 Frame Rate and Phase Control

In this example, the video scan rate is 60 Hz and the frame rate is 20 Hz. With the video hardware running at 60 Hz, each of the 20 Hz frames should be scanned to the video display three times, and the system should wait for every third vertical retrace signal before displaying the next image. The numbers across the top of the figure represent the refresh count modulo three. New images are displayed on refreshes whose count modulo three is zero, as shown by the solid lines.

In the first frame of this example, the new image isn't yet completed when the third vertical retrace signal occurs; the same image must therefore be displayed again during the next interval. This situation is known as frame *overrun*, because the frame computation time extends past a refresh boundary.

Frame Synchronization

Because of the overrun, the frame and refresh interval timing is no longer synchronized; it's out of phase. A decision must be made either to display the same image for the remaining two intervals, or to switch to the next image even though the refresh isn't aligned on a frame boundary. The frame-rate control mode, discussed in the next section, determines which choice is selected.

Knowing that the situation illustrated in Figure 5-1 is a possibility, you can specify a frame control mode to indicate what you would like the system to do when a frame overrun occurs.

To specify a method of frame-rate control, call **pfPhase()**. There are the following choices:

- Free run without phase control (PFPHASE_FREE_RUN) tells the application to run as fast as possible—to display each new frame as soon as it’s ready, without attempting to maintain a constant frame rate.
- Free run without phase control but with a limit on the maximum frame rate (PFPHASE_LIMIT) tells the application to run no faster the rate specified by pfFrameRate.
- Fixed frame rate with floating phase (PFPHASE_FLOAT) allows the drawing process to display a new frame (using **swapbuffers(3G)**) at any time, regardless of frame boundaries.
- Fixed frame rate with locked phase (PFPHASE_LOCK) requires the draw process to wait for a frame boundary before displaying a new frame.
- The draw by default will wait for a new cull result to execute its stage functions. This behavior can be changed by including the token PFPHASE_SPIN_DRAW with the desired mode token from the above choices. This will allow the draw to run every frame, redrawing the previous cull result. This can allow you to make changes of your own in draw callback functions. Objects such as viewing frustum, pfLODs, pfDCSs, and anything else normally processed by the CULL or application processes will not be updated until the next full cull result is available.

Free-Running Frame-Rate Control

The simplest form of frame-rate control, called *free-running*, is to have no control at all. This uncontrolled mode draws frames as quickly as the hardware is able to process them. In free-running mode, the frame rate may be 60 Hz in the areas of low database complexity, but could drop to a slower rate in views that place greater demand on the system. Use **pfPhase(PFPHASE_FREE_RUN)** to specify a free-running frame rate.

In applications in which real-time graphics provide the majority of visual cues to an observer, the variable frame rates produced by the free-running mode may be undesirable. The variable lag in image update associated with variable frame rate can lead to motion sickness for the simulation participants, especially in motion platform-based trainers or ingressive head-mounted displays. For these and other reasons it is usually preferable to maintain a steady, consistent frame-update rate.

Fixed Frame-Rate Control

Assume that the overrun frame in Figure 5-1 completes processing during the next refresh period, as shown. After the overrun frame, the simulation is still running at the chosen 20-Hz rate and is updating at every third vertical retrace. If a new image is displayed at the next refresh, its start time lags by 1/60th of a second, and therefore it is out of phase by that much.

Subsequent images are displayed when the refresh count modulo three is one. As the simulation continues and additional extended frames occur, the phase continues to drift. This mode of operation is called *floating phase*, as shown by the frame in Figure 5-1 labeled *Floating*. Use **pfPhase(PFPHASE_FLOAT)** to select floating-phase frame control.

The alternative to displaying a new image out of phase is to display the old image for the remainder of the current update period, then change to the new image at the normal time. This *locked phase* extends each frame overrun to an integral multiple of the selected frame time, making the overrun more evident but also maintaining phase throughout the simulation. This timing is shown by the frame in Figure 5-1 labeled *Locked*. Although this mode is the most restrictive, it is also the most desirable in many cases. Use **pfPhase(PFPHASE_LOCK)** to select phase-locked frame control.

For example, a 20-Hz phase-locked frame rate is selected by specifying:

```
pfPhase(PFPHASE_LOCK);  
pfFrameRate(20.0f);
```

These specifications prevent the system from switching to a newly computed image until a display period of 1/20th second has passed from the time the previous image was displayed. The frame rate remains fixed even when the Geometry Pipeline finishes its work in less time. Fixed frame-rate display therefore involves setting the desired frame rate and selecting one of the two fixed-frame-rate control modes.

Frame Skipping

When multiple frame times elapse during the rendering of a single frame, the system must choose which frame to draw next. If the per-frame display lists are processed in strict succession even after a frame overrun, the visual image slowly recedes in time and the positional correlation between display and simulation is lost. To avoid this problem, only the most recent frame definition received by the draw process is sent to the Geometry Pipeline, and all intervening frame definitions are abandoned. This is known as *dropping* or *skipping* frames and is performed in both of the fixed frame-rate modes.

Because the effects of variable frame rates, phase variance, and frame dropping are distracting, you should choose a frame rate with care. Steady frame rates are achieved when the frame time allows the worst-case view to be computed without overload. The structure of the visual database, particularly in terms of uniform “complexity density,” can be important in maximizing the system frame rate. See “Organizing a Database for Efficient Culling” in Chapter 4 and Figure 4-3 for examples of the importance of database structure.

Maintaining a fixed frame rate involves managing future system load by adjusting graphics display actions to compensate for varying past and present loads. The theory behind load management and suggested methods for dealing with variable load situations are discussed in the “Level-of-Detail Management” section of this chapter.

Sample Code

Example 5-1 demonstrates a common approach to frame control. The code is based on part of the *main.c* source file used in the *perfly* sample application.

Example 5-1 Frame Control Excerpt

```
/* Set the desired frame rate. */
pfFrameRate(ViewState->frameRate);

/* Set the MP synchronization phase. */
pfPhase(ViewState->phase);

/* Application main loop */
while (!SimDone())
{
    /* Sleep until next frame */
    pfSync();

    /* Should do all latency-critical processing between
     * pfSync() and pfFrame(). Such processing usually
     * involves changing the viewing position.
     */
    PreFrame();

    /* Trigger cull and draw processing for this frame. */
    pfFrame();

    /* Perform non-latency-critical simulation updates. */
    PostFrame();
}
```

Maintaining Frame Rate Using Dynamic Video Resolution

When frame rate is not maintained, some frames display longer than others. If, for example, when the frame rate is 30 frames per second, a frame takes longer than 1/30th of a second to fill the frame buffer, the frame is not displayed. Consequently, the current frame is displayed for two instead of one 1/30ths of a second. The result of inconsistent frame rates is jerky motion within the scene.

Note: You have some control over what happens when a frame rate is missed. You can choose, for example, to begin the next frame in the next 1/60th of a second, or wait for the start of the next 1/30th second. For more information about handling frame drawing overruns, see pfPhase in “Free-Running Frame-Rate Control” on page 125.

The key to maintaining frame rate is limiting the amount of information to be rendered. IRIS Performer can take care of this problem automatically for you when you use the PFPVC_DVR_AUTO token with `pfPVChanDVRMode()`.

In PFPVC_DVR_AUTO mode, IRIS Performer checks every rendered frame to see if it took too long to render. If it did, IRIS Performer reduces the size of the image, and correspondingly, the number of pixels in it. Afterwards, the video hardware enlarges the images to the same size as the pfChannel; in this way, the image is the correct size, but it contains a reduced number of pixels, as suggested in Figure 5-2.

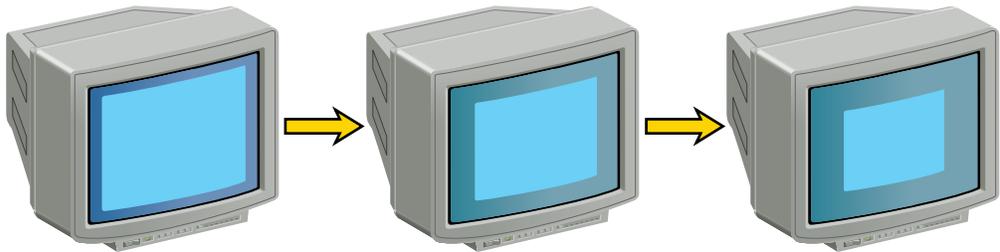


Figure 5-2 Real Size of Viewport Rendered Under Increasing Stress

Although the viewport is reduced as stress increases, the viewer never sees the image grow smaller because bipolar filtering is used to enlarge the image to the size of the channel.

The Channel in DVR

When using Dynamic Video Resolution (DVR), the origin and size of a channel are dynamic. For example, a viewport whose lower-left corner is at the center of a `pfPipe` (with coordinates 0.5, 0.5) would be changed to an origin of (0.25, 0.25) with respect to the full `pfPipe` window if the DVR settings were scaled by a factors of 0.5 in both X and Y dimensions.

If you are doing additional rendering into a `pfChannel`, you may need to know the size and the actual rendered area of the `pfChannel`. Use `pfGetChanOutputOrigin()` and `pfGetChanOutputSize()` to get the actual rendered origin and size, respectively, of a `pfChannel`. `pfGetChanOrigin()` and `pfGetChanSize()` gives the displayed origin and size of the `pfChannel` and these functions should be used for mapping mouse positions or other window-relative non-rendering positions to the `pfChannel` area.

Additionally, if DVR alters the rendered size of a `pfChannel`, a corresponding change should be made to the width of points and lines. For example, when a channel is scaled in size by one half, lines and points must be drawn half as wide as well so that when the final image is enlarged, in this case by a factor of two, the lines and points scale correctly. `pfChanPixScale()` sets the pixel scale factor. `pfGetChanPixScale()` returns this value for a channel. `pfChannels` set this pixel scale automatically.

DVR Scaling

DVR scales linearly in response to the most common cause of draw overload: filling the polygons. For example, if the DRAW stage process overran by 50%, to get back in under the frame time, the new scene must draw 30% fewer pixels. We can do this with DVR by rendering to a smaller viewport and letting the video hardware rescale the image to the correct display size.

If `pfPVChanMode()` is set to `PFPVC_DVR_AUTO`, IRIS Performer automatically scales each of the `pfChannels`. `pfChannels` automatically scale themselves according to the scale set on the `pfPipeVideoChannel` they are using.

If the `pfPVChanMode()` is `PFPVC_DVR_MANUAL`, you control scaling according to your own policy by setting the scale and size of the `pfPipeVideoChannel` in the application process between `pfSync()` and `pfFrame()`. For example:

```
Total pixels drawn last frame = ChanOutX * ChanOutY * Depth Complexity
```

To make the total pixels drawn 30% less, do the following:

```
NewChanOutX = NewChanOutY = .7 * (Chan OutX * ChanOut.)  
New ChanOut X = sqrt (.7) * ChanOutX  
New ChanOut Y = sqrt (.7) * ChanOut Y  
NewChanOut = sqrt (.7) * ChanOut
```

Customizing DVR

Your application has full control over DVR behavior. You can either configure the automatic mode or implement your own response control.

Automatic resizing can cause problems when an image has so much information in it the viewport is reduced too drastically, perhaps to only a few hundred pixels, so that when the image is enlarged, the image resolution is unacceptably blurry. To remedy this problem, `pfPipeVideoChannel` includes the following methods to limit the reduction of a video channel:

- `pfPVChanMaxDecScale()`
sets the maximum X and Y decrement scaling that can happen in a single step of automatic dynamic video resizing. A scale value of (-1), the default, removes the upper bound on decremental scales.
- `pfPVChanMaxIncScale()`
sets the maximum X and Y increment scaling that can happen in a single step of automatic dynamic video resizing. A scale value of (-1), the default, removes the upper bound on incremental scales.
- `pfPVChanMinDecScale()`
sets the minimum X and Y decrement scaling that can happen in a single step of automatic dynamic video resizing. The default value is 0.0.
- `pfPVChanMinIncScale()`
sets the minimum X and Y increment scaling that can happen in a single step of automatic dynamic video resizing. The default value is 0.0.
- `pfPVChanStress()`
sets the stress of the `pfPipeVideoChannel` for the current frame. This call should be made in the application process after `pfSync` and before `pfFrame` to affect the next immediate draw process frame.
- `pfPVChanStressFilter()`
sets the parameters for computing stress if it is not explicitly set for the current frame by `pfPVChanStress`.

Each of these methods have corresponding Get methods that return the values set by these methods.

To resize the video channel manually, use pfPipeVideoChannel sizing methods, such as pfPVChanOutputSize(), pfPVChanAreaScale(), and pfPVChanScale().

The pfPipeVideoChannel associated with a channel is returned by pfGetChanPVChan(). If there is more than one pfPipeVideoChannel associated with a pfPipeWindow, each one is identified by an index number. In the case of multiple pfPipeVideoChannels, the pfPipeVideoChannel index is set using pfChanPWinPVChanIndex() and returned by pfGetChanPWinPVChanIndex().

Understanding the Stress Filter

pfPVChanStressFilter() sets the parameters for computing stress for a pfPipeVideoChannel when the stress is not explicitly set for the current frame by pfPVChanStress().

```
void pfPipeVideoChannel::setStressFilter(float *frameFrac,
    float *lowLoad, float *highLoad, float *pipeLoadScale,
    float *stressScale, float *maxStress);
```

frameFrac is the fraction of a frame that pfPipeVideoChannel is expected to take to render the frame, for example, if the rendering time is equal to the period of the frame rate, *frameFrac* is 1.

If there is only one pfPipeVideoChannel, it is best if *frameFrac* is 1. If there are more than one pfPipeVideoChannels on the pfPipe, by default *frameFrac* is divided among the pfPipeVideoChannels. You can set *frameFrac* explicitly for each pfPipeVideoChannel such that a channel rendering visually-complex scenes is allocated more time than a channel rendering simple scenes.

pfGetPFChanStressFilter() returns the stress filter parameters for pfPipeVideoChannel. If *stressScale* is non-zero, stress is computed for the pfPipeVideoChannel every frame. *low* and *high* define a hysteresis band for system load. When the load is above *lowLoad* and below *highLoad*, stress is held constant. When the load falls outside of the *lowLoad* and *highLoad* parameters, IRIS Performer reduces or increases stress respectively by dynamically resizing the output area of the pfPipeVideoChannel until the load stabilizes between *lowLoad* and *highLoad*.

If *pipeStressScale* is non-zero, the load of the pfPipe of the pfPipeVideoChannel are considered in computing the stress. *maxStress* is the clamping value above which the stress value cannot go. For more information about the stress filter, see the reference page for pfPipeVideoChannel.

Level-of-Detail Management

All graphics systems have finite capabilities that affect the number of geometric primitives that can be displayed per frame at a specified frame rate. Because of these limitations, maximizing visual cues while minimizing the polygon count in a database is often an important aspect of database development. Level-of-detail processing is one of the most beneficial tools available for managing database complexity for the purpose of improving display performance.

The basic premise of LOD processing is that objects that are barely visible, either because they are located a great distance from the eyepoint or because atmospheric conditions reduce visibility, don't need to be rendered in great detail in order to be recognizable. This is in stark contrast to brutishly mandating that all polygons be rendered regardless of their contribution to the visual scene. Both atmospheric effects and the visual effect of perspective decrease the importance of details as range from the eyepoint increases. The predominant visual effect of distance is the perspective foreshortening of objects, which makes them appear to shrink in size as they recede into the distance.

To save rendering time, objects that are visually less important in a frame can be rendered with less detail. The LOD approach to optimizing the display of complex objects is to construct a number of progressively simpler versions of an object and to select one of them for display as a function of range.

This requires you to create multiple models of an object with varying levels of detail. You also must supply a rule to determine how much detail is appropriate for a given distance to the eyepoint. The sections that follow describe how to create multiple LOD models and how to control when the changeover to a different LOD occurs.

Level-of-Detail Models

Most objects comprise smaller objects that become visually insignificant at ranges where the conglomerate object itself is still quite prominent. For example, a complex model of an automobile might have door handles, side- and rear-view mirrors, license plates, and other small details.

A short distance away, these features may no longer be visible, even though the car itself is still a visually significant element of the scene. It is important to realize that as a group, these small features may contain as many polygons as the larger car itself, and thus have a detrimental effect on rendering speed.

You can construct two LOD models simply by providing one model that contains all of the detailed features and another model that contains only the car body itself and none of the detailed features. A more sophisticated scheme uses multiple LOD models that are grouped under an LOD node.

Figure 5-3 shows an LOD node with multiple children numbered 1 through n . In this case, the model named LOD 1 is the most detailed model and models LOD 2 through LOD n represent progressively coarser models. Each of these LOD models might contain children that also have LOD components. Associated with the LOD node is a list of ranges that define the distance at which each model is appropriate to display. There is no limit to the number of levels of detail that can be used.

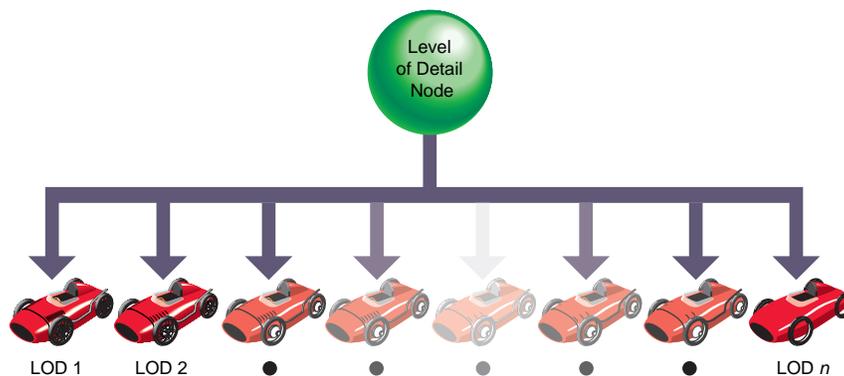


Figure 5-3 Level-of-Detail Node Structure

The object can be transformed as needed. During the culling phase of frame processing, the distance from the eyepoint to the object is computed and used (with other factors) to select which LOD model to display.

The IRIS Performer pfLOD node contains a value known as the center of LOD processing. The LOD center point is an x, y, z location that defines the point used in conjunction with the eyepoint for LOD range-switching calculations, as described in the “Level-of-Detail Range Processing” section of this chapter.

Figure 5-4 shows an example in which multiple LOD models grouped under a parent LOD node are used to represent a toy race car.

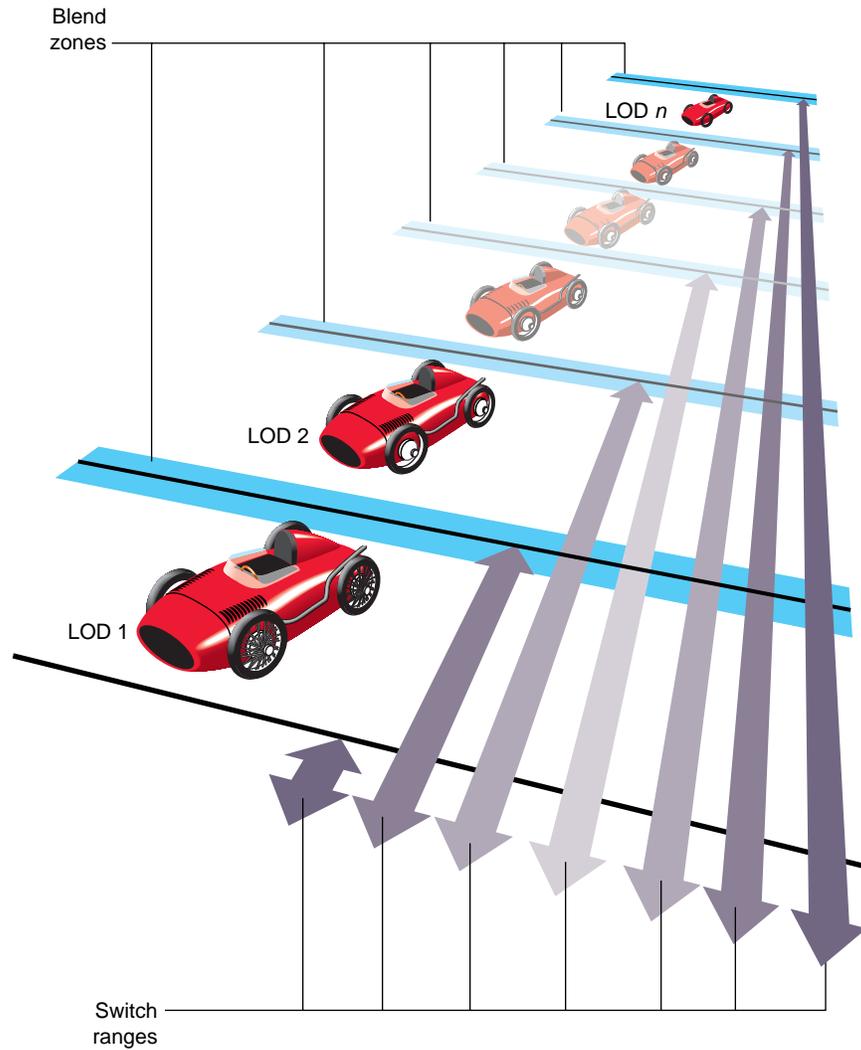


Figure 5-4 Level-of-Detail Processing

Figure 5-4 demonstrates that each car in a row of identical cars placed at increasing range from the eyepoint is drawn using a different child of the tree's LOD node.

The double-ended arrows indicate a switch range for each level of detail. When the car is closer to the eyepoint than the first range, nothing is drawn. When the car is between the first and second ranges, LOD 1 is drawn. When the car is between the second and third ranges, LOD 2 is drawn.

This range bracketing continues until the final range is passed, at which point nothing is drawn. The pfLOD node's switch range list contains one more entry than the number of child nodes to allow for this range bracketing.

IRIS Performer provides the ability to specify a blend zone for each switch between LOD models. Such that pfLOD nodes now also hold a list of these transition distances over which IRIS Performer should 'blend' between neighboring LODs. These blend zones will be discussed in more detail in "Level-of-Detail Transition Blending" on page 141.

Level of Detail States

In addition to standard LOD nodes, IRIS Performer also supports LOD state—the pfLODState. A pfLODState is an essence a way of creating classes or priorities among LODs. A pfLODstate contains eight parameters used to modify four different ways in which IRIS Performer calculates LOD switch ranges and LOD transition distances. LOD states contain the following parameters:

- Scale for LODs switch Ranges.
- Offset for LODs switch Ranges.
- Scale for the effect of Stress of switch Ranges.
- Offset for the effect of Stress on switch Ranges.
- Scale for the transition distances per LOD switch
- Offset for the transition distances per LOD switch
- Scale for the effect of Stress on transition distances
- Offset for the effect of Stress on transition distances

These LOD states can then be attached to either single or multiple LOD nodes such that the LOD behavior of groups or classes of objects can be different and be easily modified. The reference pages for **pfLODLodState()** and **pfLODLodStateIndex()** contain detailed information on how to attach pfLODStates.

LOD states are useful because in a particular scene there often exists an object of focus such as a sign, a target, or some other object of particular visual significance that needs to be treated specially with regard to visual importance and thus LOD behavior. It stands to reason, that this particular object (or small group of objects) should be at the highest detail possible despite being farther away than other elements in the scene which might not be as visually significant. In fact, it might be feasible to diminish the detail of these less important objects (like rocks and trees) in favor of the other more important objects (despite these objects being further relatively in range). In this case one would just create two LOD states. The first would be for the important objects and would effectively disable the effect of stress on these nodes as well as scale the switch ranges such that the object(s) would maintain more detail for further ranges. The second LOD state would be used to make the objects of less importance be more responsive to system stress and possibly scale their switch ranges such that they would show even less detail than normal. In this way, LOD states allow biasing among different LODs to maintain desirable rendering speeds while maintaining the visual integrity of various objects depending on their subjective importance (rather than solely on their current visual significance).

In some multichannel applications, LOD states are used to control the action of LODs in different viewing channels that have different visual significance criteria—for instance one channel might be a normal channel while a second might represent an infra-red display. Rather than simple use of LOD states, it is also possible to specify a list of LOD states to a channel and use indexes from this list for particular LODs (via **pfChanLODStateList()** and **pfLODLodStateIndex()**). In this way, in the normal channel a car's geometry might be particularly important while in the infra-red channel, the hot exhaust of the same car might be much more important to observe. This type of channel dependent LOD can be set up by using two distinct and different LOD states for the same index in the lists of LOD states specified for unique channels.

Note that because IRIS Performer performs LOD calculations in a range squared space as much as possible for efficiency reasons, LOD computation becomes more costly when LOD states contain scales that are not equal to 1.0 or offsets not equal to 0.0 for transitions or switch ranges—these offsets force IRIS Performer to perform otherwise avoidable square roots calculations in order to correctly calculate the effects of scale and offset on the LOD.

Level-of-Detail Range Processing

The LOD switch ranges present in LOD nodes are processed before being used to make the level of detail selection. The goal of range setting is to switch LODs as objects reach certain levels of perceptibility. The size of a channel in pixels, the field of view used in viewing, and the distance from the observer to the display surface all affect object perceptibility.

IRIS Performer uses a channel size of 1024x1024 pixels and a 45-degree field of view as the basis for calculating LOD switching ranges. The screen space size of a channel and the current field of view are used to compute an LOD scale factor that is updated whenever the channel size or the field of view changes.

There is an additional global LOD scale factor that can be used to adjust switch ranges based on the relationship between the observer and the display surface. The default global scale factor is 1.

Note that LOD switch ranges are also effected by LOD states that have been attached to either a particular LOD or to a channel that contains the LOD. These LOD states provide the mechanism to apply both a scale and an offset for an LODs switch ranges and to the effect of system stress on those switch ranges. See “Level of Detail States” on page 136 for more information of pfLODStates.

Ultimately a LODs switch range without regard to system stress can be computed as follows:

```
switch_range[i] =
    (range[i] *
        LODStateRangeScale *
        ChannelLODStateRangeScale +
        LODStateRangeOffset +
        ChannelLODStateRangeOffset) *
    ChannelLODScale *
    ChannelSizeAndFOVFactor;
```

If IRIS Performer channel stress processing is active, the computed range is modified as follows:

```
switch_range[i] *=
    (ChannelLODStress *
     LODStateRangeStressScale *
     ChannelLODStateRangeStressScale +
     LODStateRangeStressOffset +
     ChannelLODStateRangeStressOffset);
```

Example 5-2 illustrates how to set LOD ranges.

Example 5-2 Setting LOD Ranges

```
/* setLODRanges() -- sets the ranges for the LOD node. The
 * ranges from 0 to NumLODs are equally spaced between min
 * and max. The last range, which determines how far you
 * can get from the object and still see it, is set to
 * visMax.
 */
void
setLODRanges(pfLOD *lod, float min, float max, float visMax)
{
    int i;
    float range, rangeInc;

    rangeInc = (max - min)/(ViewState->shellLOD + 1);
    for (range = min, i = 0; i < ViewState->shellLOD; i++)
    {
        ViewState->range[i] = range;
        pfLODRange(lod, i, range);
        range += rangeInc;
    }
    ViewState->range[i] = visMax;
    pfLODRange(lod, i, visMax);
}

/* generateShellLODs() -- creates shell LOD nodes according
 * to the parameters specified in the shared data structure.
 */
void
generateShellLODs(void)
{
    int i;
    pfGroup *grp;
```

```
pfVec4 clr;
long numLOD = ViewState->shellLOD;
long numPnts = ViewState->shellPnts;
long numPcs = ViewState->shellPcs;

for (i = 1; i <= numLOD; i++)
{
    if (ViewState->shellColor == SHELL_COLOR_SING)
        pfSetVec4(clr, 0.9f, 0.1f, 0.1f, 1.0f);
    else
        /* set the color.  highest level = RED;
         * middle LOD = GREEN; lowest LOD = BLUE
         */
        pfSetVec4(clr,
            (i <= (long)floor((double)(numLOD/2.0f)))?
                (-2.0f/numLOD) * i + 1.0f + 2.0f/numLOD:
                0.0f,
            (i <= (long)floor((double)(numLOD/2)))?
                (2.0f/numLOD) * (i - 1):
                (-2.0f/numLOD) * i + 2.0f,
            (i <= (long)floor((double)(numLOD/2)))?
                0.0f:
                (2.0f/numLOD) * i - 1.0f,
            1.0f);

    /* build a shell GeoSet */
    grp = createShell(numPcs, numPnts,
        ViewState->shellSweep, &clr,
        ViewState->shellDraw);
    normalizeNode((pfNode *)grp);

    /* add geode as another level of detail node */
    pfAddChild(ViewState->LOD, grp);

    /* simplify the geometry, but don't have less than
     * 4 points per circle or less than 3 pieces */
    numPnts = (numPnts > 7) ? numPnts-4 : 4;
    numPcs = (numPcs > 6) ? numPcs-4 : 3;
}
}

...
ViewState->LOD = pfNewLOD();

generateShellLODs();
```

```

/* get the LOD's extents */
pfGetNodeBSphere(ViewState->LOD, &(ViewState->bSphere));
pfLODCenter(ViewState->LOD, ViewState->bSphere.center);
/* set ranges for LODs; there should be (num LODs + 1)
 * range entries */
setLODRanges(ViewState->LOD, ViewState->minRange,
             ViewState->maxRange, ViewState->max);

```

Level-of-Detail Transition Blending

An undesirable effect called *popping* occurs when the sudden transition from one LOD to the next LOD is visually noticeable. This distracting image artifact can be ameliorated with a slight modification to the normal LOD-switching process.

In this modified method a transition per LOD switch is established rather than making a sudden substitution of models at the indicated switch range. These transitions specify distances over which to blend between the previous and next LOD. These zones are considered to be centered at the specified LOD switch distance, as shown by the horizontal shaded bars of Figure 7-3. Note that IRIS Performer limits the transition distances to be equal to the shortest distance between the switch range and the two neighboring switch ranges. For more information, see the `pfLODTransition()` reference page.

As the range from eyepoint to LOD center-point transitions the blend zone, each of the neighboring LOD levels is drawn by using transparency to composite samples taken from the present LOD model with samples taken from the next LOD model. For example, at the near, center, and far points of the transition blend zone between LOD 1 and LOD 2, samples from both LOD 1 and LOD 2 are composited until the end of the transition zone is reached, where all the samples are obtained from LOD 2.

Table 5-2 lists the transparency factors used for transitioning from one LOD range to another LOD range.

Table 5-2 LOD Transition Zones

Distance	LOD 1	LOD 2
Near edge of blend zone	100% opaque	0% opaque
Center of blend zone	50% opaque	50% opaque
Far edge of blend zone	0% opaque	100% opaque

LOD transitions are made smoother and much less noticeable by applying a blending technique rather than making a sudden transition. Blending allows LOD transitions to look good at ranges closer to the eye than LOD popping allows. Decreasing switch ranges in this way improves the ability of LOD processing to maximize the visual impact of each polygon in the scene without creating distracting visual artifacts.

The benefits of smooth LOD transition have an associated cost. The expense lies in the fact that when an object is within a blend zone, two versions of that object are drawn. This causes blended LOD transitions to increase the scene polygon complexity during the time of transition. For this reason, the blend zone is best kept to the shortest distance that avoids distracting LOD-popping artifacts. Currently, fade level of detail is supported only on RealityEngine graphics systems.

Note that the actual ‘blend’ or ‘fade’ distance used by IRIS Performer can also be adjusted by the LOD priority structures called pFLODStates. pFLODStates hold an offset and scale for the size of transition zones as well as an offset and scale for how system stress can affect the size of the transition zones. See “Level of Detail States” on page 136 for more information on pFLODStates.

Note also, that there exists a global LOD transition scale on a per channel basis that can affect all transition distances uniformly.

Thus for an LOD with 5 switch ranges R0, R1, R2, R3, R4 to switch between four models (M0, M1, M2, M3), there are 5 transition zones T0 (fade in M0), T1 (blend between M0 and M1), T2 (blend between M1 and M2), T3 (blend between M2 and M3), T4 (fade out M3). The actual fade distances (without regard to channel stress) are as follows.

```
fadeDistance[i] =  
    (transition[i] *  
        LODStateTransitionScale *  
        ChannelLODStateTransitionScale +  
        LODStateTransitionOffset +  
        ChannelLODStateTransitionOffset) *  
    ChannelLODFadeScale;
```

If IRIS Performer management of channel stress is turned on then the above fade distance is modified as follows:

```
fadeDistance[i] /=  
    (ChannelStress *  
     LODStateTransitionStressScale *  
     ChannelLODStateTransitionStressScale +  
     LODStateTransitionStressOffset +  
     ChannelLODStateTransitionStressOffset);
```

Terrain Level of Detail

In creating LOD models and transitions for objects, it's often safe to assume that the *entire* model should transition at the same time. It's quite reasonable to make features of an automobile such as door handles disappear from the scene at the same time even when the passenger door is slightly closer than the driver's door. It is much less clear that this approach would work for very large objects such as an aircraft carrier or a space station, and it's clearly not acceptable for objects that span a large extent, such as a terrain surface.

Attempts to handle large-extent objects with discrete LOD tools focus on breaking the big object into myriad small objects and treating each small object independently. This works in some cases but often fails at the junction between two or more independent objects where cracks or seams exist when different detail levels apply to the objects. Some terrain processing systems have attempted to provide a hierarchy of crack filling geometry that is enabled based on the LOD selections of two neighboring terrain patches. This "digital grout" becomes untenable when more than a few patches share a common vertex.

You can always make the transitions between LODs smooth by using active surface definition (ASD). ASD treats the entire terrain as a single connected surface rather than multiple patches that are loaded into memory as necessary. The surface is modeled with several hierarchical level-of-detail (LOD) meshes in data structures that allow for the rapid evaluation of smooth LOD transitions, load management on the evaluation itself, and efficient generation of a meshed terrain surface of the visible triangles for the current frame. For more information, refer to the Chapter 15, "Active Surface Definition."

Arbitrary Morphing

Terrain level of detail using an interpolative active surface definition is a restricted form of the more general notion of object morphing. Morphing of models such as the car in a previous example can simply involve scaling a small detail to a single point and then removing it from the scene. Morphing is possible even when the topologies of neighboring pairs do not match. Both models and terrain can have vertex, normal, color, and appearance information interpolated between two or more representations. The advantages of this approach include: reduced graphics complexity since blending is not used, constant intersection truth for collision and similar tasks, and monotonic database complexity that makes system load management much simpler. Such evaluation might make use of the compute process and `pfFlux` objects to hold the vertex data and to modify the scene graph control to chose the proper form of the object. `pfSwitch` nodes can take a `pfFlux` for holding its value; see the `pfSwitchValFlux()` reference page. `pfLOD` nodes can take a flux for controlling range with `pfLODRangeFlux()`. See the `pfLOD` and `pfEngine` reference pages for more information on morphing.

Dynamic Load Management

Because the effects of variable image update rates can be objectionable, many simulation applications are designed to operate at a fixed frame rate. One approach to selecting this fixed frame rate is to select an update rate constrained by the most complex portion of the visual database. Although this conservative approach may be acceptable in some cases, IRIS Performer supports a more sophisticated approach using dynamic LOD scaling.

Using multiple LOD models throughout a database provides the traversal system with a parameter that can be used to control the polygonal complexity of models in the scene. The complexity of database objects can be reduced or increased by adjusting a global LOD range multiplier that determines which LOD level is drawn.

Using this facility, a closed-loop control system can be constructed that adjusts the LOD-switching criteria based on the system load, also called *stress*, in order to maintain a selected frame rate.

Figure 5-5 illustrates a stress-processing control system.

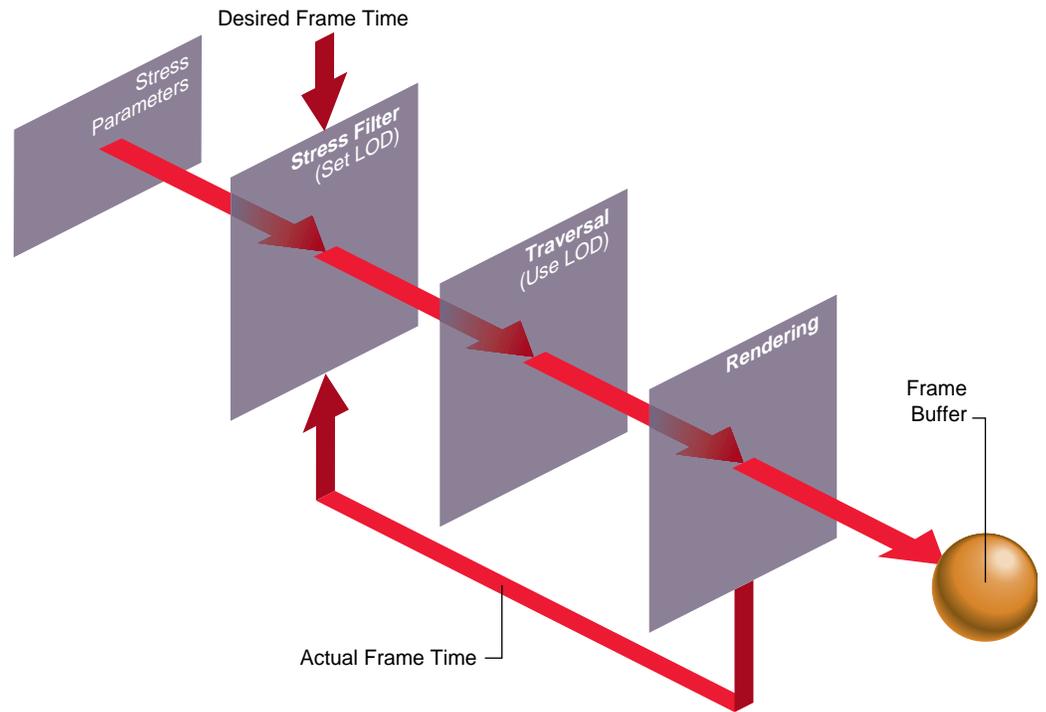


Figure 5-5 Stress Processing

In Figure 5-5, the desired and actual frame times are compared by the stress filter. Based on the user-supplied stress parameters, the stress filter adjusts the global LOD scale factor by increasing it when the system is overloaded and decreasing it when the system is underloaded. In this way, the system load is monitored and adjusted before each frame is generated.

The degree of stability for the closed-loop control system is an important issue. The ideal situation is to have a *critically damped* control system—that is, one in which just the right amount of control is supplied to maintain the frame rate without introducing undesirable effects. The effects of overdamped and underdamped systems are visually distracting. An underdamped system oscillates, causing the system to continuously alternate between two different LOD models without reaching equilibrium. Overdamped systems may fail to react within the time required to maintain the desired frame rate. In practice, though, dynamic load management works well, and simple stress functions can handle the slowly changing loads presented by many databases.

The default stress function is controlled with user-selectable parameters. These parameters are set using the function `pfChanStressFilter()`.

The default stress function is implemented by the code fragment in Example 5-3.

Example 5-3 Default Stress Function

```
/* current load */
curLoad = drawTime * frameRate * frameFrac;

/* integrated over time */
if (curLoad < lowLoad)
    stressLevel -= stressParam * stressLevel;
else
if (curLoad > highLoad)
    stressLevel += stressParam * stressLevel;

/* limited to desired range */
if (stressLevel < 1.0)
    stressLevel = 1.0;
else
if (stressLevel > maxStress)
    stressLevel = maxStress;
```

The parameters *lowLoad* and *highLoad* define a “comfort zone” for the control system. The first if-test in the code fragment demonstrates that this comfort zone acts as a dead band. Instantaneous system load within the bounds of the dead band doesn’t result in a change in the system stress level. If the size of the comfort zone is too small, oscillatory distress is the probable result. It is often necessary to keep the *highLoad* level below the 100% point so that blended LOD transitions don’t drive the system into overload situations.

For those applications in which the default stress function is either inappropriate or insufficient, you can compute the system stress yourself and then set the stress load factor. Your filter function can access the same system measures that the default stress function uses, but it’s also free to keep historical data and perform any feedback-transfer processing that application-specific dynamic load management may require.

The primary limitation of the default stress function is that it has a reactive rather than predictive nature. One of the major advantages of user-written stress filters is their ability to predict future stress levels before increased or decreased load situations reach the pipeline. Often the simulation application knows, for example, when a large number of moving models will soon enter the viewing frustum. If their presence is anticipated, then stress can be artificially increased so that no sudden LOD changes are required as they actually enter the field of view.

Successful Multiprocessing With IRIS Performer

Advanced

This section describes an advanced topic that applies only to systems with more than one CPU. If you don't have a multiple-CPU system, you may want to skip this section.

IRIS Performer uses multiprocessing to increase throughput for both rendering and intersection detection. Multiprocessing can also be used for tasks that run asynchronously from the main application like database management. Although IRIS Performer hides much of the complexity involved, you need to know something about how multiprocessing works in order to use multiple processors well.

Review of Rendering Stages

IRIS Performer application renders images using one or more pfPipes as independent software-rendering pipelines. The flow through the rendering pipeline can be modeled using these functional *stages*:

Intersection	Test for intersections between segments and geometry to simulate collision detection or line-of-sight for example.
Application	Do requisite processing for the visual simulation application, including reading input from control devices, simulating the vehicle dynamics of moving models, updating the visual database, and interacting with other networked simulation stations.
Cull	Traverse the visual database and determine which portions of it are potentially visible, perform level-of-detail selection for models with multiple representations, and build sorted, optimized display list for the draw stage.
Draw	Issue graphics library commands to a Geometry Pipeline in order to create an image for subsequent display.

You can partition these stages into separate parallel processes in order to distribute the work among multiple CPUs. Depending on your system type and configuration, you can use any of several available multiprocessing models.

Choosing a Multiprocessing Model

Use `pfMultiprocess()` to specify which functional stages, if any, should be forked into separate processes. The multiprocessing mode is actually a bitmask where each bit indicates that a particular stage should be configured as a separate process. For example, the bit `PFMP_FORK_DRAW` means the draw stage should be split into its own process. Table 5-3 lists some convenience tokens that represent common multiprocessing modes:

Table 5-3 Multiprocessing Models

Model Name	Description
<code>PFMP_APPCULLDRAW</code>	Combine the application, cull, and draw stages into a single process. In this model, all of the stages execute within a single frame period. This is the minimum- <i>latency</i> mode of operation.
<code>PFMP_APP_CULLDRAW</code> or <code>PFMP_FORK_CULL</code>	Combine the cull and draw stages in a process that is separate from the application process. This model provides a full frame period for the application process, while culling and drawing share this same interval. This mode is appropriate when the host's simulation tasks are extensive but graphic demands are light, as might be the case when complex vehicle dynamics are performed but only a simple dashboard gauge is drawn to indicate the results.
<code>PFMP_APPCULL_DRAW</code> or <code>PFMP_FORK_DRAW</code>	Combine the application and cull stages in a process that is separate from the draw process. This mode is appropriate for many simulation applications when application and culling demands are light. It allocates a full CPU for drawing and has the APP and CULL stages share a frame period. Like the <code>PFMP_APP_CULLDRAW</code> mode, this mode has a single frame period of pre-draw latency.
<code>PFMP_APP_CULL_DRAW</code> or <code>PFMP_FORK_CULL PFMP_FORK_DRAW</code>	Perform the application, cull, and draw stages as separate processes. This is the full maximum-throughput multiprocessing mode of IRIS Performer operation. In this mode, each pipeline stage is allotted a full frame period for its processing. Two frame periods of latency exist when using this high degree of parallelism.

You can also use **pfMultiprocess()** to specify the method of communication between the cull and draw stages, using the bitmasks **PFMP_CULLoDRAW** and **PFMP_CULL_DL_DRAW**.

Cull-Overlap-Draw Mode

Setting **PFMP_CULLoDRAW** specifies that the cull and draw processes for a given frame should overlap—that is, that they should run concurrently. For this to work, the cull and draw stages must be separate processes (**PFMP_FORK_DRAW** must be true). In this mode the two stages communicate in the classic producer-consumer model, by way of a **pfDispList** that is configured as a ring (FIFO) buffer; the cull process puts commands on the ring while the draw process simultaneously consumes these commands.

The main benefit of using **PFMP_CULLoDRAW** is reduced latency, since the number of pipeline stages is reduced by one and the resulting latency is reduced by an entire frame time. The main drawback is that the draw process must wait for the cull process to begin filling the ring buffer.

Forcing pfDisplayList Generation

When the cull and draw stages are in separate processes, they communicate through a **pfDispList**; the cull process generates the display list, and the draw process traverses and renders it. (The display list is configured as a ring buffer when using **PFMP_CULLoDRAW** mode, as described in the “Cull-Overlap-Draw Mode” section).

However, when the cull and draw stages are in the same process (as occurs with the **PFMP_APPCULLDRAW** or **PFMP_APP_CULLDRAW** multiprocessing models) a display list isn’t required and by default one will not be used. Leaving out the **pfDispList** eliminates overhead. When no display list is used, the cull trigger function **pfCull()** has no effect; the cull traversal takes place when the draw trigger function **pfDraw()** is invoked.

In some cases you may want an intermediate **pfDispList** between the cull and draw stages even though those stages are in the same process. The most common situation that calls for such a setup is multipass rendering, when you want to cull only once but render multiple times. With **PFMP_CULL_DL_DRAW** enabled, **pfCull()** generates a **pfDispList** that can be rendered multiple times by multiple calls to **pfDraw()**.

Intersection Pipeline

The *intersection pipeline* is a two-stage pipeline consisting of the application and the intersection stages. The intersection stage may be configured as a separate process by setting the PFMP_FORK_ISECT bit in the bitmask given to **pfMultiprocess()**. When configured as such, the intersection process is triggered for the current frame when the application process calls **pfFrame()**. Then in the special intersection callback set with **pfIsectFunc()**, you can invoke any number of intersection requests with **pfNodeIsectSegs()**. To support this operation, the intersection process keeps a copy of the scene graph pfNodes.

The intersection process is asynchronous so that if it does not finish within a frame time it does not slow down the rendering pipeline(s).

The Compute Process

The compute process is an asynchronous process provided for doing extensive asynchronous computation. The compute stage is done as part of **pfFrame()** in the application process unless it is configured to run as separate process by setting the PFMP_FORK_COMPUTE bit in the **pfMultiprocess()** bitmask. The compute process is asynchronous so that if it does not finish within a frame time, it will not slow down the rendering pipeline. The compute process is intended to work with pfFlux objects, placing the results of asynchronous computation in pfFluxes. pfFlux will automatically manage the needed multibuffering and frame consistency requirements for the data. See Chapter 14, “Dynamic Data,” for more information on pfFlux. Some IRIS Performer objects, such as pfASD, do their computation in the compute stage so **pfCompute()** must be called from any compute user callback if one has been specified with **pfComputeFunc()**.

Multiple Rendering Pipelines

By default, IRIS Performer uses a single pfPipe, which in turn draws one or more pfChannels into one or more pfPipeWindows. If you want to use multiple rendering pipelines, as on two- or three-Geometry Pipeline Onyx RealityEngine² systems, use **pfMultiPipe()** to specify the number of pfPipes required. When using multiple pipelines, the PFMP_APPCULLDRAW and PFMP_APPCULL_DRAW modes are not supported and IRIS Performer defaults to the PFMP_APP_CULL_DRAW multiprocessing configuration. Regardless of the number of pfPipes, there is always a single application process which triggers the rendering of all pipes with **pfFrame()**.

Multithreading

For additional multiprocessing and attendant increased throughput, the CULL stage of the rendering pipeline may be *multithreaded*. Multithreading means that a single pipeline stage is split into multiple processes, or threads which concurrently work on the same frame. Use **pfMultithread()** to allocate a number of threads for the cull stage of a particular rendering pipeline.

Cull multithreading takes place on a per-pfChannel basis, that is, each thread does all the culling work for a given pfChannel. Thus, an application with only a single channel will not benefit from multithreading the cull and an application with multiple, equally complex channels will benefit most by allocating a number of cull threads equal to the number of channels. However, it is legal to allocate fewer cull threads if you do not have enough CPUs—in this case the threads are assigned to channels on a need basis.

Order of Calls

The multiprocessing model set by **pfMultiprocess()** is used for each of the rendering pipelines. In programs that configure the application stage as a separate process, all IRIS Performer calls must be made from the process that calls **pfConfig()** or the results are undefined. Both **pfMultiprocess()**, **pfMultithread()**, and **pfMultipipe()** must be called after **pfInit()** but before **pfConfig()**. **pfConfig()** configures IRIS Performer according to the required number of pipelines and the desired multiprocessing and multithreading modes, forks the appropriate number of processes, and then returns control to the application. **pfConfig()** should be called only once during each IRIS Performer application.

Comparative Structure of Models

Figure 5-6 shows timing diagrams for each of the process models. The vertical lines are frame boundaries. Five frames of the simulation are shown to allow the system to reach steady-state operation. Only one of these models can be selected at a time, but they are shown together so that you can compare their structures.

Boxes represent the functional stages and are labeled as follows:

A_n	application process for the n th frame
C_n	cull process for the n th frame
D_n	draw process for the n th frame

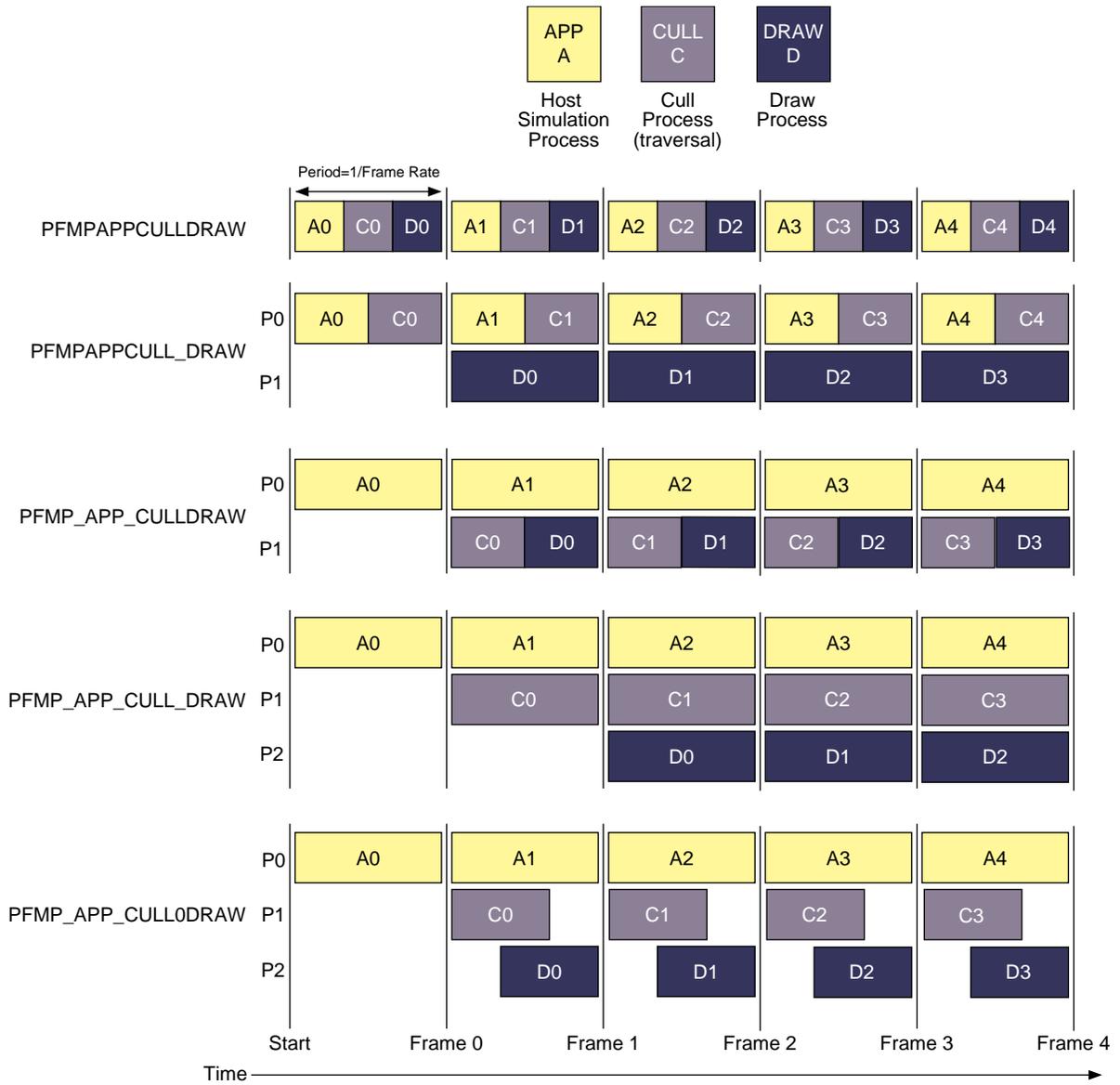


Figure 5-6 Multiprocessing Models

Notice that when a stage is split into its own process, the amount of time available for all stages increases. For example, in the case where the application, cull, and draw stages are 3 separate processes, it is possible for total system performance to be tripled over the single process configuration.

Asynchronous Database Processing

Many databases are too large to fit into main memory. A common solution to this problem is called *database paging* where the database is divided into manageable chunks on disk and loaded into main memory when needed. Usually chunks are paged in just before they come into view and are deleted from the scene when they are comfortably out of viewing range.

All this paging from disk and deleting from main memory takes a lot of time and is certainly not amenable to maintaining a fixed frame rate. The solution supported by IRIS Performer is *asynchronous database paging* in which a process, completely separate from the main processing pipeline(s), handles all disk I/O and memory allocations and deletions. To facilitate asynchronous database paging, IRIS Performer provides the `pfBuffer` structure and the `DBASE` process.

DBASE Process

The database (or `DBASE`) process is forked by `pfConfig()` if the `PFMP_FORK_DBASE` bit was set in the mode given to `pfMultiprocess()`. The database process is triggered when the application process calls `pfFrame()` and invokes the user-defined callback set with `pfDBaseFunc()`. The database process is totally asynchronous. If it exceeds a frame time it does not slow down any rendering or intersection pipelines.

The `DBASE` process is intended for asynchronous database management when used with `pfBuffer`.

pfBuffer

A `pfBuffer` is a logical buffer which isolates database changes to a single process, avoiding disastrous collisions on data from multiple processes. In typical use, a `pfBuffer` is created with `pfNewBuffer()`, made current with `pfSelectBuffer()` and merged with the main IRIS Performer buffer with `pfMergeBuffer()`. While the `DBASE` process is intended for `pfBuffer` use, other processes forked by the application may also use different `pfBuffers` in parallel for multithreaded database management. By ensuring that only a

single process uses a given `pfBuffer` at a given time and following a few scoping rules discussed below, the application can safely and efficiently implement asynchronous database paging

A `pfNode` is said to have *buffer scope* or be “in” a particular `pfBuffer`. This is an important concept because it affects what you can do with a given node. A newly-created node is automatically “in” the currently active `pfBuffer` until that `pfBuffer` is merged using `pfMergeBuffer()`. At that instant, the `pfNode` is moved into the main IRIS Performer buffer, otherwise known as the *application buffer*.

A rule in `pfBuffer` management is that a process may only access nodes that are in its current `pfBuffer`. As a result, a database process may not directly add a newly created subgraph of nodes to the main scene graph because all nodes in the main scene graph have application buffer scope only—they are isolated from the database `pfBuffer`. This may seem inconvenient at first but it eliminates catastrophic errors like, for example, the application process traverses a group at the same time you add a child, changing its child list and causing the traversal to chase a bad pointer.

Remedies to the inconveniences stated above are the `pfBufferAddChild()`, `pfBufferRemoveChild()` and `pfBufferClone()` routines. The first two routines are identical to their non-buffer counterparts `pfAddChild()` and `pfRemoveChild()` except the buffer versions do not happen immediately. Other functions, `pfBufferAdd()`, `pfBufferInsert()`, `pfBufferReplace()`, and `pfBufferRemove()`, perform the buffer-oriented delayed-action versions of the corresponding non-buffer `pfList` functions. In all cases the add, insert, replace, or removal request is placed on a list in the current `pfBuffer` and is processed later at `pfMergeBuffer()` time.

`pfBufferClone()` supports the notion of maintaining a “library” of common objects like trees or houses in a special library `pfBuffer`. The main database process then clones objects from the library `pfBuffer` into the database `pfBuffer`, possibly `pfFlatten()`ing them for improved rendering performance. `pfBufferClone()` is identical to `pfClone()` except the buffer version requires that the source `pfBuffer` be specified and that all cloned nodes have scope in the source `pfBuffer`.

`pfAsyncDelete`

We’ve discussed how to create subgraphs for database paging: create and select a current `pfBuffer`, create nodes and build the subgraph, call `pfBufferAddChild()` and finally `pfMergeBuffer()` to incorporate the subgraph into the application’s scene. But what about freeing the memory of old, unwanted subgraphs? For this we turn to `pfAsyncDelete()`.

pfDelete() is the normal mechanism for deleting objects and freeing their associated memory. However, **pfDelete()** can be a very costly routine since it must traverse, unreference, and register a deletion request for every IRIS Performer object it encounters which has a 0 reference count. **pfAsyncDelete()**, in conjunction with a forked DBASE process, moves the burden of deletion to the asynchronous database process so that all rendering and intersection pipelines are not adversely affected.

pfAsyncDelete() may be called from any process and places an asynchronous deletion request on a global list that is processed later by the DBASE stage when its trigger routine, **pfDBase()** is called. A major difference from **pfDelete()** is that **pfAsyncDelete()** does not immediately check the reference count of the object to be deleted and so does not return a value indicating whether the deletion was successful or not. At this time there is no way of querying the result of a **pfAsyncDelete()** request so care should be taken that the object to be deleted has no reference counts or memory leaks will result.

Rules for Invoking Functions While Multiprocessing

There are some restrictions on which functions can be called from an IRIS Performer process while multiple processes are running. Some specialized processes (such as the process handling the draw stage) can call only a few specific IRIS Performer functions, and can't call any other kinds of functions. This section lists general and specific rules concerning function invocation in the various IRIS Performer and user processes.

In this section, the term “the draw process” refers to whichever process is handling the draw stage, regardless of whether that process is also handling other stages. Similarly, “the cull process” and “the application process” refer to the processes handling the cull and application stages, respectively.

This is a general list of the kinds of routines you can call from each process:

application	configuration routines, creation and deletion routines, set and get routines, and trigger routines such as pfAppFrame() , pfSync() , pfFrame()
database	creation and deletion routines, set and get routines, pfDBase() , pfMergeBuffer()
cull	pfCull() , pfCullPath() , IRIS Performer graphics routines
draw	pfClearChan() , pfDraw() , pfDrawChanStats() , IRIS Performer graphics routines, graphics library routines

More specific elaborations:

- You should call configuration routines only from the application process, and only after **pfInit()** and before **pfConfig()**. **pfInit()** must be the first IRIS Performer call except for those routines that configure shared memory (see “Memory Allocation” in Chapter 13). Configuration routines don’t take effect until **pfConfig()** is called. These are the configuration routines:
 - **pfMultiPipe()**
 - **pfMultiProcess()**
 - **pfMultiThread()**
 - **pfHyperPipe()**
- You should call creation routines, such as **pfNewChan()**, **pfNewScene()**, and **pfAllocIsectData()**, only in the application process after calling **pfConfig()** or in a process which has an active **pfBuffer**. There is no restriction on creating *libpr* objects like **pfGeoSets** and **pfTextures**.
- **pfDelete()** should only be called from the application or database processes. **pfAsyncDelete()** may be called from any process.
- Read-only routines—that is, the **pfGet*()** functions—can be called from any IRIS Performer process. However, if a forked draw process queries a **pfNode**, the data returned will not be frame-accurate. (See “Multiprocessing and Memory” on page 158.)
- Write routines—functions that set parameters—should be called only from the application process or a process with an active **pfBuffer**. It is possible to call a write routine from the cull process, but it isn’t recommended since any modifications to the database will not be visible to the application process if it is separate from the cull (as when using **PFMP_APP_CULLDRAW** or **PFMP_APP_CULL_DRAW**). However, for transient modifications like custom level-of-detail switching, it is reasonable for the cull process to modify the database. The draw process should never modify any **pfNode**.

- IRIS Performer graphics routines should be called only from the cull or draw processes. These routines may modify hardware graphics state. They are the routines which can be captured by an open pfDispList. (See “Display Lists” in Chapter 9.) If invoked in the cull process, these routines are captured by an internal pfDispList and later invoked in the draw process; but if they are invoked in the draw process they immediately affect the current window. These graphics routines can be roughly partitioned into those that
 - apply a graphics entity: **pfApplyMtl()**, **pfApplyTex()**, and **pfLightOn()**
 - enable or disable a graphics mode: **pfEnable()**, **pfDisable()**
 - set or modify graphics state: **pfTransparency()**, **pfPushState()**, **pfMultMatrix()**
 - draw geometry or modify the screen: **pfDrawGSet()**, **pfDrawString()**, **pfClear()**
- Graphics library routines should be called only from the draw process. Since there is no open display list to capture these commands, an open window is required to accept them.
- “Trigger” routines should be called only from the appropriate processes (see Table 5-4).

Table 5-4 Trigger Routines and Associated Processes

Trigger Routine	Process/Context
pfAppFrame pfSync pfFrame	APP/main loop
pfPassChanData pfPassIsectData	APP/main loop
pfApp	APP/channel APP callback
pfCull pfCullPath	CULL/channel CULL callback
pfDraw pfDrawBin	DRAW/channel DRAW callback
pfNodeIsectSegs pfChanNodeIsectSegs	ISECT/callback or APP/main loop
pfDBase	DBASE/callback

- User-spawned processes created with `sproc()` can trigger parallel intersection traversals through multiple calls to `pfNodeIsectSegs()` and `pfChanNodeIsectSegs()`.
- Functions `pfApp()`, `pfCull()`, `pfDraw()`, and `pfDBase()` are only called from within the corresponding callback specified by `pfChanTravFunc()` or `pfDBaseFunc()`.

Multiprocessing and Memory

In IRIS Performer, as is often true of multiprocessing systems, memory management is the most difficult aspect of multiprocessing. Most data management problems in an IRIS Performer application can be partitioned into three categories:

- Memory visibility. IRIS Performer uses `fork()`, which—unlike `sproc()`—generates processes that don't share the same address space. The processes also cannot share global variables that are modified after the `fork()` call. After calling `fork()`, processes must communicate through explicit shared memory.
- Memory exclusion. If multiple processes read or write the same chunk of data at the same time, consequences can be dire. For example, one process might read the data while in an inconsistent state and end up dumping core while dereferencing a NULL pointer.
- Memory synchronization. IRIS Performer is configured as a pipeline where different processes are working on different frames at the same time. This pipelined nature is illustrated in Figure 5-6, which shows that, for instance, in the `PFMP_APP_CULL_DRAW` configuration the application process is working on frame n while the draw process is working on frame $n-2$. If, in this case, if we have only a single memory location representing the viewpoint, then it is possible for the application to set the viewpoint to that of frame n and the draw process to incorrectly use that same viewpoint for frame $n-2$. Properly synchronized data is called *frame accurate*.

Fortunately, IRIS Performer transparently solves all of the above problems for most IRIS Performer data structures and also provides powerful tools and mechanisms that the application can use to manage its own memory.

Shared Memory and `pfInit()`

`pfInit()` creates a shared memory arena that is shared by all processes spawned by IRIS Performer and all user processes that are spawned from any IRIS Performer process. A handle to this arena is returned by `pfGetSharedArena()` and should be used as the arena argument to routines that create data that must be visible to all processes. Routines that accept an arena argument are the `pfNew*()` routines found in the *libpr* library and the IRIS Performer memory allocator, `pfMalloc()`. In practice, it is usually safest to create *libpr* objects like `pfGeoSets` and `pfMaterials` in shared memory. *libpf* objects like `pfNodes` are always created in shared memory.

Allocating shared memory does not by itself solve the memory visibility problem discussed above. You must also make sure that the pointer that references the memory is visible to all processes. IRIS Performer objects, once incorporated into the database via routines like `pfAddGSet()`, `pfAddChild()`, and `pfChanScene()`, automatically ensure that the object pointers are visible to all IRIS Performer processes.

However, pointers to application data must be explicitly shared. A common way of doing this is to allocate the shared memory after `pfInit()` but before `pfConfig()` and to reference the memory with a global pointer. Since the pointer is set before `pfConfig()` forks any processes, these processes will all share the pointer's value and can thereby access the same shared memory region. However, if this pointer value changes in a process, its value will not change in any other process, since forked processes don't share the same address space.

Even with data visible to all processes, data exclusion is still a problem. The usual solution is to use hardware spin locks so that a process can lock the data segment while reading or writing data. If all processes must acquire the lock before accessing the data, then a process is guaranteed that no other processes will be accessing the data at the same time. All processes must adhere to this locking protocol, however, or exclusion isn't guaranteed.

In addition to a shared memory arena, `pfInit()` creates a semaphore arena whose handle is returned by `pfGetSemaArena()`. Locks can be allocated from this semaphore arena by `usnewlock()` and can be set and unset by `ussetlock()` and `usunsetlock()`, respectively.

pfDataPools

pfDataPools—named shared memory arenas with named allocation blocks—provide a complete solution to the memory visibility and memory exclusion problems, thereby obviating the need to set global pointers between **pfInit()** and **pfConfig()**. For more information about pfDataPools, see the pfDataPools reference page.

Passthrough Data

The techniques discussed thus far don't solve the memory synchronization problem. IRIS Performer's *libpf* library provides a solution in the form of *passthrough data*. When using pipelined multiprocessing, data must be passed through the processing pipeline so that data modifications reach the appropriate pipeline stage at the appropriate time.

Passthrough data is implemented by allocating a data buffer for each stage in the processing pipeline. Then, at well-defined points in time, the passthrough data is copied from its buffer into the next buffer along the pipeline. This copying guarantees memory exclusion, but you should minimize the amount of passthrough data to reduce the time spent copying.

Allocate a passthrough data buffer for the rendering pipeline using **pfAllocChanData()**; for data to be passed down the intersection pipeline, call **pfAllocIsectData()**. Data returned from **pfAllocChanData()** is passed to the channel cull and draw callbacks that are set by **pfChanTravFunc()**. Data returned from **pfAllocIsectData()** is passed to the intersection callback specified by **pfIsectFunc()**.

Passthrough data isn't automatically passed through the processing pipeline. You must first call **pfPassChanData()** or **pfPassIsectData()** to indicate that the data should be copied downstream. This requirement allows you to copy only when necessary—if your data hasn't changed in a given frame, simply don't call a **pfPass*()** routine, and you'll avoid the copy overhead. When you do call a **pfPass*()** routine, the data isn't immediately copied but is delayed until the next call to **pfFrame()**. The data is then copied into internal IRIS Performer memory and you're free to modify your passthrough data segment for the next frame.

Modifications to all *libpf* objects—such as `pfNodes` and `pfChannels`—are automatically passed through the processing pipeline, so frame-accurate behavior is guaranteed for these objects. However, in order to save substantial amounts of memory, *libpr* objects such as `pfGeoSets` and `pfGeoStates` don't have frame-accurate behavior; modifications to such objects are immediately visible to all processes. If you want frame-accurate modifications to *libpr* objects you must use the passthrough data mechanism, use a frame-accurate `pfSwitch` to select among multiple copies of the objects you want to change or use the `pfCycleBuffer` memory type.

“Creating Visual Effects”

This chapter describes how to use environmental, atmospheric, lighting, and other visual effects to enhance the realism of your application.

Creating Visual Effects

This chapter describes how to use environmental, atmospheric, lighting, and other visual effects to enhance the realism of your application.

Using pfEarthSky

A pfEarthSky is a special set of functions that clears a pfChannel's viewport efficiently and implements various atmospheric effects. A pfEarthSky is attached to a pfChannel with **pfChanESky()**. Several pfEarthSky definitions can be created, but only one can be in effect for any given channel at a time.

A pfEarthSky can be used to draw a sky and horizon, to draw sky, horizon, and ground, or just to clear the entire screen to a specific color and depth. The colors of the sky, horizon, and ground can be changed in real time to simulate a specific time of day. At the horizon boundary, the ground and sky share a common color, so that there is a smooth transition from sky to horizon color. The width of the horizon band can be defined in degrees.

A pfChannel's earth-sky model is automatically drawn by IRIS Performer before the scene is drawn unless the pfChannel has a draw callback set with **pfChanTravFunc()**. In this case it is the application's responsibility to clear the viewport. Within the callback **pfClearChan()** draws the channel's pfEarthSky.

Example 6-1 shows how to set up an `pfEarthSky()`.

Example 6-1 How to Configure a `pfEarthSky`

```
pfEarthSky *esky;  
pfChannel *chan;  
  
sky = pfNewESky();  
pfESkyMode(esky, PFES_BUFFER_CLEAR, PFES_SKY_GRND);  
pfESkyAttr(esky, PFES_GRND_HT, -1.0f);  
pfESkyColor(esky, PFES_GRND_FAR, 0.3f, 0.1f, 0.0f, 1.0f);  
pfESkyColor(esky, PFES_GRND_NEAR, 0.5f, 0.3f, 0.1f, 1.0f);  
pfChanESky(chan, esky);
```

Atmospheric Effects

The complexities of atmospheric effects on visibility are approximated within IRIS Performer using a multiple-layer sky model, set up as part of the `pfEarthSky` function. In this design, individual layers are used to represent the effects of ground fog, clear sky, and clouds. Figure 6-1 shows the identity and arrangement of these layers.

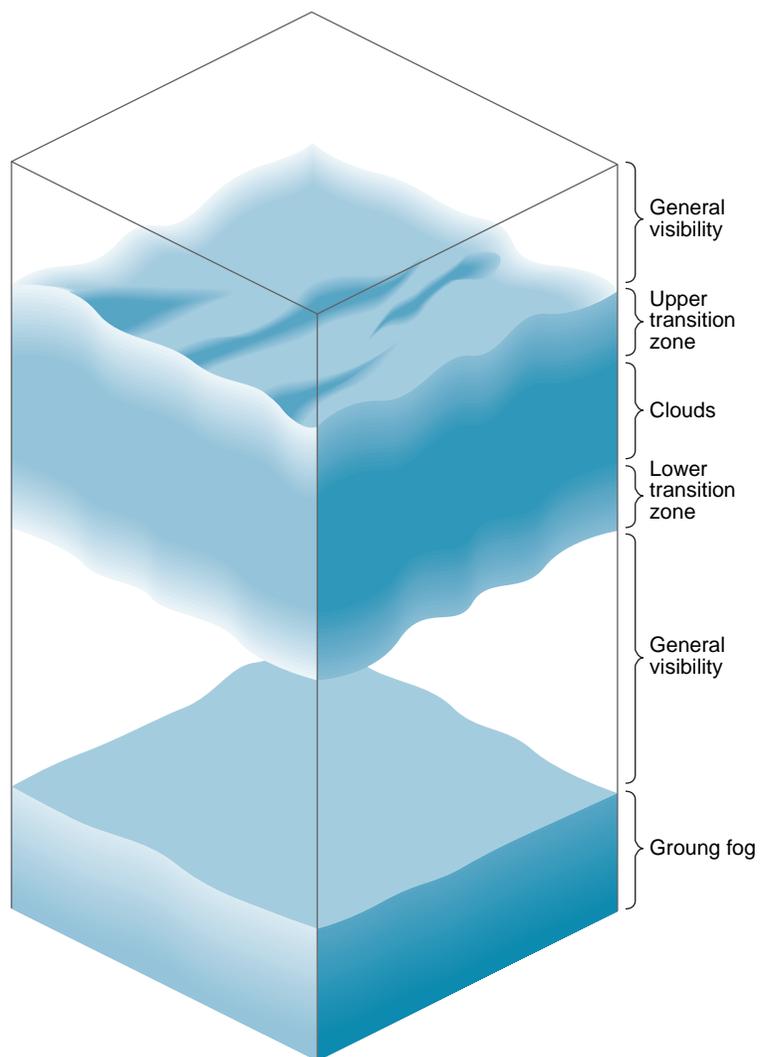


Figure 6-1 Layered Atmosphere Model

The lowest layer consists of ground fog, extending from the ground up to a user-selected altitude. The fog thins out with increasing altitude, disappearing entirely at the bottom of the general visibility layer. This layer extends from the top of the ground fog layer to the bottom of the cloud layer's lower transition zone, if such a zone exists. The transition zone provides a smooth transition between general visibility and the cloud layer. (If there is no cloud layer, then general visibility extends upward forever.) The cloud layer is defined as an opaque region of near-zero visibility; you can set its upper and lower boundaries. You can also place another transition zone above the cloud layer to make the clouds gradually thin out into clear air.

Set up the atmospheric simulation with the commands listed in Table 6-1

Table 6-1 pfEarthSky Routines

Function	Action
pfNewESky	Create a pfEarthSky
pfESkyMode	Set the render mode
pfESkyAttr	Set the attributes of the earth and sky models
pfESkyColor	Set the colors for earth and sky and clear
pfESkyFog	Set the fog functions

You can set any pfEarthSky attribute, mode, or color in real time. Selecting the active pfFog definition can also be done in real time. However, changing the parameters of a pfFog once they are set isn't advised when in multiprocessing mode.

The default characteristics of a pfEarthSky are listed in Table 6-2.

Table 6-2 pfEarthSky Attributes

Attribute	Default
Clear method	PFES_FAST (full screen clear)
Clear color	0.0 0.0 0.0
Sky top color	0.0 0.0 0.44
Sky bottom color	0.0 0.4 0.7
Ground near color	0.5 0.3 0.0

Table 6-2 (continued) pfEarthSky Attributes

Attribute	Default
Ground far color	0.4 0.2 0.0
Horizon color	0.8 0.8 1.0
Ground fog	NULL (no fog)
General visibility	NULL (no fog)
Cloud top	20000.0
Cloud bottom	20000.0
Cloud bottom color	0.8 0.8 0.8
Cloud top color	0.8 0.8 0.8
Transition zone bottom	15000.0
Transition zone top	25000.0
Ground height	0
Horizon angle	10 degrees

By default, an earth-sky model isn't drawn. Instead, the channel is simply cleared to black and the Z-buffer is set to its maximum value. This default action also disables all other atmospheric attributes. To enable atmospheric effects, select PFES_SKY, PFES_SKY_GRND, or PFES_SKY_CLEAR when turning on the earth-sky model.

Clouds are disabled when the cloud top is less than or equal to the cloud bottom. Cloud transition zones are disabled when clouds are disabled.

Fog is enabled when either the general or ground fog is set to a valid pfFog. If ground fog isn't enabled, no ground fog layer will be present and fog will be used to support general visibility. Setting a fog attribute to NULL disables it. See "Atmospheric Effects" on page 166 for further information on fog parameters and operation.

The earth-sky model is an attribute of the channel and thus accesses information about the viewer's position, current field of view, and other pertinent information directly from pfChannel. To set the pfEarthSky in a channel, use **pfChanESky()**.

“Importing Databases”

This chapter describes a variety of database formats and their corresponding conversion utilities.

Importing Databases

Once you've learned how to create visual simulation applications with IRIS Performer your next task is to import visual databases into those applications. IRIS Performer provides import and export functions for more than 30 popular database formats to ease this effort.

This chapter describes:

- The steps involved in creating custom loaders for other data formats.
- Each pre-existing file-loading utilities.
- Several utility functions in the IRIS Performer database utility library that can make the process of database conversion easier for you.

Overview of IRIS Performer Database Creation and Conversion

Source code is provided for most of the tools discussed in this chapter. In most cases the loaders are short, easy to understand, and easy to modify.

Table 7-1 lists the subdirectories of */usr/share/Performer/src/lib* where you can find the source code for the database processing tools.

Table 7-1 Database-Importer Source Directories

Directory Name	Directory Contents
<i>libpfd</i>	General database processing tools and utilities
<i>libpfd</i>	Load, convert, and store specific database formats
<i>libpfutil</i>	Additional utility functions

Before you can import a database, you must create it. Some simulation applications create data procedurally; for examples of this approach, see the “Silicon Graphics PHD Format” on page 219 or the “Sierpinski Sponge Format” sections of this chapter.

In most cases, however, you must create visual databases manually. Several software packages are available to help with this task, and most such systems facilitate geometric modeling, texture creation, and interactive specification of colors and material properties. Some advanced systems support level-of-detail specification, animation sequences, motion planning for jointed objects, automated roadway and terrain generation, and other specialized functions.

***libpfd* - Utilities for Creation of Efficient IRIS Performer Run-Time Structures**

There are several layers of support in IRIS Performer for loading 3-D models and 3-D environments into IRIS Performer run-time scene graphs. IRIS Performer contains the *libpfd* library devoted to the import of data into (and export of data from) IRIS Performer run-time structures. Note that two database exporters have already been written for the Medit and DWB database formats.

At the top level of the API, IRIS Performer provides a standard set of functions to read in files and convert databases of unknown type. This functionality is centered around the notion of a database converter. A database converter is an abstract entity that knows how to perform some or all of a set of database format conversion functions with a particular database format. Moreover, converters must follow certain API guidelines for standard functionality such that they can be easily integrated into IRIS Performer in a run-time environment without IRIS Performer needing any prior knowledge of a particular converter’s existence. This run-time integration is done through the use of dynamic shared object (DSO) libraries.

pfdLoadFile - Loading Arbitrary Databases into IRIS Performer

Table 7-2 describes the general routines for 3-D databases provided by *libpfd*.

Table 7-2 *libpfd* Database Converter Functions

Function Name	Description
pfdInitConverter	Initialize the library and its classes for the desired format
pfdLoadFile	Load a database file into an IRIS Performer scene graph
pfdStoreFile	Store a run-time scene graph into a database file
pfdConvertFrom	Convert an external run-time format into an IRIS Performer scene graph
pfdConvertTo	Convert an IRIS Performer scene graph into an external run-time format

The database loader utility library, *libpfd*, provides a convenient function, named **pfdLoadFile()**, that imports database files stored in any of the supported format listed in Table 7-6.

Loading database files with **pfdLoadFile()** is easy. The function prototype is

```
pfNode *pfdLoadFile(char *fileName);
```

pfdLoadFile() tests the filename-extension portion of *fileName* (the substring starting at the last period in *fileName*, if any) for one of the format-name codes listed in Table 7-6, then calls the appropriate importer.

The file-format selection process is implemented using dynamic loading of DSOs, which are IRIX Dynamic Shared Objects. This process allows new loaders that are developed as database formats change to be used with IRIS Performer-based applications without requiring recompilation of the IRIS Performer application. If at all possible, **pfdInitConverter()** should be called before **pfConfig()** for the potential formats that may be loaded. This will pre-load the DSO and allow it to initialize any of its own data structures and classes. This is required if the loader DSO extends IRIS Performer classes or uses any node traversal callbacks so that if multiprocessing these data elements will all have been pre-created and be valid in all potential processes. **pfdInitConverter()** automatically calls **pfdLoadNeededDSOs_EXT()** to pre-load additional DSOs needed by the loader if the given loader has defined that routine. These routines take a file name so that the loader has the option to search through the file for possible DSO references in the file.

Loading Process Internals

The details of the loading process internal to **pfdLoadFile()** include:

1. Searching for the named file using the current IRIS Performer file path.
2. Extraction of the file-type extension.
3. Translation of the extension using a registered alias facility, formation of the DSO name.
4. Formation of a loader function name.
5. Finding that function within the DSO using **dlsym()**.
6. Searching first the current executable and loaded DSOs for the proper load function and then searching through a list of user-defined and standard directories for that DSO. Dynamic loading of the indicated DSO using **dlopen()**.
7. Invocation of the loader function.

Loader Name

The loader function name is constructed from two components:

- A prefix always consisting of “pfdLoadFile_”.
- Loader suffix, which is the file extension string.

Examples of several complete loader function names are shown in Table 7-3.

Table 7-3 Loader Name Composition

File Extension	Loader Function Name
dwb	pfdLoadFile_dwb
ft	pfdLoadFile_ft
medit	pfdLoadFile_medit
obj	pfdLoadFile_obj
pfb	pfdLoadFile_pfb

Shell Environment Variables

Several shell environment variables are used in the loader location process. These are PFLD_LIBRARY{N32,64}_PATH, LD_LIBRARY{N32,64}_PATH, and PFHOME. Confusion about loader locations can be resolved by consulting the sources mentioned above to understand the use of these directory lists and reading the following section, “Database Loading Details” on page 177. When the pfNotifyLevel is set to the value for PFNFY_DEBUG (5) or greater, the DSO and loader function names are printed as database are loaded, as is the name of each directory that is searched for the DSO.

The IRIS Performer sample programs, including *perfly*, use **pfLoadFile()** for database importing. This allows them to simultaneously load and display databases in many disparate formats. As you develop your own database loaders, follow the source code examples in any of the *libpfd* loaders. Then you will be able to load your data into any IRIS Performer application. You will not need to rebuild *perfly* or other applications to view your databases.

Database Loading Details

Details about the database loading process are described further in this section, the pfLoadFile reference page, and the source code which is in */usr/share/Performer/src/lib/libpfd/pfdLoadFile.c*.

The routines **pfInitConverter()**, **pfLoadFile()**, **pfStoreFile()**, **pfConvertFrom()**, and **pfConvertTo()** exist only as a level of indirection to allow a user to manipulate all databases regardless of format through a central API. They are in fact merely a mechanism for creating an open environment for data sharing among the multitudes of three-dimensional database formats. Each of these routines determines, using file-type extensions, which database converter to load as a run-time DSO. The routine then calls the appropriate functionality from that converter’s DSO. All converters must provide API that is exactly the same as the corresponding *libpfd* API with *_EXT* added to the routine names (for example, for “.medit” files, the suffix is “_medit”). Note that multiple physical extensions can be mapped to one converter extension via calls to **pfAddExtAlias()**. Several aliases are pre-defined upon initialization of *libpfd*.

It is also important to note that because each of these converters are unique entities that they each may have state that is important to their proper function. Moreover, their database format may allow for multiple IRIS Performer interpretations and so there exists API, shown in Table 7-4, not only to initialize and exit database converters, but also to set and get modes, attributes, and values that might affect the converter's methodology.

Table 7-4 *libpfd* Database Converter Management Functions

Function Name	Description
<code>pfdInitConverter</code>	Initialize a database conversion DSO
<code>pfdExitConverter</code>	Exit a database conversion DSO
<code>pfdConverterMode</code>	Specify a mode for a specific conversion DSO
<code>pfdGetConverterMode</code>	Get a mode setting from a specific conversion DSO
<code>pfdConverterAttr</code>	Specify an attribute for a conversion DSO
<code>pfdGetConverterAttr</code>	Get an attribute setting from a conversion DSO
<code>pfdConverterVal</code>	Specify a value for a conversion DSO
<code>pfdGetConverterVal</code>	Get a value setting from a conversion DSO

Once again each converter provides the equivalent routines with *_EXT* added to the function name.

For example, the converter for the Open Inventor format would define the function `pfdInitConverter_iv()` if it needed to be initialized before it was used. Likewise, it would define the function `pfdLoadFile_iv()` to read an Open Inventor ".iv" file into an IRIS Performer scene graph.

Note: Because each converter is an individual entity (DSO) and deals with a particular type of database, it may be the case that a converter will *not* provide all of the functionality listed above, but rather only a subset. For instance, most converters that come with IRIS Performer only implement their version of `pfdLoadFile` but not `pfdStoreFile`, `pfdConvertFrom`, or `pfdConvertTo`. However, users are free to add this functionality to the converters via compliant API and IRIS Performer's *libpfd* will immediately recognize this functionality. Also, *libpfd* traps access to non-existent converter functionality and returns gracefully to the calling code while notifying the user that the functionality could not be found.

Finding and initializing a Converter

When one of the general database converter functions is called, it in turn calls the corresponding routine provided by the converter, passing on the arguments it was given.

But the first time a converter is called, a search occurs to identify the converter and the functions it provides. This is accomplished as follows.

- Parse the extension - what appears after the final “.” in the filename. This is referred to as EXT in the following bulleted items.
- Check to see if any alias was created for the EXT extension with **pfAddExtAlias()**. If a translation is defined, EXT is replaced with that extension.
- Check the current executable to see if the symbol **pfLoadFile_EXT** is already defined, i.e. if the loader was statically linked into the executable or a DSO was previously loaded by some other mechanism. If not, the search continues.

- Generate a DSO library name to search for using on the extension prototype “**libpfEXT_{igl,ogl}{-g,.}so**”. This means the following strings will be constructed based upon whether OpenGL or IRIS GL is being used with IRIS Performer:

libpfEXT_igl.so for the optimized IRIS GL loader

libpfEXT_igl-g.so for the debug IRIS GL loader

libpfEXT_ogl.so for the optimized OpenGL loader

libpfEXT_ogl-g.so for the debug OpenGL loader

- Look for the DSO in several places including:

```
.  
$PFLD_LIBRARY_PATH  
$LD_LIBRARY_PATH  
$PFHOME/usr/lib{,32,64}/libpfdb  
$PFHOME/usr/share/Performer/lib/libpfdb
```

- Open the DSO via **dlopen()**.

- Once the object has been found, processing continues.
 - Query all libpfd converter functionality from the symbol table of the DSO using `dlsym()` with function names generated by appending `_EXT` to the name of the corresponding pfd routine name. This symbol dictionary is retained for future use.
 - Invoke the converter’s initialization function, `pdfInitConverter_EXT()`, if it exists.
 - Invoke `pdfLoadNeededDSOs_EXT()` if it exists. This routine can then recursively call `pdfInitConverter_EXT()`, as needed.

Developing Custom Importers

Having fully described how database converters can be integrated into IRIS Performer and the types of functionality they provide, the next undertaking is actually implementing a converter from scratch. IRIS Performer makes a great effort at allowing the quick and easy development of effective and efficient database converters.

While creating a new file loader for IRIS Performer isn’t inherently difficult, it does require a solid understanding of the following issues:

- The structure and interpretation of the data file to be read
- The scene graph concepts and nodes of *libpf*
- The geometry and attribute definition objects of *libpr*

Structure and Interpretation of the Database File Format

In order to effectively convert a database into an IRIS Performer scene graph it is important to have a substantial understanding of several concepts related to the original database format:

- the parsing of the file based on the database format
- the data types represented in the format and their IRIS Performer correspondence
- the scene graph structure of the file (if any)
- the method of graphics state definition and inheritance defined in the format.

Before trying to convert sophisticated 3-D database formats into IRIS Performer it is important to have a thorough grasp of how every structure in the format needs to affect how IRIS Performer performs its run-time management of a scene graph. However, although it requires a great deal of understanding to convert complex behaviors of external formats into IRIS Performer, it is still very straight forward to migrate basic structure, geometry, and graphics state into efficient IRIS Performer run-time structures via the functionality provided in the IRIS Performer database builder - *pfdBuilder*.

Scene Graph Creation using Nodes as defined in *libpf*

Creating an IRIS Performer scene graph requires a definite knowledge of the following IRIS Performer *libpf* node types - *pfScene*, *pfGroup*, and *pfGeode*.

These nodes can be used to define a minimally functional IRIS Performer scene graph. See Chapter 5 for more details on *libpf* and IRIS Performer scene graphs and node types.

Defining Geometry and Graphics State for *libpr*

In order to input geometry and graphics into IRIS Performer, it is important to have an understanding of how IRIS Performer's low level rendering objects work in *libpr*, IRIS Performer's performance rendering library. The main *libpr* rendering primitives are a *pfGeoSet* and a *pfGeoState*. A *pfGeoSet* is a collection of like geometric primitives that can all be rendered in exactly the same way in one large continuous chunk. A *pfGeoState* is a complete definition of graphics mode settings for the rendering hardware and software. It contains many attributes such as texture and material. Given a *pfGeoSet* and a corresponding *pfGeoState*, *libpr* can completely and efficiently render all of the geometry in the *pfGeoSet*. For a more detailed description of *pfGeoSets* and *pfGeoStates* see Chapter 10 which goes into detail on all *libpr* primitives and how IRIS Performer will use them.

However, realizing that IRIS Performer's structuring of geometry and graphics state is optimized for rendering speed and not for modelling ease or general conceptual partitioning, IRIS Performer now contains a new mechanism for translating external graphics state and geometry into efficient *libpr* structures. This new mechanism is the *pfdBuilder* that exists in *libpfdu*.

The pfdBuilder allows the immediate mode input of graphics state and primitives through very simple and exposed data structures. After having received all of the relevant information, the pfdBuilder builds efficient and somewhat optimized libpr data structures and returns a low-level libpf node that can be attached to an IRIS Performer scene graph. The pfdBuilder is the recommended method of importing data from non IRIS Performer-based formats into IRIS Performer.

Creation of a IRIS Performer Database Converter using *libpfd*

Creating a new format converter is very simple process. More than thirty database loaders are shipped with IRIS Performer in source code form to serve as practical examples of this process. The loaders read formats that range from trivial to complex, and should serve as an instructive starting point for those developing loaders for other formats. These loaders can be found in the directory `/usr/share/Performer/src/lib/libpfd/libpf*`.

This section describes the libpfd framework for creating a 3-D database format converter. Let's consider writing a converter for a simple ASCII format that is called the Imaginary Immediate Mode format with the file type extension ".iim". This format is much like the more elaborate ".im" format loader used at SGI for the purposes of testing basic IRIS Performer functionality.

The first thing to do is set up the routine that **pfdLoadFile()** will call when it attempts to load a file with the extension ".iim".

```
extern pfNode *pfdLoadFile_iim(char *fileName)
{
}
```

This function needs to perform several basic actions:

1. Find and open the given file.
2. Reset the libpfd pfdBuilder for input of new geometry and state.
3. Setup any pfdBuilder modes that the converter needs enabled.
4. Setup local data structures that can be used to communicate geometry and graphics state with the pfdBuilder.
5. Setup a libpf pfGroup which can hold all of the logical partitions of geometry in the file (or hold a subordinate collection of nodes as a general scene graph if the format supports it).

6. Optionally set up a default state to use for geometry with unspecified graphics state.
7. Parse the file which entails:
 - Filling in the local geometry and graphics state data structures.
 - Passing them to the pfdBuilder as inputted from the file
 - Ask the pfdBuilder to build the data structures into IRIS Performer data structures when a logical partition of the file has ended.
 - Attach the IRIS Performer node returned by the build to the higher level group which will hold the entire IRIS Performer representation of this file. Note that this step becomes more complex if the format supports the notion of hierarchy only in that the appropriate libpf nodes must be created and attached to each other via **pfAddChild()** to build the hierarchy. In this case requests are made for the builder to build after inputting all of the geometry and state found in a particular leaf node in the database.
8. Delete local data structures used to input geometry and graphics state.
9. Close the file.
10. Perform any optional optimization of the IRIS Performer scene graph. Optimizations might include calls to **pfFreezeTransforms()**, **pfFlatten()** or **pfCleanTree()**.
11. Return the pfGroup containing the entire IRIS Performer representation of the database file.

Steps 1-8 expand the function outline to the following:

```
extern pfNode *pfdLoadFile_iim(char *fileName)
{
    FILE* iimFile;
    pfdGeom* polygon;
    pfGroup* root;

    /* Performer has utility for finding and opening file */
    if ((iimFile = pfdOpenFile(fileName)) == NULL)
        return NULL;

    /* Clear builder from previous converter invocations */
    pfdResetBldrGeometry();
    pfdResetBldrState();

    /* Call pfdBldrMode for any needed modes here */
```

```
/* Create polygon structure */
/* holds one N-sided polygon where N is < 300 */
polygon = pfdNewGeom(300);

/* Create pfGroup to hold entire database */
/* loaded from this file */
root = pfNewGroup();

/* Specify state for geometry with no graphics state */
/* As well as default enables, etc. This routine */
/* should invoke pfdCaptureDefaultBldrState()*/
SetupDefaultGraphicsStateIfThereIsOne();

/* Do all the real work in parsing the file and */
/* converting into Performer */
ParseIIMFile(iimFile, root, polygon);

/* Delete local polygon struct */
pfdDelGeom(polygon);

/* Close File */
fclose(iimFile);

/* Optimize IRIS Performer scene graph */
/* via use of pfFlatten, pfdCleanTree, etc. */
OptimizeGraph(root);

return (pfNode*)root;
}
```

Now, for at the heart of the file loader lies the **ParseIIMFile()** function. The specifics of parsing a file are completely dependent on the format so the parsing will be left as an exercise to the reader. However, the following code fragments should show a framework for what goes into integrating the parser with the pfdBuilder framework for geometry and graphics state data conversion. Note that several possible graphics state inheritance models might be used in external formats and that the pfdBuilder is designed to support all of them:

- The default pfdBuilder state inheritance is that of immediate mode graphics state. Immediate mode state is specified through calls to **pfdBldrStateMode()**, **pfdBldrStateAttr()**, and **pfdBldrStateVal()**.
- There also exists a pfdBuilder state stack for hierarchical state application to geometry. This is accomplished through the use of **pfdPushBldrState()** and **pfdPopBldrState()** in conjunction with the normal use of the immediate mode pfdBuilder state API.
- Lastly, there is a pfdBuilder named state list that can be used to define a number of 'named materials' or 'named state definitions' that can then be recalled in one API called (for instance a user might define a 'brick' state with a red material and a brick texture. Later he might just want to say 'brick' is the current state and then input the walls of several buildings). This type of state naming is accomplished by fully specifying the state to be named via the immediate mode API, and then calling **pfdSaveBldrState()**. This state can then be recalled via **pfdLoadBldrState()**.

```
ParseIIMFile(FILE *iimFile, pfGroup *root, pfdGeom *poly)
{
    while((op = GetNextOp(iimFile)) != NULL)
    {
        switch(op)
        {
            case GEOMETRY_POLYGON:
                polygon->numVerts = GetNumVerts(iimFile);

                /* Determine if polygon has Texture Coords */
                if (pfdGetBldrStateMode(PFSTATE_ENTEXTURE)==PF_ON)
                    polygon->tbind = PFGS_PER_VERTEX;
                else
                    polygon->tbind = PFGS_OFF;

                /* Determine if Polygon has normals */
                if (AreThereNormalsPerVertex() == TRUE)
                    polygon->nbind = PFGS_PER_VERTEX;
                else if
                    (pfdGetBldrStateMode(PFSTATE_ENLIGHTING)==PF_ON)
```

```
    polygon->nbind = PFGS_PER_PRIM;
else
    polygon->nbind = PFGS_OFF;

/* Determine if Polygon has colors */
if (AreThereColorsPerVertex() == TRUE)
    polygon->cbind = PFGS_PER_VERTEX;
else if (AreThereColorsPerPrim() == TRUE)
    polygon->cbind = PFGS_PER_PRIM;
else
    polygon->cbind = PFGS_OFF;
for(i=0;i<polygon->numVerts;i++)
{
    /* Read ith Vertex into local data structure */
    polygon->coords[i][0] = GetNextVertexFloat();
    polygon->coords[i][1] = GetNextVertexFloat();
    polygon->coords[i][2] = GetNextVertexFloat();

    /* Read texture coord for ith vertex if any */
    if (polygon->tbind == PFGS_PER_VERTEX)
    {
        polygon->texCoords[i][0] = GetNextTexFloat();
        polygon->texCoords[i][1] = GetNextTexFloat();
    }

    /* Read normal for ith Vertex if normals bound*/
    if (polygon->nbind == PFGS_PER_VERTEX)
    {
        polygon->norms[i][0] = GetNextNormFloat();
        polygon->norms[i][1] = GetNextNormFloat();
        polygon->norms[i][2] = GetNextNormFloat();
    }
    /* Read only one normal per prim if necessary */
    else if ((polygon->nbind == PFGS_PER_PRIM) &&
             (i == 0))
    {
        polygon->norms[0][0] = GetNextNormFloat();
        polygon->norms[0][1] = GetNextNormFloat();
        polygon->norms[0][2] = GetNextNormFloat();
    }
}

/* Get Color for the ith Vertex if color bound*/
if (polygon->cbind == PFGS_PER_VERTEX)
{
    polygon->colors[i][0] =
```

```

        GetNextColorFloat();
        polygon->colors[i][1] =
            GetNextColorFloat();
        polygon->colors[i][2] =
            GetNextColorFloat();
    }
    /* Get one color per prim if necessary */
    else if ((polygon->cbind == PFGS_PER_PRIM) &&
            (i == 0))
    {
        polygon->colors[0][0] =
            GetNextColorFloat();
        polygon->colors[0][1] =
            GetNextColorFloat();
        polygon->colors[0][2] =
            GetNextColorFloat();
    }
}
/* Add this polygon to pfdBuilder */
/* Because it is a single poly, 1 */
/* is specified here */
pfdAddBlldrGeom(1);
break;
case GRAPHICS_STATE_TEXTURE:
{
    char *texName;
    pfTexture *tex;
    texName = ReadTextureName(iimFile);
    if (texName != NULL)
    {
        /* Get prototype tex from pfdBuilder*/
        tex =
            pfdGetTemplateObject(pfGetTexClassType());

        /* This clears that object to default */
        pfdResetObject(tex);

        /* If just the name of a pfTexture is */
        /* set, pfdBuilder will auto find & Load */
        /* the texture*/
        pfTexName(tex, texName);

        /* This is the current pfdBuilder */
        /* texture and texturing is on */
        pfdBlldrStateAttr(PFSTATE_TEXTURE, tex);
    }
}

```

```
        pfdBldrStateMode(PFSTATE_ENTEXTURE, PF_ON);
    }
    else
    {
        /* No texture means disable texturing */
        /* And set current texture to NULL */
        pfdBldrStateMode(PFSTATE_ENTEXTURE, PF_OFF);
        pfdBldrStateAttr(PFSTATE_TEXTURE, NULL);
    }
}
break;
case GRAPHICS_STATE_MATERIAL:
{
    pfMaterial *mtl;
    mtl = pfdGetTemplateObject(pfGetMtlClassType());
    pfdResetObject(mtl);
    pfMtlColor(mtl, PFMTL_AMBIENT,
        GetAmRed(), GetAmGreen(), GetAmBlue());
    pfMtlColor(mtl, PFMTL_DIFFUSE,
        GetDfRed(), GetDfGreen(), GetDfBlue());
    pfMtlColor(mtl, PFMTL_SPECULAR,
        GetSpRed(), GetSpGreen(), GetSpBlue());
    pfMtlShininess(mtl, GetMtlShininess());
    pfMtlAlpha(mtl, GetMtlAlpha());
    pfdBldrStateAttr(PFSTATE_FRONTMTL, mtl);
    pfdBldrStateAttr(PFSTATE_BACKMTL, mtl);
}
break;
case GRAPHICS_STATE_STORE:
    pfdSaveBldrState(GetStateName());
    break;
case GRAPHICS_STATE_LOAD:
    pfdLoadBldrState(GetStateName());
    break;
case GRAPHICS_STATE_PUSH:
    pfdPushBldrState();
    break;
case GRAPHICS_STATE_POP:
    pfdPopBldrState();
    break;
case GRAPHICS_STATE_RESET:
    pfdResetBldrState();
    break;
case GRAPHICS_STATE_CAPTURE_DEFAULT:
    pfdCaptureDefaultBldrState();
```

```

        break;
    case BEGIN_LEAF_NODE:
        /* Not really necessary because it is */
        /* destroyed on build*/
        pfdResetBldrGeometry();
        break;
    case END_LEAF_NODE:
        {
            pfNode *nd = pfdBuild();
            if (nd != NULL)
                pfAddChild(root,nd);
        }
        break;
    }
}
}

```

One of the fundamental structures involved in the above routine outline is the `pfGeom` structure which users fill in with information about a single primitive, or a single strip of primitives. The `pfGeom` structure is essential in communicating with the `pfBuilder` and is defined as follows:

```

typedef struct _pfGeom
{
    int flags;
    int nbind, cbind, tbind;

    int numVerts;
    short primtype;
    float pixelsize;

    /* Non-indexed attributes */
    /* ..do not set if poly is indexed */
    pfVec3 *coords;
    pfVec3 *norms;
    pfVec4 *colors;
    pfVec2 *texCoords;

    /* Indexed attributes */
    /* ..do not set if poly is non-indexed */
    pfVec3 *coordList;
    pfVec3 *normList;
    pfVec4 *colorList;
    pfVec2 *texCoordList;

    /* Index lists*/

```

```
/* ..do not set if poly is non-indexed */
ushort *icoords;
ushort *inorms;
ushort *icolors;
ushort *itexCoords;

struct _pfdGeom *next;
} pfdGeom;
```

See the `pfdGeoBuilder(3pf)` reference pages for more information on using this structure along with its sister structure, the `pfdPrim`.

The above should provide a well-defined framework for creating a database converter that can be used with any IRIS Performer applications via the **`pfdLoadFile()`** functionality.

However, it is also important to note that there are a multitude of `pfdBuilder` modes and attributes that can be used to affect some of the basic methods that the builder actually uses:

Table 7-5 pfdBuilder Modes and Attributes

Function Name	Token Description
pfd{Get}BlDrMode	PFDBLDR_MESH_ENABLE
	PFDBLDR_MESH_SHOW_TSTRIPS
	PFDBLDR_MESH_INDEXED
	PFDBLDR_MESH_MAX_TRIS
	PFDBLDR_MESH_RETESSELLATE
	PFDBLDR_MESH_LOCAL_LIGHTING
	PFDBLDR_AUTO_COLORS
	PFDBLDR_AUTO_NORMALS
	PFDBLDR_AUTO_ORIENT
	PFDBLDR_AUTO_ENABLES
	PFDBLDR_AUTO_CMODE
	PFDBLDR_AUTO_DISABLE_TCOORDS_BY_STATE
	PFDBLDR_AUTO_DISABLE_NCOORDS_BY_STATE
	PFDBLDR_AUTO_LIGHTING_STATE_BY_NCOORDS
	PFDBLDR_AUTO_LIGHTING_STATE_BY_MATERIALS
	PFDBLDR_AUTO_TEXTURE_STATE_BY_TEXTURES
	PFDBLDR_AUTO_TEXTURE_STATE_BY_TCOORDS
	PFDBLDR_BREAKUP
	PFDBLDR_BREAKUP_SIZE
	PFDBLDR_BREAKUP_BRANCH
	PFDBLDR_BREAKUP_STRIP_LENGTH
	PFDBLDR_SHARE_MASK
	PFDBLDR_ATTACH_NODE_NAMES
	PFDBLDR_DESTROY_DATA_UPON_BUILD
	PFDBLDR_PF12_STATE_COMPATIBLE
	PFDBLDR_BUILD_LIMIT
PFDBLDR_GEN_OPENGL_CLAMPED_TEXTURE_COORDS	
PFDBLDR_OPTIMIZE_COUNTS_NULL_ATTRS	
pfd{Get}BlDrAttr	PFDBLDR_NODE_NAME_COMPARE
	PFDBLDR_STATE_NAME_COMPARE

Because the pfdBuilder is released as source code, it is easy to add further functionality and more modes and attributes to even further customize this central functionality.

In fact, because the pfdBuilder acts as a “data funnel” in converting data into IRIS Performer run-time structures, it is easy to control the behavior of many standard conversion tasks through merely globally setting builder modes which will subsequently affect all converters that use the pfdBuilder to process their data.

Maximizing Database Loading and Paging Performance with PFB and PFI Formats

“Description of Supported Formats” on page 195 describes all of the file formats supported by IRIS Performer. Although you can use files in these formats directly, you can dramatically reduce database loading time by pre-converting databases into the PFB format and images into the PFI format.

To convert to the PFB file format or the PFI image format, use the pfconv and pficonv utilities.

pfconv

The pfconv utility converts from any format for which a **pdfLoadFile...()** function exists into any format for which a **pdfStoreFile...()** exists. The most common format to convert to is the PFB format. For example, to convert *cow.obj* into the PFB format, use the following command:

```
% pfconv cow.obj cow.pfb
```

By default, pfconv optimizes the scene graph when doing the conversion. The optimizations are controlled with the **-o** and **-O** command line options. Builder options are controlled with the **-b** and **-B** command line options. Converter modes are controlled with the **-m** and **-M** command line options. Refer to the help page for more specific information about the command line options by entering:

```
% pfconv -h
```

Example Conversion

When converting to the PFB format, texture files can be converted to the PFI format using the following command line options:

```
% pfconv -M pfb, 5, 1
```

5 means PFPFB_SAVE_TEXTURE_PFI.

1 means convert *.rgb* texture images to *.pfi*.

pficonv

The `pficonv` utility converts from IRIS libimage format to PFI format image files. For example, to convert *cafe.rgb* into the PFI format, use the following command:

```
% pficonv cafe.rgb cafe.pfi
```

Mipmaps can be automatically generated and stored in the resulting PFI files by adding `-m` to the command line.

Supported Database Formats

Vendors of several leading database construction and processing tools have provided database-loading software for you to use with IRIS Performer. This section describes these loaders, the loaders developed by the IRIS Performer engineering team, and several loaders developed in the IRIS Performer user community for other database formats.

Importing your databases is simple if they're in formats for which IRIS Performer database loaders have already been written. Each of the loaders listed in Table 7-6 is included with IRIS Performer. If you want to import or export databases in any of these formats, refer to the appropriate section of this chapter for specific details about the individual loaders.

Table 7-6 Supported Database Formats

Name	Description
3ds	AutoDesk 3DStudio binary data
bin	SGI format used by powerflip
bpoly	Side Effects Software PRISMS binary data
byu	Brigham Young University CAD/FEA data
csb	OpenGL Optimizer Format
ct	Cliptexture config file loader - auto-generates viewing geometry
dwb	Coryphaeus Software Designer's Workbench data
dxf	AutoDesk AutoCAD ASCII format
flt11	MultiGen public domain Flight v11 format
flt	MultiGen OpenFlight format provided by MultiGen
gds	McDonnell-Douglas GDS things data
gfo	Old SGI radiosity data format
im	Simple IRIS Performer data format
irtp	AAI/Graphicon Interactive Real-Time PHIGS
iv	SGI Open Inventor format (VRML 1.0 superset)
lsa	Lightscape Technologies ASCII radiosity data
lsb	Lightscape Technologies binary radiosity data
medit	Medit Productions medit modeling data
nff	Eric Haines' ray tracing test data
pfb	IRIS Performer fast binary format
obj	Wavefront Technologies data format
pegg	Radiosity research data format
phd	SGI polyhedron data format

Table 7-6 (continued) Supported Database Formats

Name	Description
poly	Side Effects Software PRISMS ASCII data
ptu	Simple IRIS Performer terrain data format
sgf	US Naval Academy standard graphics format
sgo	Paul Haeberli's graphics data format
spf	US Naval Academy simple polygon format
sponge	Sierpinski sponge 3D fractal generator
star	Astronomical data from Yale University star chart
stla	3D Structures ASCII stereolithography data
stlb	3D Structures binary stereolithography data
stm	Michael Garland's terrain data format
sv	John Kichury's i3dm modeler format
tri	University of Minnesota Geometry Center data
unc	University of North Carolina walkthrough data
wrl	OpenWorlds VMRL 2.0 provided by DRaW Computing

Description of Supported Formats

This section describes the different database file for mats that IRIS Performer supports.

AutoDesk 3DS Format

The AutoDesk 3DS format is used by the 3DStudio program and by a number of 3D file-interchange tools. The IRIS Performer loader for 3DS files is located in the `/usr/share/Performer/src/lib/libp3ds` directory. This loader uses an auxiliary library, `3dsftk.a`, to parse and interpret the 3ds file.

pfLoadFile() uses the function **pfLoadFile_3ds()** to import data from 3DStudio files into IRIS Performer run-time data structures.

Silicon Graphics BIN Format

The Silicon Graphics BIN format is supported by both Showcase™ and the *powerflip* demonstration program. BIN files are in a simple format that specifies only independent quadrilaterals.

The image in Figure 7-1 shows several of the BIN-format objects provided in the IRIS Performer sample data directory.

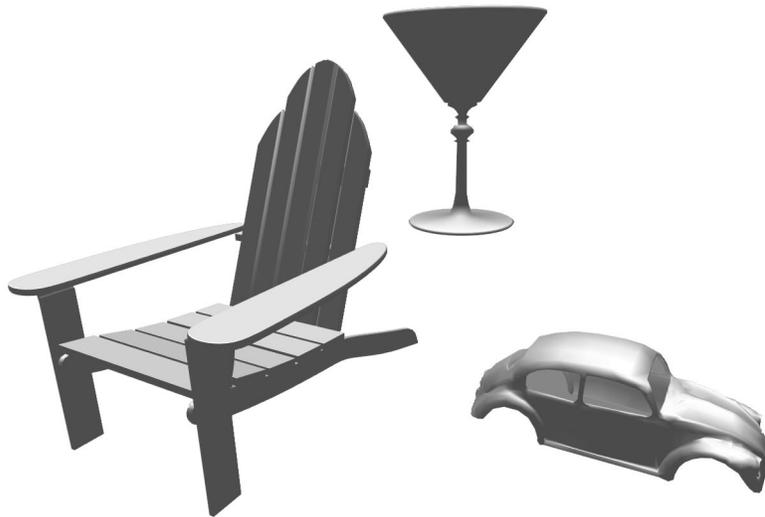


Figure 7-1 BIN-Format Data Objects

The source code for the BIN-format importer **pfLoadFile_bin()** is provided in the file *pfbin.c*. This code shows how easy it can be to implement an importer. Since **pfLoadFile_bin()** is based on the **pfBuilder()** utility function, it will build efficient triangle-strip *pfGeoSets* from the quadrilaterals of a given BIN file. The BIN format has the following structure:

1. A 4-byte magic number, 0x5432, which identifies the file as a BIN file.
2. A 4-byte number that contains the number of vertices, which is four times the number of quadrilaterals.
3. Four bytes of zero.
4. A list of polygon data for each vertex in the object. The data consists of three floating-point words of information about normals, followed by three floating-point words of vertex information.

The BIN format uses these data structures:

```
typedef struct
{
    float normal[3];
    float coordinate[3];
} Vertex;

typedef struct
{
    long magic;
    long vertices;
    long zero;
    Vertex vertex[1];
} BinFile;
```

pdfLoadFile() uses the function **pdfLoadFile_bin()** to import data from BIN format files into IRIS Performer run-time data structures:

The **pdfLoadFile_bin()** function composes a random color for each file it reads. The chosen color has red, green, and blue components uniformly distributed within the range 0.2 to 0.7 and is fully opaque.

Side Effects POLY Format

The Side Effects software PRISMS database modeler format supports both ASCII and binary forms of the POLY format. The IRIS Performer loader for ASCII “.poly” files is located in the */usr/share/Performer/src/lib/libpfdp/libpfpoly* directory. The binary format “.bpoly” loader is located in the directory */usr/share/Performer/src/lib/libpfdp/libpfbpoly*. These formats are equivalent in content and differ only in representation.

The POLY format is an easy to understand ASCII data representation with the following structure:

1. A text line containing the keyword "POINTS"
2. One text line for each vertex in the file. Each line begins with a vertex number, followed by a colon, followed by the X, Y, and Z axis coordinates of the vertex, optional additional information, and a new-line character. The optional information includes color specification in the form "c(R,G,B,A)", a normal vector of the form "n(NX,NY,NZ)", or a texture coordinate in the form "uv(S,T)" where each of the values shown are floating point numbers.
3. A text line containing the keyword "POLYS"
4. One text line for each polygon in the file. Each line begins with a polygon number, followed by a colon, followed by a series of vertex indices, optional additional information, an optional "<" character, and a new-line. The optional information includes color specification in the form "c(R,G,B,A)", a normal vector of the form "n(NX,NY,NZ)", or a texture coordinate in the form "uv(S,T)" where the values in parentheses are floating point numbers.

Here is a sample POLY format file for a cube with colors, texture coordinates, and normals specified at each vertex:

```
POINTS
1: -0.5 -0.5 -0.5 c(0, 0, 0, 1) uv(0, 0) n(0, -1, 0)
2: -0.5 -0.5 0.5 c(0, 0, 1, 1) uv(0, 0) n(0, -1, 0)
3: 0.5 -0.5 0.5 c(1, 0, 1, 1) uv(1, 0) n(0, -1, 0)
4: 0.5 -0.5 -0.5 c(1, 0, 0, 1) uv(1, 0) n(0, -1, 0)
5: -0.5 -0.5 0.5 c(0, 0, 1, 1) uv(0, 0) n(0, 0, 1)
6: -0.5 0.5 0.5 c(0, 1, 1, 1) uv(0, 1) n(0, 0, 1)
7: 0.5 0.5 0.5 c(1, 1, 1, 1) uv(1, 1) n(0, 0, 1)
8: 0.5 -0.5 0.5 c(1, 0, 1, 1) uv(1, 0) n(0, 0, 1)
9: -0.5 0.5 0.5 c(0, 1, 1, 1) uv(0, 1) n(0, 1, 0)
10: -0.5 0.5 -0.5 c(0, 1, 0, 1) uv(0, 1) n(0, 1, 0)
11: 0.5 0.5 -0.5 c(1, 1, 0, 1) uv(1, 1) n(0, 1, 0)
12: 0.5 0.5 0.5 c(1, 1, 1, 1) uv(1, 1) n(0, 1, 0)
13: -0.5 -0.5 -0.5 c(0, 0, 0, 1) uv(0, 0) n(0, 0, -1)
14: 0.5 -0.5 -0.5 c(1, 0, 0, 1) uv(1, 0) n(0, 0, -1)
15: 0.5 0.5 -0.5 c(1, 1, 0, 1) uv(1, 1) n(0, 0, -1)
16: -0.5 0.5 -0.5 c(0, 1, 0, 1) uv(0, 1) n(0, 0, -1)
17: -0.5 -0.5 -0.5 c(0, 0, 0, 1) uv(0, 0) n(-1, 0, 0)
18: -0.5 0.5 -0.5 c(0, 1, 0, 1) uv(0, 1) n(-1, 0, 0)
19: -0.5 0.5 0.5 c(0, 1, 1, 1) uv(0, 1) n(-1, 0, 0)
20: -0.5 -0.5 0.5 c(0, 0, 1, 1) uv(0, 0) n(-1, 0, 0)
```

```

21: 0.5 0.5 0.5 c(1, 1, 1, 1) uv(1, 1) n(1, 0, 0)
22: 0.5 0.5 -0.5 c(1, 1, 0, 1) uv(1, 1) n(1, 0, 0)
23: 0.5 -0.5 -0.5 c(1, 0, 0, 1) uv(1, 0) n(1, 0, 0)
24: 0.5 -0.5 0.5 c(1, 0, 1, 1) uv(1, 0) n(1, 0, 0)

```

POLYS

```

1: 1 2 3 4 <
2: 5 6 7 8 <
3: 9 10 11 12 <
4: 13 14 15 16 <
5: 17 18 19 20 <
6: 21 22 23 24 <

```

pdfLoadFile() uses the functions **pdfLoadFile_poly()** and **pdfLoadFile_bpoly()** to import data from “.poly” and “.bpoly” format files into IRIS Performer run-time data structures:

Brigham Young University BYU Format

The Brigham Young University “.byu” format is used as an interchange format by some finite element analysis packages. The IRIS Performer loader for “.byu” files is located in the `/usr/share/Performer/src/lib/libpfdlibpfbbyu` directory.

The format of a BYU file consists of four parts as defined below:

1. A text line containing four counts: the number of *parts*, the number of *vertices*, the number of *polygons*, and the number of *elements* in the connectivity array.
2. The part definition list, containing the starting polygon number and ending polygon number (one pair per line) for *parts* lines.
3. The vertex list, which has the X, Y, Z coordinates of each vertex in the database packed two per line. This means that vertices 1 and 2 are on the first line, 3 and 4 are on the second, and so on for $(vertices + 1)/2$ lines of text in the file.
4. The connectivity array, with an entry for each polygon. These entries may span multiple lines in the input file and each consists of three or more vertex indices with the last negated as an end of list flag. For example, if the first polygon were a quad, the connectivity array might start with “1 2 3 -4” to define a polygon that connects the first four vertices in order.

The following BYU format file defines two adjoining quads:

```
2 6 2 0
1 1
2 2
0 0 0 10 0 0
10 10 0 0 10 0
10 10 10 0 10 10
1 2 3 -4
4 3 5 -6
```

pfLoadFile() uses the function **pfLoadFile_byu()** to import data from “.byu” format files into IRIS Performer run-time data structures.

Optimizer CSB Format

IRIS Performer can load native OpenGL Optimizer format files using this loader. OpenGL Optimizer can also load IRIS Performer’s PFB native format files, providing full database interoperability. This allows you to use OpenGL Optimizer database simplification and optimization tools on IRIS Performer databases.

Virtual Cliptexture CT Loader

The IRIS Performer CT loader allows you to create and configure cliptextures and virtual cliptextures, complete with a scenegraph containing simple geometry and callbacks. See the Cliptexture chapter for more details.

Designer’s Workbench DWB Format

The binary DWB format is used for input and output by the Designer’s Workbench, EasyT, and EasyScene database modeling tools produced by Coryphaeus Software. DWB is an advanced database format that directly represents many of IRIS Performer’s attribute and hierarchical scene graph concepts.

An importer for this format, named **pfLoadFile_dwb()**, has been provided by Coryphaeus Software for your use. The loader code and its associated documentation are in the `/usr/share/Performer/src/lib/libpfdw/libpfdwb` directory. The image in Figure 7-2 shows a model of the Soma Cube puzzle invented by Piet Hein. The model was created using

Designer's Workbench. Each of the pieces is stored as an individual DWB-format file. Do you see how to form the 3 x 3 cube at the lower left from the seven individual pieces?

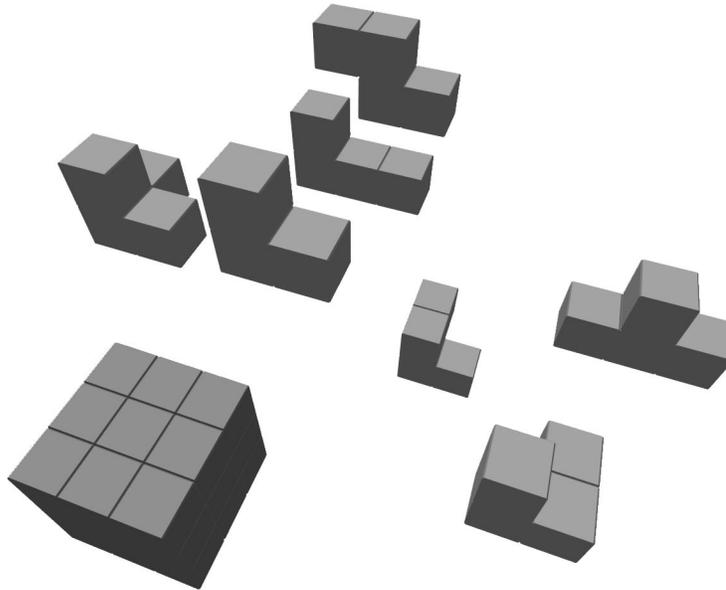


Figure 7-2 Soma Cube Puzzle in DWB Form

pfdLoadFile() uses the function **pfdLoadFile_dwb()** to load Designer's Workbench files into IRIS Performer run-time data structures.

AutoCAD DXF Format

The DXF format originated with Autodesk's AutoCAD database modeling system. The version recognized by the **pfdLoadFile_dxf()** database importer is a subset of ASCII Drawing Interchange Format (DXF) Release 12. The binary version of the DXF format, also known as DXB, isn't supported. Source code for the importer is in the file `/usr/share/Performer/src/lib/libpfd/db/libpfdx/pfdx.c`. **pfdLoadFile_dxf()** was derived from the DXF-to-DKB data file converter developed and placed in the public domain by Aaron A. Collins.

The image in Figure 7-3 shows a DXF model of the famous Utah teapot. This model was loaded from DXF format using the **pfdLoadFile_dxf()** database importer.



Figure 7-3 The Famous Teapot in DXF Form

The DXF format has an unusual though well-documented structure. The general organization of a DXF file is

1. HEADER section with general information about the file
2. TABLES section to provide definitions for named items, including:
 - LTYPE, the line-type table
 - LAYER, the layer table
 - STYLE, the text-style table
 - VIEW, the view table
 - UCS, the user coordinate-system table
 - VPORT, the viewport configuration table
 - DIMSTYLE, the dimension style table
 - APPID, the application identification table

3. BLOCKS section containing block definition entities
4. ENTITIES section containing entities and block references
5. END-OF-FILE

Within each section are groups of values, where each value is defined by a two-line pair of tokens. The first token is a numeric code indicating how to interpret the information on the next line. For example, the sequence

```
10
1.000
20
5.000
30
3.000
```

defines a “start point” at the XYZ location (1, 5, 3). The codes 10, 20, and 30 indicate, respectively, that the primary X, Y, and Z values follow. All data values are retained in a set of numbered registers (10, 20, and 30 in this example), which allows values to be reused. This simple state-machine type of run-length coding makes DXF files space-efficient at the cost of making them harder to interpret.

pdfLoadFile() uses the function **pdfLoadFile_dxf()** to load DXF format files into IRIS Performer run-time data structures.

Several widely available technical books provide full details of this format if you need more information. Chief among these are *AutoCAD Programming, 2nd Edition*, by Dennis N. Jump, Windcrest Books, 1991, and *AutoCAD: The Complete Reference, Second Edition*, by Nelson Johnson, Osborne McGraw-Hill, 1991.

MultiGen OpenFlight Format

The OpenFlight format is a binary format used for input and output by the MultiGen and ModelGen database modeling tools produced by MultiGen. It is a comprehensive format that can represent nearly all of IRIS Performer’s advanced concepts, including object hierarchy, instancing, level-of-detail selection, light-point specification, texture mapping, and material property specification.

MultiGen has provided an OpenFlight-format importer, **pdfLoadFile_ftt()**, for your use. The loaders and associated documentation are in the directories */usr/share/Performer/src/lib/libpfd*/*libpfft11* and *libpfft14*. Refer to the *Readme* files in these directories for important information about the loaders and for help in contacting MultiGen for information about **pdfLoadFile_ftt()** or the OpenFlight format.

The image in Figure 7-4 shows a model of a spacecraft created by Viewpoint Animation Engineering using MultiGen. This OpenFlight format model was loaded into IRIS Performer using **pdfLoadFile_ftt()**.

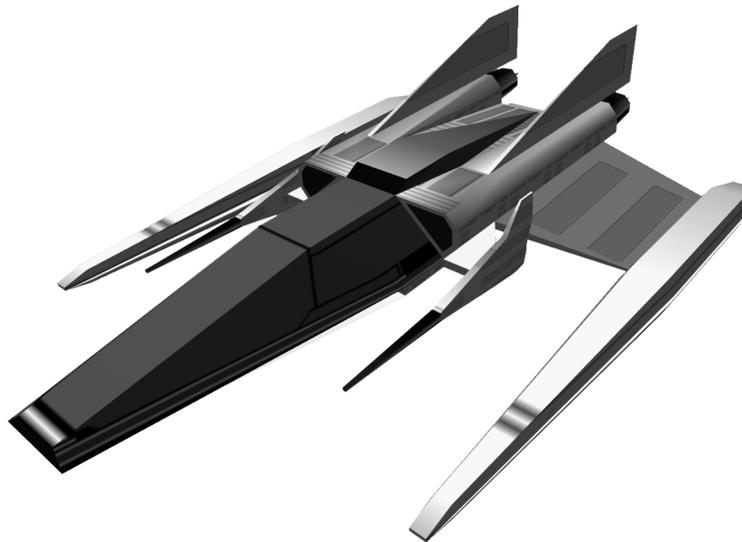


Figure 7-4 Spacecraft Model in FLIGHT Format

pdfLoadFile() uses the function **pdfLoadFile_ftt()** to load OpenFlight format files into IRIS Performer run-time data structures.

Files in the OpenFlight format are structured as a linear sequence of records. The first few bytes of each record are a header containing an op-code, the length of the record, and possibly an ASCII name for the record. The first record in the file is a special “database header” record whose op-code, stored as a 2-byte short integer, has the value 1. This opcode header can be used to identify OpenFlight-format files. By convention, these files have a “.ftt” filename extension.

pdfLoadFile_fit() makes use of several environment variables when locating data and texture files. These variables and several additional functions, including **pdfConverterMode_fit()**, **pdfGetConverterMode_fit()**, and **pdfConverterAttr_fit()** assist in OpenFlight file processing.

McDonnell-Douglas GDS Format

The “.gds” format (also known as the “Things” format) is used in at least one CAD system, and a minimal loader for this format has been developed for IRIS Performer users. The IRIS Performer loader for “.gds” files is located in the */usr/share/Performer/src/lib/libpfdb/libpfgds* directory.

The GDS format subset accepted by the **pdfLoadFile_gds()** function is easy to describe. It consists of the following five sequential sections in an ASCII file.

1. The number of *vertices*, which is given following a “YIN” tag.
2. The vertices, with one X, Y, Z triple per line for *vertices* lines.
3. The number zero on a line by itself.
4. The number of *polygons* on a line by itself.
5. A series of polygon definitions, each of which is represented on two or more lines. The first line contains the number one and the name of a material to use for the polygon. The next line or lines contain the indices for the polygons vertices. The first number on the first line is the number of *vertices*. This is followed by that number of vertex indices on that, and possibly subsequent, lines.

pdfLoadFile() uses the function **pdfLoadFile_gds()** to load “.gds” format files into IRIS Performer.

Silicon Graphics GFO Format

The GFO format is the simple ASCII format of the *barcelona* database that is provided in the IRIS Performer sample database directory. This database represents the famous German Pavilion at the Barcelona Exhibition of 1929, which was designed by Ludwig Mies van der Rohe and is shown in Figure 7-5.

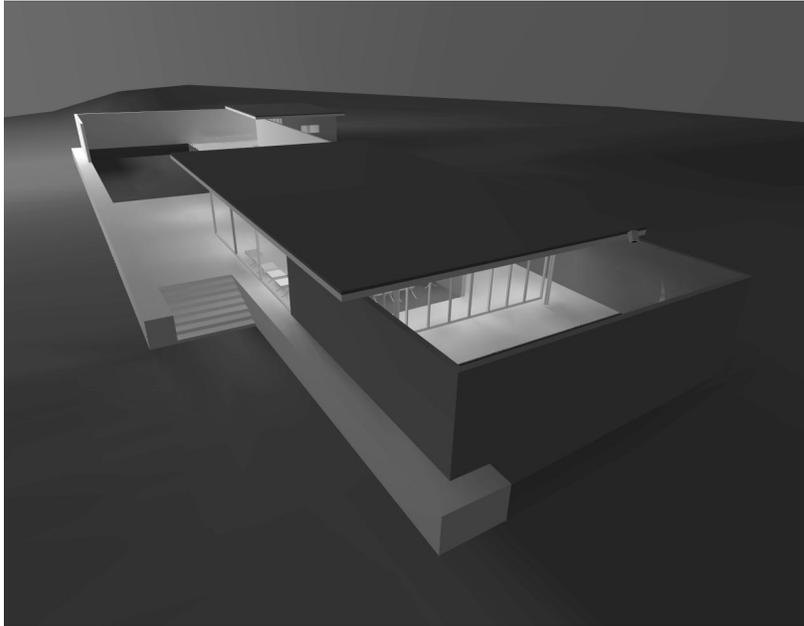


Figure 7-5 GFO Database of Mies van der Rohe's German Pavilion

The source code for the GFO-format loader is provided in the file */usr/share/Performer/src/lib/libpfdb/libpfgfo/pfbin.c*.

pfLoadFile() uses the function **pfLoadFile_gfo()** to load GFO format files into IRIS Performer run-time data-structures.

When working with GFO files, remember that hardware lighting isn't used since all illumination effects have already been accounted for with the ambient color at each vertex.

The GFO format defines polygons with a color at every vertex. It is the output format of an early radiosity system. Files in this format have a simple ASCII structure, as indicated by the following abbreviated GFO file:

```

scope {
v3f {42.9632 8.7500 0.9374}
cpack {0x8785a9}
v3f {42.9632 8.0000 0.9374}
cpack {0x8785a9}
...
v3f {-1.0000 -6.5858 10.0000}
cpack {0xffffffff}
polygon {cpack[0] v3f[0] cpack[1] v3f[1] cpack[2] v3f[2] cpack[3] v3f[3] }
polygon {cpack[4] v3f[4] cpack[5] v3f[5] cpack[6] v3f[6] cpack[7] v3f[7] }
...
polygon {cpack[7330] v3f[7330] cpack[7331] v3f[7331] cpack[7332] v3f[7332]
cpack[7333] v3f[7333] }
instance {
polygon[0]
polygon[1]
...
polygon[2675]
}
}

```

This example is taken from the file *barcelona-l.gfo*, one of only two known databases in the GFO format. The importer uses functions from the *libpfd* library (such as those from the *pfBuilder*) to generate efficient shared triangle strips. This increases the speed with which GFO databases can be drawn and reduces the size and complexity of the loader, since the builder's functions hide the details of the *pfGeoSet* construction process.

Silicon Graphics IM Format

The “.im” format is a simple format developed for test purposes by the IRIS Performer engineering team. As new features are added to IRIS Performer, the “.im” loader is extended to allow experimentation and testing. A recent example of this is support for *pfText*, *pfString*, and *pfFont* objects which can be seen by running *perfly* on the sample data file *fontsample.im*. The IRIS Performer “.im” loader is in the */usr/share/Performer/src/lib/libpfdb/libpfim* directory.

Here is an example IM format file that creates an extruded 3D text string. Copy this to a file ending in the extension “.im” and load it into *Perfly*. For a complete example of how text is handled in IRIS Performer, use *Perfly* to examine the file */usr/share/Performer/data/fontsample2.im*.

```
breakup 0 0.0 0 0
new root top
end_root

new font mistr-extruded Mistr 3
end_font

new str_text textnode mistr-extruded 1
Hello World||
end_text

attach top textnode
```

pfLoadFile() uses the function **pfLoadFile_im()** to load “.im” format files into IRIS Performer run-time data structures:

pfLoadFile_im() searches the current IRIS Performer file path for the named file and returns a pointer to the pfNode parenting the imported scene graph, or NULL if the file isn’t readable or doesn’t contain a valid database.

AAI/Graphicon IRTP Format

The AAI/Graphicon “.irtp” format is used by the TopGen database modeling system and by the Graphicon-2000 image generator. The name IRTP is an acronym for Interactive Real-Time PHIGS. The IRIS Performer “.irtp” loader is in the */usr/share/Performer/src/lib/libpfd/libpfirtp* directory. Though loader does not support the more arcane IRTP features, such as binary separating planes or a global matrix table, it has served as a basis for porting applications to IRIS Performer and the RealityEngine.

pfLoadFile() uses the function **pfLoadFile_irtp()** to load IRTP format files into IRIS Performer run-time data-structures.

Silicon Graphics Open Inventor Format

The Open Inventor object-oriented 3D-graphics toolkit defines a persistent data format that is also a superset of the VRML networked graphics data format. The image in Figure 7-6 shows a sample Open Inventor data file.

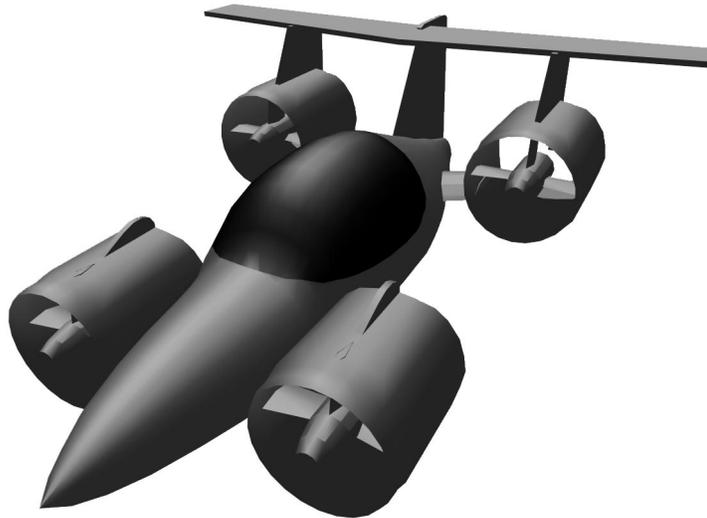


Figure 7-6 Aircar Database in IRIS Inventor Format

The model in Figure 7-6 represents one design for the perennial “personal aircar of the future” concept. It was created, using Imagine, by Mike Halvorson of Impulse, and was modeled after the Moller 400 as described in *Popular Mechanics*.

The Open Inventor data-file loader provided with IRIS Performer reads both binary and ASCII format Open Inventor data files. Open Inventor scene graph description files in both formats have the suffix “.iv” appended to their file names.

Here is a simple Open Inventor file that defines a cone:

```
#Inventor V2.1 ascii

Separator {
  Cone {
  }
}
```

The source code for the Open Inventor format importer is provided in the *libpfd*/*libpfiv* source directory.

pfdLoadFile() uses the function **pfdLoadFile_iv()** to load Open Inventor format files into IRIS Performer run-time data-structures. IRIS Performer also comes with an Inventor loader that works with Open Inventor 2.0, if Open Inventor 2.1 is not installed.

Lightscape Technologies LSA and LSB Formats

The Lightscape Visualization system is a product of Lightscape Technologies, Inc., and is designed to compute accurate simulations of global illumination within complex 3D environments. The output files created with Lightscape Visualization can be read into IRIS Performer for real-time visual exploration.

Lightscape Technologies provides importers for two of their database formats, the simple ASCII LSA format and the comprehensive binary LSB format. These loaders are in the */usr/share/Performer/src/lib/libpfdlib/pflsa* and *libpflsb* directories, in the files *pflsa.c* and *pflsb.c*. Files in the LSA format are in ASCII and have the following components:

1. a 4x4 view matrix representing a default transformation
2. counts of the number of independent triangles, independent quadrilaterals, triangle meshes, and quadrilateral meshes in the file
3. geometric data definitions

There are four types of geometric definitions in LSA files. The formats of these definitions are as shown in Table 7-7.

Table 7-7 Geometric Definitions in LSA Files

Geometric Type	Format
Triangle	t X1 Y1 Z1 C1 X2 Y2 Z2 C2 X3 Y3 Z3 C3
Triangle mesh	tm n X1 Y1 Z1 C1 X2 Y2 Z2 C2 ...
Quadrilateral	q X1 Y1 Z1 C1 X2 Y2 Z2 C2 X3 Y3 Z3 C3 X4 Y4 Z4 C4
Quadrilateral mesh	qm n X1 Y1 Z1 C1 X2 Y2 Z2 C2 ...

The *Cn* values in Table 7-7 refer to colors in the format accepted by the IRIS GL function `cpack()`; these colors should be provided in decimal form. The X, Y, and Z values are vertex coordinates. Polygon vertex ordering in LSA files is consistently counter-clockwise, and polygon normals are not specified. The first few lines of the LSA sample file *chamber.0.lsa* provide an example of the format:

```
0.486911 0.03228900 0.979046 0.9596590
-1.665110 0.00944197 0.286293 0.2806240
0.000000 1.92730000 -0.017805 -0.0174524
0.240398 -5.54670000 13.021200 13.4945000
```

```
1782 4751 0 0
```

```
t 4.35 -7.3677 2.57 6188666 6.5 -9.3 2.57 5663353 4.35 -9.3 2.57 5728890
t 6.5 -9.3 2.57 5663353 4.35 -7.3677 2.57 6188666 6.5 -8.2463 2.57 6057596
```

The count line indicates that the file contains 1782 independent triangles and 4751 independent quadrilaterals, which together represent 11,284 triangles. The image in Figure 7-7 shows this database, the New Jerusalem City Hall. This was produced by A.J. Diamond of Donald Schmitt and Company, Toronto, Canada, using the Lightscape Visualization system.



Figure 7-7 LSA-Format City Hall Database

pfLoadFile() uses the function **pfLoadFile_lsa()** to load LSA format files into IRIS Performer run-time data-structures.

Files in the LSB binary format have a very different structure from LSA files. Representing not just polygon data, they contain much of the structural information present in the “.ls” files used by the Lightscape Visualization system, including material, layer, and texture definitions as well as a hierarchical mesh definition for geometry. This information is structured as a series of data sections, which include:

- the signature, a text string that identifies the file
- the header, which contains global file information
- the material table, defining material properties
- the layer table, defining grouping and association
- the texture table, referencing texture images
- geometry in the form of clusters

The format of the geometric clusters is somewhat complicated. A cluster is a group of coplanar surfaces called patches that share a common material, layer, and normal. Each patch shares at least one edge with another patch in the cluster. Each patch defines either a convex quadrilateral or a triangle, and patches represent quad-trees called nodes. Each node points to its corner vertices and its children. The leaf nodes point to their corner vertices and the child pointers can optionally point to the vertices that split an edge of the node. Only the locations of vertices that are corners of the patches are stored in the file; other vertices are created by subdividing nodes of the quad-tree as the LSB file is loaded. The color information for each vertex is unique and is specified in the file.

The image in Figure 7-8 shows an LSB-format database developed during the design of a hospital operating room. This database was produced by the DeWolff Partnership of Rochester, New York, using the Lightscape Visualization system.

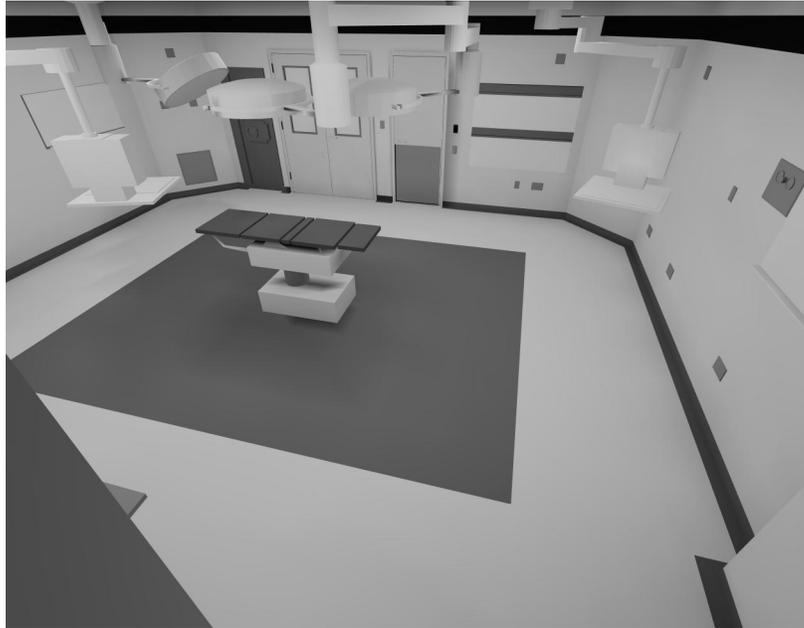


Figure 7-8 LSB-Format Operating Room Database

pfLoadFile() uses the function **pfLoadFile_lsb()** to load LSB format files into IRIS Performer run-time data-structures.

When working with Lightscape Technologies files, remember that hardware lighting isn't needed because all illumination effects have already been accounted for with the ambient color at each vertex.

Medit Productions MEDIT Format

The ".medit" format is used by the Medit database modeling system produced by Medit Productions. The IRIS Performer ".medit" loader is in the */usr/share/Performer/src/lib/libpfdp/libpfmedit* directory.

pfLoadFile() uses the function **pfLoadFile_medit()** to load MEDIT format files into IRIS Performer run-time data-structures.

NFF Neutral File Format

The “.nff” format was developed by Eric Haines as a way to provide standard procedural databases for evaluating ray tracing software. IRIS Performer includes an extended NFF loader with superquadric torus support, a named `build` keyword, and numerous small bug fixes. The “.nff” loader is located in the `/usr/share/Performer/src/lib/libpfdp/libpfnff` directory.

The file `/usr/share/Performer/data/sampler.nff` uses each of the NFF data types. It is an excellent way to explore the “Show Tree”, “Draw Style”, and “Highlight Mode” features of Perfly. It is included here:

```
#-- torus
f .75 .00 .25 .6 .8 20 0
t 5 5 0 0 0 1 2 1
build torus

#-- cylinder
f .00 .75 .25 .6 .8 20 0
c
15 5 -3 2
15 5 3 2
#-- put a disc on the top and bottom of the cylinder
d 15 5 -3 0 0 -1 0 2
d 15 5 3 0 0 1 0 2
build cylinder

#-- cone
f .00 .25 .75 .6 .8 20 0
c
25 5 -3 3
25 5 3 0
#-- put a disc on the bottom of the cone
d 25 5 -3 0 0 -1 0 3
build cone

#-- sphere
f .75 .00 .75 .6 .8 20 0
s 5 15 0 3
build sphere

#-- hexahedron
f .25 .25 .50 .6 .8 20 0
h 13 13 -2 17 17 2
```

```
build hexahedron

#-- superquadric sphere
f .80 .10 .30 .6 .8 20 0
ss 25 15 0 2 2 2 .1 .4
build superquadric_sphere

#-- disc (washer shape)
f .20 .20 .90 .6 .8 20 0
d 5 25 0 0 0 1 1 2.5
build disc

#-- grid (height field)
f .80 .80 .10 .6 .8 20 0
g 4 4 12 18 22 28 0 4
0 0 0 0
0 1 0 0
0 0 -1 0
0 0 0 0
build grid

#-- superquadric torid
f .40 .20 .60 .6 .8 20 0
st 25 25 0 0.5 0.5 0.5 .33 .33 3
build superquadric_torid

#-- polygon with no normals
f .20 .20 .20 .6 .8 20 0
p 4
-5 -5 -10
35 -5 -10
35 35 -10
-5 35 -10
build polygon
```

pfdLoadFile() uses the function **pfdLoadFile_nff()** to load NFF format files into IRIS Performer run-time data-structures.

Wavefront Technology OBJ Format

The OBJ format is an ASCII data representation read and written by the Wavefront Technology *Model* program. A number of database models in this format have been placed in the public domain, making this a useful format to have available. IRIS Performer provides the function `pfLoadFile_obj()` to import OBJ files. The source code for `pfLoadFile_obj()` is in the file `pfobj.c` in the `/usr/share/Performer/src/lib/libpfdp/libpfobj` loader source directory.

The OBJ-format database shown in Figure 7-9 models an office building that's part of the Silicon Graphics corporate campus in Mountain View, California.

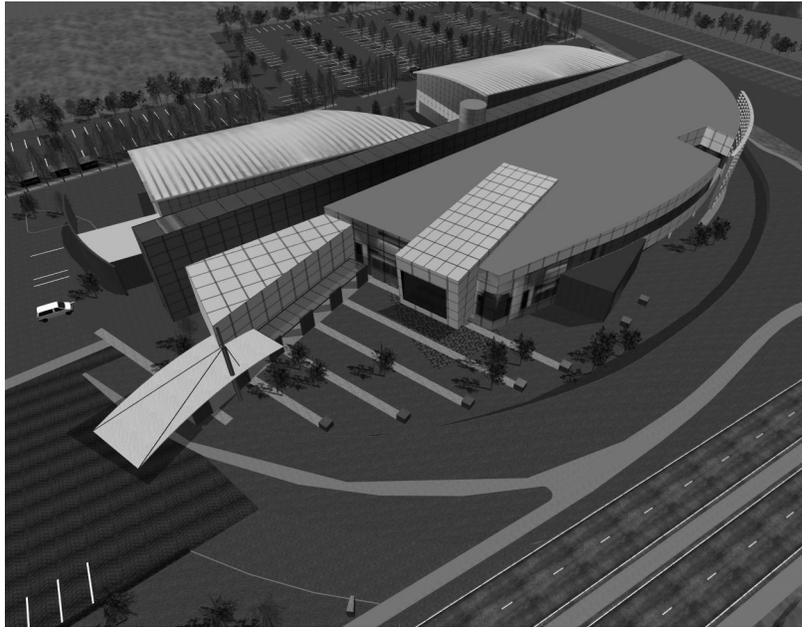


Figure 7-9 Silicon Graphics Office Building as OBJ Database

Files in the OBJ format have a flexible all-ASCII structure, with simple keywords to direct the parsing of the data. This format is best illustrated with a short example that defines a texture-mapped square:

```
#-- 'v' defines a vertex; here are four vertices
v -5.000000  5.000000  0.000000
v -5.000000 -5.000000  0.000000
v  5.000000 -5.000000  0.000000
v  5.000000  5.000000  0.000000

#-- 'vt' defines a vertex texture coordinate; four are given
vt 0.000000 1.000000 0.000000
vt 0.000000 0.000000 0.000000
vt 1.000000 0.000000 0.000000
vt 1.000000 1.000000 0.000000

#-- 'usemtl' means select the material definition defined
#-- by the name MaterialName
usemtl MaterialName

#-- 'usemap' means select the texturing definition defined
#-- by the name TextureName
usemap TextureName

#-- 'f' defines a face. This face has four vertices ordered
#-- counter-clockwise from the upper left in both geometric
#-- and texture coordinates. Each pair of numbers separated
#-- by a slash indicates vertex and texture indices,
#-- respectively, for a polygon vertex.
f 1/1 2/2 3/3 4/4
```

pfLoadFile() uses the function **pfLoadFile_obj()** to load Wavefront OBJ files into IRIS Performer run-time data-structures.

Silicon Graphics PFB Format

Although IRIS Performer has no true, native database format, the PFB format is designed to exactly replicate the IRIS Performer scene graph, which increases loading speed. A file in the PFB format has the following advantages:

- PFB files often load in one tenth (or less) of the time it takes an equivalent file in another format to load.
- PFB files are often half the size of equivalent files in another format.

You can think of the PFB format as being a cache. You can convert your files into PFB for fast and efficient loading or paging, but you should always keep your original files in case you wish to modify them.

Converting to the PFB Format

You can convert files into the PFB format in one of the following ways:

- Use the function, **pfStoreFile_pfb()** in libpfb.
- Use pfconv.

Silicon Graphics PFI Format

The PFI image file format is designed for fast loading of images into pfTextures. **pfLoadTexFile()** can load PFI files as the image of a pfTexture. Since the format of the image in a PFI file matches that of a pfTexture, data is not reformatted at load time. Eliminating the reformatting often cuts the load time of textures to half of the load time of the same image in the IRIS libimage format.

PFI files can contain the mipmaps of the image. This feature saves significant time in the IRIS Performer DRAW process since it does not have to generate the mipmaps.

Creating PFI Files

PFI files are created in the following ways:

- **pfSaveTexFile()** creates a PFI file from a pfTexture.
- The pfImage methods in libpfd create PFI files.
- pfconv converts IRIS libimage files into PFI files.
- pfconv converts all referenced image files into PFI files when the setting **PF_PFB_SAVE_TEXTURE_PFI** mode is **PF_ON**. The command line options to do this with pfconv is **-Mpfb,5**.

Silicon Graphics PHD Format

The PHD format was created to describe the geometric polyhedron definitions derived mathematically by Andrew Hume and by the *Kaleido* program of Zvi Har'El. This format describes only the geometric shape of polyhedra; it provides no specification for color, texture, or appearance attributes such as specularity.

The IRIS Performer sample data directories contain numerous polyhedra in the PHD format. The image in Figure 7-10 shows many of the polyhedron definitions laboriously computed by Andrew Hume.

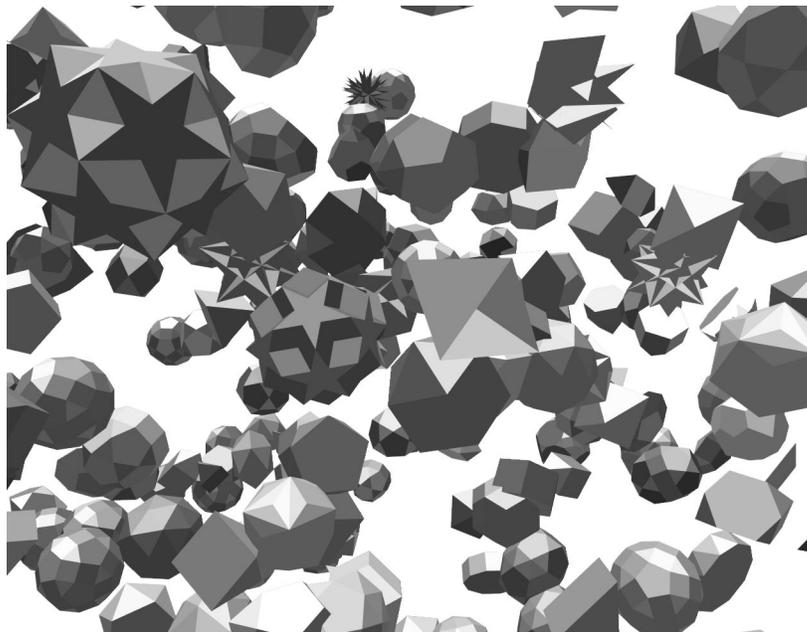


Figure 7-10 Plethora of Polyhedra in PHD Format

The source code for the PHD-format importer is in the file `/usr/share/Performer/src/lib/libpfdlib/libpfpoly/pfphd.c`.

PHD format files have a line-structured ASCII form; an initial keyword defines the contents of each line of data. The file format consists of a filename definition (introduced by the keyword *file*) followed by one or more object definitions.

Object definitions are bracketed by the keywords *object.begin* and *object.end* and contain one or more polygon definitions. Objects can have a name in quotes following the *object.begin* keyword; such a name is used by the loader for the name of the corresponding IRIS Performer node.

Polygon definitions are bracketed by the keywords *polygon.begin* and *polygon.end* and contain three or more vertex definitions.

Vertex definitions are introduced by the *vertex* keyword and define the X, Y, and Z coordinates of a single vertex.

The following is a PHD-format definition of a unit-radius tetrahedron centered at the origin of the coordinate axes. It is derived from the database developed by Andrew Hume but has since been translated, scaled, and reformatted.

```
file 000.phd
object.begin "tetrahedron"
polygon.begin
vertex -0.090722 -0.366647 0.925925
vertex 0.544331 -0.628540 -0.555555
vertex 0.453608 0.890430 0.037037
polygon.end
polygon.begin
vertex -0.907218 0.104757 -0.407407
vertex -0.090722 -0.366647 0.925925
vertex 0.453608 0.890430 0.037037
polygon.end
polygon.begin
vertex -0.090722 -0.366647 0.925925
vertex -0.907218 0.104757 -0.407407
vertex 0.544331 -0.628540 -0.555555
polygon.end
polygon.begin
vertex 0.453608 0.890430 0.037037
vertex 0.544331 -0.628540 -0.555555
vertex -0.907218 0.104757 -0.407407
polygon.end
object.end
```

pfdLoadFile() uses the function **pfdLoadFile_phd()** to load PHD format files into IRIS Performer run-time data-structures.

The **pfdLoadFile_phd()** function composes a color with red, green, and blue components uniformly distributed within the range 0.2 to 0.7 that is consistent for each polygon with the same number of vertices within a single polyhedron.

Silicon Graphics PTU Format

The PTU format is named for the *IRIS Performer Terrain Utilities*, of which the **pfdLoadFile_ptu()** function is the sole example at the present time. This function accepts as input the name of a control file (the file with the “.ptu” filename extension) that defines the desired terrain parameters and references additional data files.

The database shown in Figure 7-11 represents a portion of the Yellowstone National Park. This terrain database was generated completely by the IRIS Performer Terrain Utility data generator from digital terrain elevation data and satellite photographic images. Image manipulation is performed using the Silicon Graphics ImageVision Library™ functions.

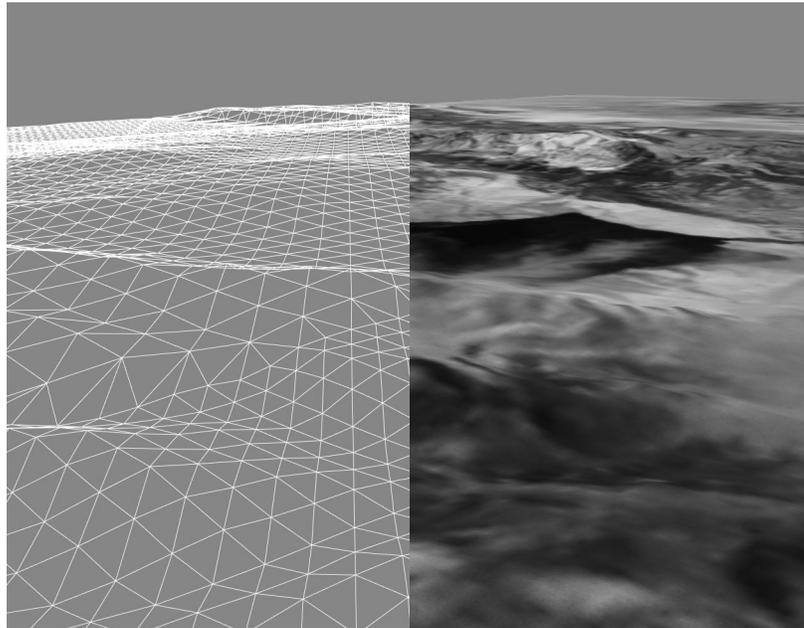


Figure 7-11 Terrain Database Generated by PTU Tools

The PTU control file has a fixed format that doesn't use keywords. The contents of this file are simply ASCII values representing the following data items:

1. The name to be assigned to the top-level pfNode built by **pfLoadFile_ptu()**.
2. The number of desired levels-of-detail (LOD) for the resulting terrain surface. The **pfLoadFile_ptu()** function will construct this many versions of the terrain, each representing the whole surface but with exponentially fewer numbers of polygons in each version.
3. The numbers of highest-LOD tiles that will tessellate the entire terrain surface in the X and Y axis directions.
4. Two numeric values that define the mapping of texture image pixels to world-coordinate terrain geometry. These values are the number of meters per *texel* (texture pixel) of filtered grid post data in the X and Y axis dimensions.
5. The name of an image file that represents terrain height at regularly spaced sample points in the form of a monochrome image whose brightness at each pixel indicates the height at that sample point. Additional arguments are the number of samples in the input image in the X and Y directions, as well as the desired number of samples in these directions. The **pfLoadFile_ptu()** function resamples the grid posts from the original to the desired resolution by filtering the height image using SGI ImageVision Library functions.
6. The name of an image file that represents the terrain texture image at regularly spaced sample points. Subsequent arguments are the number of samples in the image in the X and Y directions as well as the desired number of samples in these directions. This image will be applied to the terrain geometry. The scale values provided in the PTU file allow the terrain grid and texture image to be adjusted to create an orthographic alignment.
7. An optional second texture-image filename that serves as a detail texture when the terrain is viewed on RealityEngine systems. This texture is used in addition to the base texture image.
8. An optional detail-texture spline-table definition. The blending of the primary texture image and the secondary detail texture is controlled by a blend table defined by this spline function. The spline table is optional even when a detail texture is specified. Detail texture and its associated blend functions are applicable only on RealityEngine systems.

The source code for the PTU-format importer is provided in the file `/usr/share/Performer/src/lib/libpfdb/libpfptu/pfptu.c`.

pfdLoadFile() uses the function **pfdLoadFile_ptu()** to load PTU format files into IRIS Performer run-time data-structures.

USNA Standard Graphics Format

The “.sgf” format is used at the United States Naval Academy as a standard graphics format for geometric data. The loader was developed based on the description of the standard graphics format as described by David F. Rogers and J. Alan Adams in the book *Mathematical Elements for Computer Graphics*. The IRIS Performer “.sgf” format loader is located in the directory `/usr/share/Performer/src/lib/libpfdb/libpfsf`.

Here is the vector definition for four stacked squares in SGF form:

```
0, 0, 0
1, 0, 0
1, 1, 0
0, 1, 0
0, 0, 0
1.0e37, 1.0e37, 1.0e37
0, 0, 1
1, 0, 1
1, 1, 1
0, 1, 1
0, 0, 1
1.0e37, 1.0e37, 1.0e37
0, 0, 2
1, 0, 2
1, 1, 2
0, 1, 2
0, 0, 2
1.0e37, 1.0e37, 1.0e37
0, 0, 3
1, 0, 3
1, 1, 3
0, 1, 3
0, 0, 3
1.0e37, 1.0e37, 1.0e37
```

pfdLoadFile() uses the function **pfdLoadFile_sgf()** to load SGF format files into IRIS Performer run-time data-structures.

Silicon Graphics SGO Format

The Silicon Graphics Object format is used by several cool utility programs and was one of the first database formats supported by IRIS Performer. The image in Figure 7-12 shows a model generated by Paul Haerberli and loaded into *perfly* by the `pfdLoadFile_sgo()` database importer.



Figure 7-12 Model in SGO Format

Objects in the SGO format have per-vertex color specification and multiple data formats. Objects contained in SGO files are constructed from three data types:

- lists of quadrilaterals
- lists of triangles
- triangle meshes

Objects of different types can be included as data within one SGO file.

The SGO format has the following structure:

1. A magic number, 0x5424, which identifies the file as an SGO file.
2. A set of data for each object. Each object definition begins with an identifying token, followed by geometric data. There can be multiple object definitions in a single file. An end-of-data token terminates the file.

The layout of an SGO file is

```
<SGO-file magic number>
<data-type token for object #1>
<data for object #1>
<data-type token for object #2>
<data for object #2>
...
<data-type token for object #n>
<data for object #n>
<end-of-data token>
```

Each of the identifying tokens is 4 bytes long. Table 7-8 lists the symbol, value, and meaning for each token.

Table 7-8 Object Tokens in the SGO Format

Symbol	Value	Meaning
OBJ_QUADLIST	1	Independent quadrilaterals
OBJ_TRILIST	2	Independent triangles
OBJ_TRIMESH	3	Triangle mesh
OBJ_END	4	End-of-data token

The next word following any of the three object types is the number of 4-byte words of data for that object. The format of this data varies depending on the object type.

For quadrilateral list (OBJ_QUADLIST) and triangle list (OBJ_TRILIST) objects, there are nine words of floating-point data for each vertex, as follows:

1. Three words that specify the components of the normal vector at the vertex.
2. Three words that specify the red, green, and blue color components, scaled to the range 0.0 to 1.0.
3. Three words that specify the X, Y, and Z coordinates of the vertex itself.

In quadrilateral lists, vertices are in groups of four, so there are $4 \times 9 = 36$ words of data for each quadrilateral. In triangle lists, vertices are in groups of three, for $3 \times 9 = 27$ words per triangle.]

The triangle mesh, OBJ_TRIMESH, is the most complicated of the three object data types. Triangle mesh data consists of a set of vertices followed by a set of mesh-control commands. Triangle mesh data has the following format:

1. A long word that contains the number of words in the complete triangle mesh data packet.
2. A long word that contains the number of floating-point words required by the vertex data, at nine words per vertex.
3. The data for each vertex, consisting of nine floating-point words representing normal, color, and coordinate data.
4. A list of triangle mesh controls.

The triangle mesh controls, each of which is one word in length, are listed in Table 7-9.

Table 7-9 Mesh Control Tokens in the SGO Format

Symbol	Value	Meaning
OP_BGNTMESH	1	Begin a triangle strip.
OP_SWAPTMESH	2	Exchange old vertices.
OP_ENDBGNTMESH	3	End, then begin a strip.
OP_ENDTMESH	4	Terminate triangle mesh.

The triangle-mesh controls are interpreted sequentially. The first control must always be OP_BGNTMESH, which initiates the mesh-decoding logic. After each mesh control is a word (of type long integer) that indicates how many vertex indices follow. The vertex

indices are in byte offsets, so to access vertex n , you must use the byte offset $n \times 9 \times 4$. See the graphics library reference books listed under “Bibliography” on page xxxvi for more information on triangle meshes (particularly see the IRIS GL books, if you’re using IRIS GL, for information on the swap-triangle-mesh concept).

pfdLoadFile() uses the function **pfdLoadFile_sgo()** to load SGO format files into IRIS Performer run-time data-structures.

You can find the source code for the SGO-format importer in the file *pfsgo.c*. This importer doesn’t attempt to decode any triangle meshes present in input files; instead, it terminates the file conversion process as soon as an OBJ_TRIMESH data-type token is encountered. If you use SGO-format files containing triangle meshes you’ll need to extend the conversion support to include the triangle mesh data type.

USNA Simple Polygon File Format

The “.spf” format is used at the United States Naval Academy as a simple polygon file format for geometric data. The loader was developed based on the description in the book *Mathematical Elements for Computer Graphics*. The IRIS Performer “.spf” loader is in the `/usr/share/Performer/src/lib/libpfdlibpfs` directory.

The following “.spf” format file is defined in that book.

```
polygon with a hole
14,2
4,4
4,26
20,26
28,18
28,4
21,4
21,8
10,8
10,4
10,12
10,20
17,20
21,16
21,12
9,1,2,3,4,5,6,7,8,9
5,10,11,12,13,14
```

If you look at this file in Perfly you will see that the hole is not cut out of the letter “A” as might be desired. Such computational geometry computations are not considered the province of simple database loaders.

pfdLoadFile() uses the function **pfdLoadFile_spf()** to load SPF format files into IRIS Performer run-time data-structures.

Sierpinski Sponge Loader

The Sierpinski Sponge (a.k.a. Menger Sponge) loader is not based on a data format but rather is a procedural data generator. The loader interprets the portion of the user provided “file name” before the period and extension as an integer which specifies the number of recursive subdivisions desired in data generation. For example, providing the pseudo filename “3.sponge” to perfly will result in the Sponge loader being invoked and generating a sponge object using three levels of recursion, resulting in a 35712 polygon database object. The IRIS Performer “.sponge” loader can be found in the */usr/share/Performer/src/lib/libpfdb/libpfsponge* directory.

pfdLoadFile() uses the function **pfdLoadFile_sponge()** to load Sponge format files into IRIS Performer run-time data-structures.

Star Chart Format

The “.star” format is a distillation of astronomical data from the Yale Compact Star Chart. The sample data file */usr/share/Performer/data/3010.star* contains data from the YCSC that has been reduced to a list of the 3010 brightest stars as seen from Earth and positioned as 3010 points of light on a unit-radius sphere. The IRIS Performer “.star” loader can read this data and is provided as a convenience for making dusk, dawn, and night-time scenes. The loader is in the */usr/share/Performer/src/lib/libpfdb/libpfstar* directory.

Data in a “.star” file is simply a series of ASCII lines with the “s” (for star) keyword followed by X, Y, and Z coordinates, brightness, and an optional name. Here are the 10 brightest stars (excluding Sol) in the “.star” format:

```
s -0.18746032  0.93921369 -0.28763914  1.00  Sirius
s -0.06323564  0.60291260 -0.79529721  1.00  Canopus
s -0.78377002 -0.52700269  0.32859191  1.00  Arcturus
s  0.18718566  0.73014212  0.65715599  1.00  Capella
s  0.12507832 -0.76942003  0.62637711  0.99  Vega
s  0.13051330  0.68228769  0.71933979  0.99  Capella
```

```
s 0.19507207 0.97036278 -0.14262892 0.98 Rigel
s -0.37387931 -0.31261155 -0.87320572 0.94 Rigil Kentaurus
s -0.41809806 0.90381104 0.09121194 0.94 Procyon
s 0.49255905 0.22369388 -0.84103900 0.92 Achernar
```

pfdLoadFile() uses the function **pfdLoadFile_star()** to load Star format files into IRIS Performer run-time data-structures.

3D Lithography STL Format

The STL format is used to define 3D solids to be imaged by 3D lithography systems. STL defines objects as collections of triangular facets, each with an associated face normal. The ASCII version of this format is known as STLA and has a very simple structure.

The image in Figure 7-13 shows a typical STLA mechanical CAD database. This model is defined in the *bendix.stla* sample data file.

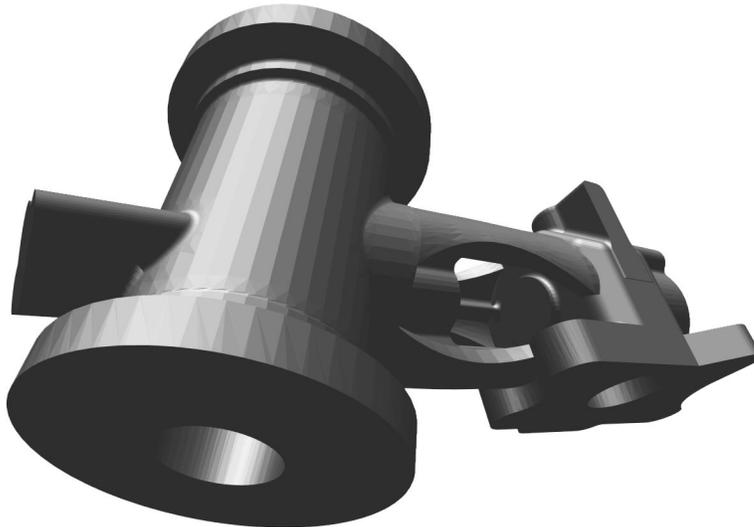


Figure 7-13 Sample STLA Database

The source code for the STLA-format loader is in the files */usr/share/Performer/src/lib/libpfdlib/libpfstla/pfstla.c*.

STLA-format files have a line-structured ASCII form; an initial keyword defines the contents of each line of data. An STLA file consists of one or more facet definitions, each of which contains

1. the facet normal, indicated with the *facet normal* keyword
2. the facet vertices, bracketed by *outer loop* and *endloop* keywords
3. the *endloop* keyword

Here is an excerpt from *nut.stla*, one of the STLA files provided in the IRIS Performer sample data directories. These are the first two polygons of a 524-triangle hex-nut object:

```
facet normal 0 -1 0
  outer loop
    vertex 0.180666 -7.62 2.70757
    vertex -4.78652 -7.62 1.76185
    vertex -4.436 -7.62 0
  endloop
endfacet
facet normal -0.381579 -0.921214 -0.075915
  outer loop
    vertex -4.48833 -7.59833 0
    vertex -4.436 -7.62 0
    vertex -4.78652 -7.62 1.76185
  endloop
endfacet
```

Use this function to import data from STLA-format files into IRIS Performer run-time data structures:

```
pfNode *pfdLoadFile_stla(char *fileName);
```

pfdLoadFile_stla() searches the current IRIS Performer file path for the file named by the *fileName* argument and returns a pointer to the pfNode that parents the imported scene graph, or NULL if the file isn't readable or doesn't contain recognizable STLA format data.

SuperViewer SV Format

The SuperViewer (SV) format is one of the several database formats that the I3DM database modeling tool can read and write. The I3DM modeler was developed by John Kichury of Silicon Graphics and is provided with IRIS Performer. The source code for the SV format importer is in the file *pfsv.c*.

The passenger vehicle database shown in Figure 7-14 was modeled using I3DM and is stored in the SV database format.



Figure 7-14 Early Automobile in SuperViewer SV Format

Within SV files, object geometry and attributes are described between text lines that contain the keywords *model* and *endmodel*. For example:

```
model wing
  geometry and attributes
endmodel
```

Any number of models can appear within a SuperViewer file. The geometry and attribute data mentioned above each consist of one of the following types:

- 3D Polygon with vertex normals and optional texture coordinates

```
poly3dn <num_vertices> [textured]
x1 y1 z1 nx1 ny1 nz1 [s1 t1]
x2 y2 z2 nx2 ny2 nz2 [s2 t2]
...
```

Where

- $X_n Y_n Z_n$ are the n th vertex coordinates
- $N_{xn} N_{yn} N_{zn}$ are the n th vertex normals
- $S_n T_n$ are the n th texture coordinates

- 3D Triangle mesh with vertex normals and optional texture coordinates

```
tmeshn <num_vertices> [textured]
x1 y1 z1 nx1 ny1 nz1 [s1 t1]
x2 y2 z2 nx2 ny2 nz2 [s2 t2]
...
```

Where

- $X_n Y_n Z_n$ are the n th vertex coordinates
- $N_{xn} N_{yn} N_{zn}$ are the n th vertex normals
- $S_n T_n$ are the n th texture coordinates

- Material definition. If the material directive exists before a model definition, it is taken as a new material specification. Its format is:

```
material n Ar Ag Ab Dr Dg Db Sr Sg Sb Shine Er Eg Eb
```

Where

- n is an integer specifying a material number
- $Ar Ag Ab$ is the ambient color
- $Dr Dg Db$ is the diffuse color
- $Sr Sg Sb$ is the specular color
- $Shine$ is the material shininess
- $Er Eg Eb$ is the emissive color

If the material directive exists within a model description, the format is:

```
material n
```

Where *n* is an integer specifying which material (as defined by the material description above) is to be assigned to subsequent data.

- Texture definition. If the texture directive exists before a model definition it is taken as a new texture specification. Its format is:

```
texture n TextureFileName
```

If the texture directive exists within a model description, the format is:

```
texture n
```

Where *n* is an integer specifying which texture (as defined by the texture description above) is to be assigned to subsequent data.

- Backface polygon display mode. The backface directive is specified within model definitions to control backface polygon culling:

```
backface mode
```

Where a *mode* of “on” allows the display of backfacing polygons and a *mode* of “off” suppresses their display.

In actual use the SV format is somewhat self-documenting. Here is part of the SV file *apple.sv* from the */usr/share/Performer/data* directory:

```
material 20 0.0 0.0 0 0.400000 0.000000 0 0.333333 0.000000 0.0 10.0000 0 0 0
material 42 0.2 0.2 0 0.666667 0.666667 0 0.800000 0.800000 0.8 94.1606 0 0 0
material 44 0.0 0.2 0 0.000000 0.200000 0 0.000000 0.266667 0.0 5.0000 0 0 0

texture 4 prchmnt.rgb
texture 6 wood.rgb

model LEAF
material 44
texture 4
backface on
poly3dn 4 textured
  1.35265 1.35761 13.8338 0.0686595 -0.234553 -0.969676 0 1
  0.88243 0.96366 14.0329 0.0502096 -0.376701 -0.924973 0 0.75
-4.44467 1.24026 13.5669 0.0363863 -0.337291 -0.940697 0.0909091 0.75
-2.37938 2.17479 13.3626 0.0363863 -0.337291 -0.940697 0.0909091 1
```

```
poly3dn 4 textured
-2.37938 2.17479 13.3626 0.0363863 -0.337291 -0.940697 0.0909091 1
-4.44467 1.24026 13.5669 0.0363863 -0.337291 -0.940697 0.0909091 0.75
-9.23775 2.34664 13.1475 0.0344832 -0.284369 -0.958095 0.181818 0.75
-6.69592 3.94535 12.6716 0.0344832 -0.284369 -0.958095 0.181818 1
```

This excerpt specifies material properties and references texture images stored in the files *prchmnt.rgb* and *wood.rgb*, and then defines two polygons.

pdfLoadFile() uses the function **pdfLoadFile_sv()** to load SuperViewer files into IRIS Performer run-time data-structures.

Geometry Center Triangle Format

The “.tri” format is used at the University of Minnesota’s Geometry Center as a simple geometric data representation. The loader was developed by inspection of a few sample files. The IRIS Performer “.tri” loader is in the */usr/share/Performer/src/lib/libpfdb/libpftri* directory.

These files have a very simple format: a line per vertex with position and normal given on each line as 6 ASCII numeric values. The file is simply a series of these triangle definitions. Here are the first two triangles from the data file */usr/share/Performer/data/mobrect.tri*:

```
1.788180 1.000870 0.135214 0.076169 -0.085488 0.993423
1.574000 0.925908 0.146652 0.089015 -0.086072 0.992304
1.793360 0.634711 0.099409 0.076402 -0.111845 0.990784
0.836848 -0.595230 0.197960 0.156677 0.044503 0.986647
0.709638 -0.345676 0.210010 0.157642 0.021968 0.987252
0.581200 -0.535321 0.234807 0.145068 0.030985 0.988936
```

pdfLoadFile() uses the function **pdfLoadFile_tri()** to load “.tri” format files into IRIS Performer run-time data-structures.

UNC Walkthrough Format

The “.unc” format was once used at the *University of North Carolina* as a format for geometric data in an architectural walkthrough application. The loader was developed based on inspection of a few sample files. The IRIS Performer “.unc” loader is in the */usr/share/Performer/src/lib/libpfdb/libpfunc* directory.

pdfLoadFile() uses the function **pdfLoadFile_unc()** to load UNC format files into IRIS Performer run-time data-structures.

WRL Format

The VRML 2.0 format for IRIS Performer, wrl, is made by DRaW Computing Associates[®]. It accepts geometry and texture only. Basic geometry nodes like Sphere, Cone, Cylinder, Box and related nodes like Shape, Material, Appearance, TextureTransform, ImageTexture, and ElevationGrid are supported. Also, complex geometries can be obtained using the IndexedFaceSet node. You can do geometric manipulations to nodes using Group nodes and Transform nodes. You can also make very complex structures using PROTOs, where you group many geometry nodes.

Database Operators with Pseudo Loaders

The IRIS Performer dynamic database loading mechanism provides additional DSOs that operate on the resulting scene graph from a file or set of files after the file(s) are loaded. This mechanism, called “pseudo loaders,” enables the desired-operator DSO to be specified as additional suffixes to the file name. The DSO matching the last suffix is loaded first and provided the entire filename. That pseudo loader then can parse the arbitrary filename and invoke the next operator or loader and then operate on the results. This process allows additional arguments to be buried in the specified filename for the pseudo loader to detect and parse.

One set of pseudo loaders included with IRIS Performer are the rot, trans, and scale loaders. These loaders take hpr and xyz arguments in addition to their Filename and can be invoked from any program using **pdfLoadFile()**, for example:

```
% perfly cow.obj.-90,90,0.rot
```

-90, 90, and 0 are the *h*, *p*, and *r* values, respectively.

If you are using a shell with argument expansion, such as **csH**, you can create interesting cow art. Try out the following example:

```
% perfly cow.obj.{0,1},0,0.trans cow.obj.{0,1,2,3,4},0,-5.trans
```

Specifying a base filename is only needed if the specified pseudo loader expects a file to operate on. Loaders can generate their scene graphics procedurally based on simple parameters specified in the command string.

The pseudo loaders in the IRIS Performer distribution are described in Table 7-10.

Table 7-10 IRIS Performer Pseudo Loaders

Pseudo Loaders	Description
libpfrot	Add pfSCS at root to rotate scene graph by specified <h>,<p>,<r>
libpftrans	Add pfSCS at root to translate scene graph by specified <x>,<y>,<z>
libpfscale	Add pfSCS at root to scale scene graph by specified <x>,<y>,<z>
libpfclosest	Adds run-time app callback to highlight closest point each frame
libpfcliptile	Adds callback to compute for the specified <tilename>,<minS>,<minT>,<maxS>,<maxT> the proper virtual cliptexture viewing parameters.
libpfsphere	Generates a sphere database with morphing LOD starting from an n-gon for specified <n>, power of 2.
libpfvct	Convert normal cliptexture .ct file to virtual cliptexture

Pseudo loaders should define **pfLoadNeededDSOs_EXT()** for:

- Pre-initializing DSOs.
- Loading other, special files.
- Performing additional initialization, such as class initialization, that should happen before **pfConfig()**.

Chapter 8

“Geometry”

This chapter discusses the classes used to create the shapes in Performer scenes.

Geometry

All *libpr* geometry is defined by modular units that employ a flexible specification method. These basic groups of geometric primitives are termed pfGeoSets.

Geometry Sets

A pfGeoSet is a collection of geometry that shares certain characteristics. All items in a pfGeoSet must be of the same primitive type (whether they're points, lines, or triangles) and share the same set of attribute bindings (you can't specify colors-per-vertex for some items and colors-per-primitive for others in the same pfGeoSet). A pfGeoSet forms primitives out of lists of attributes that may be either indexed or nonindexed. An indexed pfGeoSet uses a list of unsigned short integers to index an attribute list. (See "Attributes" on page 246 for information about attributes and bindings.)

Indexing provides a more general mechanism for specifying geometry than hard-wired attribute lists and also has the potential for substantial memory savings as a result of shared attributes. Nonindexed pfGeoSets are sometimes easier to construct, usually a bit faster to render, and may save memory (since no extra space is needed for index lists) in situations where vertex sharing isn't possible. A pfGeoSet must be either completely indexed or completely nonindexed; it's not legal to have some attributes indexed and others nonindexed.

Note: *libpf* applications can include pfGeoSets in the scene graph with the pfGeode (Geometry Node).

Table 8-1 lists a subset of the routines that manipulate pfGeoSets.

Table 8-1 pfGeoSet Routines

Function	Description
pfNewGSet	Create a new pfGeoSet.
pfDelete	Delete a pfGeoSet.
pfCopy	Copy a pfGeoSet.
pfGSetGState	Specify the pfGeoState to be used.
pfGSetGStateIndex	Specify the pfGeoState index to be used.
pfGSetNumPrims	Specify the number of primitive items.
pfGSetPrimType	Specify the type of primitive.
pfGSetPrimLengths	Set the lengths array for strip primitives.
pfGetGSetPrimLength	Get the length for the specified strip primitive.
pfGSetAttr	Set the attribute bindings.
pfGSetDrawMode	Specify draw mode, e.g., flat shading or wireframe.
pfGSetLineWidth	Set the line width for line primitives.
pfGSetPntSize	Set the point size for point primitives.
pfGSetHlight	Specify highlighting type for drawing.
pfDrawGSet	Draw a pfGeoSet.
pfGSetBBox	Specify a bounding box for the geometry.
pfGSetIsectMask	Specify an intersection mask for pfGSetIsectSegs .
pfGSetIsectSegs	Intersect line segments with pfGeoSet geometry.
pfQueryGSet	Determine the number of triangles or vertices.
pfPrint	Print the pfGeoSet contents.

Primitive Types

All primitives within a given `pfGeoSet` must be of the same type. To set the type of all primitives in a `pfGeoSet` named *gset*, call `pfGSetPrimType(gset, type)`. Table 8-2 lists the primitive type tokens, the primitive types that they represent, and the number of vertices in a coordinate list for that type of primitive.

Table 8-2 Geometry Primitives

Token	Primitive Type	Number of Vertices
PFGS_POINTS	Points	<i>numPrims</i>
PFGS_LINES	Independent line segments	$2 * \textit{numPrims}$
PFGS_LINESTRIPS	Strips of connected lines	Sum of <i>lengths</i> array
PFGS_FLAT_LINESTRIPS	Strips of flat-shaded lines	Sum of <i>lengths</i> array
PFGS_TRIS	Independent triangles	$3 * \textit{numPrims}$
PFGS_TRISTRIPS	Strips of connected triangles	Sum of <i>lengths</i> array
PFGS_FLAT_TRISTRIPS	Strips of flat-shaded triangles	Sum of <i>lengths</i> array
PFGS_TRIFANS	Fan of connected triangles	Sum of <i>lengths</i> array
PFGS_FLAT_TRIFANS	Fan of flat-shaded triangles	Sum of <i>lengths</i> array
PFGS_QUADS	Independent quadrilaterals	$4 * \textit{numPrims}$
PFGS_POLYS	Independent polygons	Sum of <i>lengths</i> array

where the parameters in the last column represent:

numPrims is the number of primitive items in the `pfGeoSet`, as set by `pfGSetNumPrims()`.

lengths is the array of strip lengths in the `pfGeoSet`, as set by `pfGSetPrimLengths()` (note that length is measured here in terms of number of vertices).

Connected primitive types (line strips, triangle strips, and polygons) require a separate array that specifies the number of vertices in each primitive. Length is defined as the number of vertices in a strip for STRIP primitives and is the number of vertices in a polygon for the POLYS primitive type. The number of line segments in a line strip is $numVerts - 1$, while the number of triangles in a triangle strip and polygon is $numVerts - 2$. Use **pfGSetPrimLengths()** to set the length array for strip primitives.

The number of primitives in a pfGeoSet is specified by **pfGSetNumPrims(gset, num)**. For strip and polygon primitives, *num* is the number of strips or polygons in *gset*.

pfGeoSet Draw Mode

In addition to the primitive type, **pfGSetDrawMode()** further defines how a primitive is drawn. Triangles, triangle strips, quadrilaterals and polygons can be specified as either filled or as wireframe, where only the outline of the primitive is drawn. Use the PFGS_WIREFRAME argument to enable/disable wireframe mode. Another argument, PFGS_FLATSHADE, specifies that primitives should be shaded. If flat shading is enabled, each primitive or element in a strip is shaded with a single color.

PFGS_COMPILE_GL

At the next draw for each pfState, compile *gset*'s geometry into a GL *display list* and subsequently render the display list.

PFGS_DRAW_GLOBJ

Select the rendering of an already created display list but do not force a re-compile.

PFGS_PACKED_ATTRS

Use the *gset*'s packed attribute arrays, set with the PFGS_PACKED_ATTRS to pfGSetAttr, to render geometry with GL vertex arrays. This mode is only available under OpenGL operation.

pfGeoSets are normally processed in immediate mode which means that **pfDrawGSet()** sends attributes from the user-supplied attribute arrays to the Graphics Pipeline for rendering. However, this kind of processing is subject to some overhead, particularly if the pfGeoSet contains few primitives. In some cases it may help to use GL display lists (this is different from the *libpr* display list type pfDispList) or *compiled mode*. In compiled mode, pfGeoSet attributes are copied from the attribute lists into a special data structure called a display list during a compilation stage. This data structure is highly optimized for efficient transfer to the graphics hardware. However, compiled mode has some major disadvantages:

- compilation is usually costly
- a GL display list must be recompiled whenever its pfGeoSet's attributes change
- the GL display list uses a significant amount extra host memory

In general, immediate-mode will offer excellent performance with minimal memory usage and no restrictions on attribute volatility which is a key aspect in many advanced applications. Despite this, experimentation may show databases or machines where compiled mode offers a performance benefit.

To enable or disable compiled mode, call **pfGSetDrawMode()** with the **PFGS_COMPILE_GL** token. When enabled, compilation is delayed until the next time the pfGeoSet is drawn with **pfDrawGSet()**. Subsequent calls to **pfDrawGSet()** will then send the compiled pfGeoSet to the graphics hardware.

To select a display list to render, without recompiling it, use **pfGSetDrawMode(PFGS_DRAW_GLOBJ)**.

Packed Attributes

Packed attributes is an optimized way of sending formatted data to the graphics pipeline under OpenGL that does not incur the same memory overhead or re-compilation burden as GL display lists. To render geometry with packed attributes, use the **pfGSetDrawMode(PFGS_PACKED_ATTRS)** method when using OpenGL. This pfGSetAttr list includes the currently bound PER_VERTEX vertex attribute data packed into a single non-indexed array. When specifying a packed attribute array, the optional vertex attributes, colors, normals, and texture coordinates, can be NULL. This array, like the other attribute arrays, is then shared between Performer, the GL, and accessible by the user. Optionally, you can put your vertex coordinates in this packed array but in this case the vertices must be duplicated in the normal coordinate array because vertex coordinate data is used internally for other non-drawing operations such as intersections and computation of bounding geometry. Packed attribute arrays also allow IRIS Performer to extend the vertex attribute types accepted by pfGeoSets. There are several base formats that expect all currently bound attributes of specified data type (unsigned byte, short, or float) to be in the attribute array. Attributes specified by the format but not bound to vertices are assumed to not be present and the present data packed with the data for each vertex starting on a 32bit word-aligned boundary. Then, there are several derived formats that let you put some attribute data in the packed array while leaving the rest in the normal individual coordinate attribute arrays. Table 8-3 shows the different base formats supported.

Table 8-3 pfGeoSet PACKED_ATTR Formats

Format	Description
PFGS_PA_C4UBN3ST2FV3F	Accepts all currently bound coordinate attributes, colors are unsigned bytes normals are shorts. Vertices are duplicated in the packed attribute array.
PFGS_PA_C4UBN3ST2F	Vertices are in the normal coordinate array.
PFGS_PA_C4UBT2F	Normals and vertices are in the normal coordinate array.
PFGS_PA_C4UBN3ST2SV3F	All bound coordinate attributes are in the packed attribute array. Colors are unsigned bytes, normals are shorts, and texture coordinates are unsigned shorts.
PFGS_PA_C4UBN3ST3FV3F	Texture coordinates are 3D floats.
PFGS_PA_C4UBN3ST3SV3F	Texture coordinates are 2D shorts.

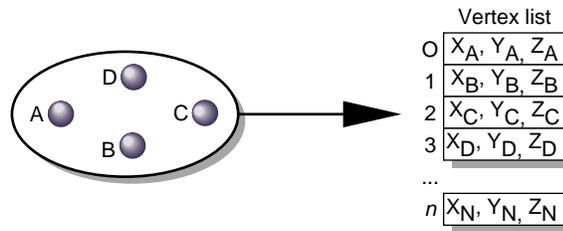
To create packed attributes, you can use the utility **pfuTravCreatePackedAttrs()**, which traverses a scene graph to create packed attributes for pfGeoSets and, optionally, pfDelete redundant attribute arrays. This utility packs the pfGeoSet attributes using **pfuFillGSetPackedAttrs()**. Examples of packed attribute usage can be seen in */usr/share/Performer/src/pguide/libpr/C/packedattrs.c* and in */usr/share/Performer/src/sample/C/perfly.c* and */usr/share/Performer/src/sample/C++/perfly.C*.

Primitive Connectivity

A pfGeoSet requires a coordinate array that specifies the world coordinate positions of primitive vertices. This array is either indexed or not, depending on whether a coordinate index list is supplied. If the index list is supplied, it's used to index the coordinate array; if not, the coordinate array is interpreted in a sequential order.

A pfGeoSet's primitive type dictates the connectivity from vertex to vertex to define geometry. Figure 8-1 shows a coordinate array consisting of four coordinates, A, B, C, and D, and the geometry resulting from different primitive types. This example uses index lists that index the coordinate array.

Note: Flat-shaded line strip and flat-shaded triangle strip primitives have the vertices listed in the same order as for the smooth-shaded varieties.



Primitive type	Points	Line segments		Line strips																					
Geometry																									
Index list	<table border="1" style="margin: auto;"> <tr><td>0</td></tr> <tr><td>1</td></tr> <tr><td>2</td></tr> <tr><td>3</td></tr> </table>	0	1	2	3	<table border="1" style="margin: auto;"> <tr><td>0</td></tr> <tr><td>3</td></tr> <tr><td>1</td></tr> <tr><td>2</td></tr> </table>	0	3	1	2	<table border="1" style="margin: auto;"> <tr><td>0</td></tr> <tr><td>1</td></tr> <tr><td>3</td></tr> <tr><td>2</td></tr> </table>	0	1	3	2	<table border="1" style="margin: auto;"> <tr><td>2</td></tr> <tr><td>3</td></tr> <tr><td>0</td></tr> <tr><td>1</td></tr> </table>	2	3	0	1	<table border="1" style="margin: auto;"> <tr><td>3</td></tr> <tr><td>2</td></tr> <tr><td>1</td></tr> <tr><td>0</td></tr> </table>	3	2	1	0
0																									
1																									
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Primitive type	Independent triangles	Quadrilaterals	Triangle strips	Polygons																						
Geometry																										
Index list	<table border="1" style="margin: auto;"> <tr><td>0</td></tr> <tr><td>1</td></tr> <tr><td>3</td></tr> <tr><td>3</td></tr> <tr><td>1</td></tr> <tr><td>2</td></tr> </table>	0	1	3	3	1	2	<table border="1" style="margin: auto;"> <tr><td>0</td></tr> <tr><td>1</td></tr> <tr><td>2</td></tr> <tr><td>3</td></tr> </table>	0	1	2	3	<table border="1" style="margin: auto;"> <tr><td>0</td></tr> <tr><td>1</td></tr> <tr><td>3</td></tr> <tr><td>2</td></tr> <tr><td>...</td></tr> <tr><td>n</td></tr> </table>	0	1	3	2	...	n	<table border="1" style="margin: auto;"> <tr><td>0</td></tr> <tr><td>1</td></tr> <tr><td>2</td></tr> <tr><td>3</td></tr> <tr><td>...</td></tr> <tr><td>n</td></tr> </table>	0	1	2	3	...	n
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Figure 8-1 Primitives and Connectivity

Attributes

The definition of a primitive isn't complete without attributes. In addition to a primitive type and count, a `pfGeoSet` references four attribute arrays (see Figure 8-2):

- colors (red, green, blue, alpha)
- normals (N_x , N_y , N_z)
- texture coordinates (S, T)
- vertex coordinates (X, Y, Z)

(A `pfGeoState` is also associated with each `pfGeoSet`; see Chapter 9, "Graphics State" for details.) The four components listed above can be specified with `pfGSetAttr()` and in two ways: by indexed specification—using a pointer to an array of components and a pointer to an array of indices; or by direct specification—providing a NULL pointer for the indices, which indicates that the indices are sequential from the initial value of zero. The choice of indexed or direct components applies to an entire `pfGeoSet`; that is, all of the supplied components within one `pfGeoSet` must use the same method. However, you can emulate partially indexed `pfGeoSets` by using indexed specification and making each nonindexed attribute's index list be a single shared "identity mapping" index array whose elements are 0, 1, 2, 3, ..., N-1 where N is the largest number of attributes in any referencing `pfGeoSet`. (You can share the same array for all such emulated `pfGeoSets`.) The direct method avoids one level of indirection and may have a performance advantage compared with indexed specification for some combinations of CPU and graphics subsystem.

Note: it is highly recommended that `pfMalloc()` be used to allocate your arrays of attribute data. This will allow IRIS Performer to reference-count the arrays and delete them when appropriate. It will also allow you to easily put your attribute data into shared memory for multiprocessing by specifying an arena such as `pfGetSharedArena()` to `pfMalloc()`. While perhaps convenient, it is very dangerous to specify pointers to static data for `pfGeoSet` attributes. Early versions of IRIS Performer permitted this but it is strongly discouraged and may have undefined and unfortunate consequences.

Attribute arrays can be created through `pfFlux` to support the multiprocessed generation of the vertex data for a dynamic object, such as ocean waves, or morphing geometry. `pfFlux` will automatically keep separate copies of data for separate processes so that one process can generate data while another draws it. The `pfFluxed` buffer can be handed directly to `pfGSetAttr()`. In fact, the entire `pfGeoSet` can be contained in a `pfFlux`. Index lists cannot be `pfFluxed`. See Chapter 14, "Dynamic Data," for more information on `pfFlux`.

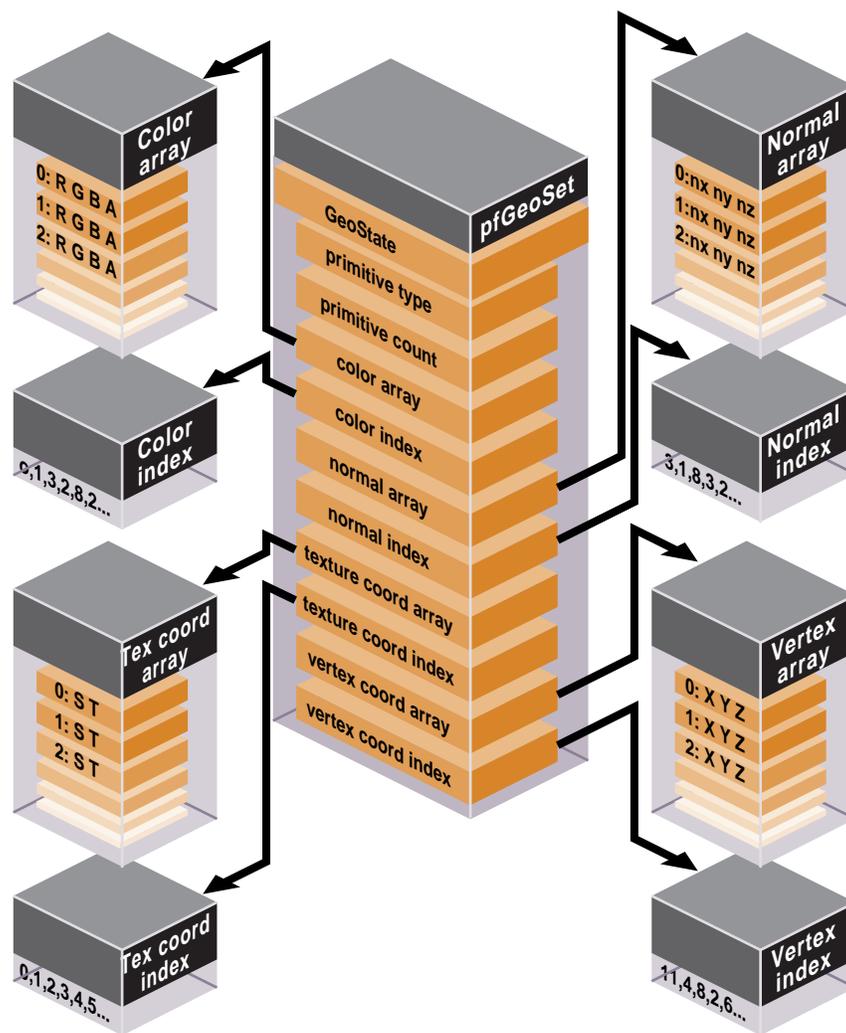


Figure 8-2 pfGeoSet Structure

Attribute Bindings

Attribute bindings specify where in the definition of a primitive an attribute has effect. You can leave a given attribute unspecified; otherwise, its binding location is one of the following:

- overall (one value for the entire pfGeoSet)
- per primitive
- per vertex

Only certain binding types are supported for some attribute types.

Table 8-4 shows the attribute bindings that are legal for each type of attribute.

Table 8-4 Attribute Bindings

Binding Token	Color	Normal	Texture Coordinate	Coordinate
PFGS_OVERALL	Yes	Yes	No	No
PFGS_PER_PRIM	Yes	Yes	No	No
PFGS_PER_VERTEX	Yes	Yes	Yes	Yes
PFGS_OFF	Yes	Yes	Yes	No

Attribute lists, index lists, and binding types are all set by **pfGSetAttr()**.

For FLAT primitives (PFGS_FLAT_TRISTRIPS, PFGS_FLAT_TRIFANS, PFGS_FLAT_LINESTRIPS), the PFGS_PER_VERTEX binding for normals and colors has slightly different meaning. In these cases, per-vertex colors and normals should not be specified for the first vertex in each line strip or for the first two vertices in each triangle strip since FLAT primitives use the last vertex of each line segment or triangle to compute shading.

Indexed Arrays

A cube has six sides; together those sides have 24 vertices. In a vertex array, you could specify the primitives in the cube using 24 vertices. However, most of those vertices overlap. If more than one primitive can refer to the same vertex, the number of vertices can be streamlined to 8. The way to get more than one primitive to refer to the same vertex is to use an index; three vertices of three primitives use the same index which points to the same vertex information. Adding the index array adds an extra step in the determination of the attribute, as shown in Figure 8-3.

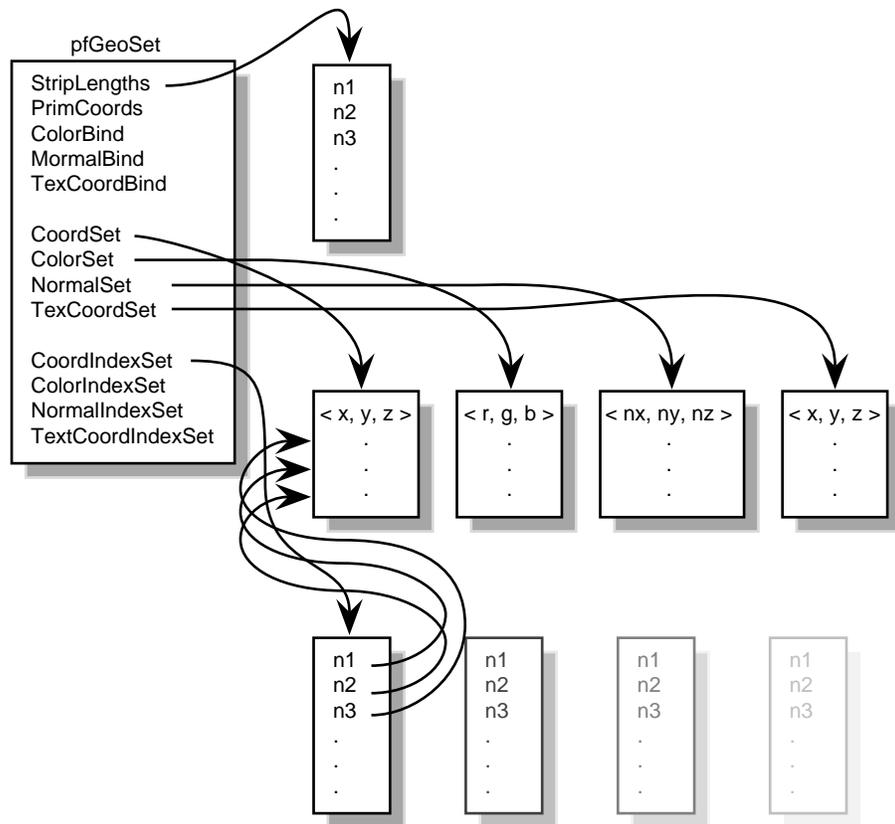


Figure 8-3 Indexing Arrays

Indexing can save system memory, but rendering performance is often lost.

When to Index Attributes

The choice of using indexed or sequential attributes applies to all of the primitives in a **pfGeoSet**; that is, all of the primitives within one **pfGeoSet** must be referenced sequentially or by index; you cannot mix the two.

The governing principle for indexing attributes or not is how many vertices in a geometry are shared. Consider the following two examples in Figure 8-4 where each dot marks a vertex.

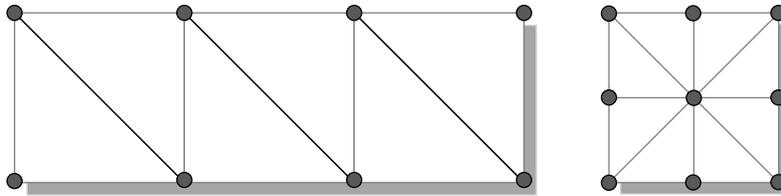


Figure 8-4 Deciding Whether to Index Attributes

In the triangle strip, each vertex is shared by two adjoining triangles. In the square, the same vertex is shared by eight triangles. Consider the task that is required to move these vertices when, for example, morphing the object. If the vertices were not indexed, in the square, the application would have to look up and alter eight triangles to change one vertex.

In the case of the square, it is much more efficient to index the attributes. On the other hand, if the attributes in the triangle strip were indexed, since each vertex is shared by only two triangles, the index look-up time would exceed the time it would take to simply update the vertices sequentially. In the case of the triangle strip, rendering is improved by handling the attributes sequentially.

The deciding factor governing whether or not to index attributes relates to the number of primitives that share the same attribute: if attributes are shared by many primitives, the attributes should be indexed; if attributes are not shared by many primitives, the attributes should be handled sequentially.

pfGeoSet Operations

There are many operations you can perform on pfGeoSets. **pfDrawGSet()** “draws” the indicated pfGeoSet by sending commands and data to the Geometry Pipeline, unless IRIS Performer’s display-list mode is in effect. In display-list mode, rather than sending the data to the pipeline, the current pfDispList “captures” the **pfDrawGSet()** command. The given pfGeoSet is then drawn along with the rest of the pfDispList with the **pfDrawDList()** command.

When the PFGS_COMPILE_GL mode of a pfGeoSet is not active (**pfGSetDrawMode()**), **pfDrawGSet()** uses rendering loops tuned for each primitive type and attribute binding combination to reduce CPU overhead in transferring the geometry data to the hardware pipeline. Otherwise, **pfDrawGSet()** sends a special, compiled data structure.

Table 8-1 lists other operations that you can perform on pfGeoSets. **pfCopy()** does a shallow copy, copying the source pfGeoSet’s attribute arrays by reference and incrementing their reference counts. **pfDelete()** frees the memory of a pfGeoSet and its attribute arrays (if those arrays were allocated with **pfMalloc()** and provided their reference counts reach zero). **pfPrint()** is strictly a debugging utility and will print a pfGeoSet’s contents to a specified destination. **pfGSetIsectSegs()** allows intersection testing of line segments against the geometry in a pfGeoSet; see “Intersecting With pfGeoSets” in Chapter 17 for more information on that function.

3D Text

In addition to the pfGeoSet, *libpr* offers two other primitives which together are useful for rendering a specific type of geometry—three-dimensional characters. See Chapter 3, “Nodes and Node Types” and the description for pfText nodes for an example of how to set up three-dimension text within the context of *libpf*.

pfFont

The basic primitive supporting text rendering is the *libpr* pfFont primitive. A pfFont is essentially a collection of pfGeoSets in which each pfGeoSet represents one character of a particular font. pfFont also contain metric data, such as a per-character *spacing*, the three-dimensional escapement offset used to increment a text ‘cursor’ after the character has been drawn. Thus, pfFont maintain all of the information that is necessary to draw any and all valid characters of a font. However, note that pfFont are passive and have

little functionality on their own, for example you cannot draw a `pfFont`—it simply provides the character set for the next higher-level text data object, the `pfString`.

Table 8-5 lists some routines that are used with a `pfFont`.

Table 8-5 `pfFont` Routines

Function	Description
<code>pfNewFont</code>	Create a new <code>pfFont</code> .
<code>pfDelete</code>	Delete a <code>pfFont</code> .
<code>pfFontCharGSet</code>	Set the <code>pfGeoSet</code> to be used for a specific character of this <code>pfFont</code> .
<code>pfFontCharSpacing</code>	Set the 3D spacing to be used to update a text cursor after this character has been rendered.
<code>pfFontMode</code>	Specify a particular mode for this <code>pfFont</code> . Valid Modes to set: PFFONT_CHAR_SPACING — specify whether to use fixed or variable spacings for all characters of a <code>pfFont</code> . Possible values are PFFONT_CHAR_SPACING_FIXED and PFFONT_CHAR_SPACING_VARIABLE , the latter being the default. PFFONT_NUM_CHARS — specify how many characters are in this font. PFFONT_RETURN_CHAR — specify the index of the character that is considered a 'return' character and thus relevant to line justification.
<code>pfFontAttr</code>	Specify a particular attribute of this <code>pfFont</code> . Valid Attributes to set: PFFONT_NAME - name of this font. PFFONT_GSTATE - <code>pfGeoState</code> to be used when rendering this font. PFFONT_BBOX - bounding box that bounds each individual character. PFFONT_SPACING - Set the overall character spacing if this is a fixed width font (also the spacing used if one hasn't been set for a particular character).

Example 8-1 Loading Characters into a pfFont

```

/* Setting up a pfFont */
pfFont *ReadFont(void)
{
    pfFont *fnt = pfNewFont(pfGetSharedArena());
    for(i=0;i<numCharacters;i++)
    {
        pfGeoSet* gset = getCharGSet(i);
        pfVec3* spacing = getCharSpacing(i);

        pfFontCharGSet(fnt, i, gset);
        pfFontCharSpacing(fnt, i, spacing);
    }
}

```

pfString

Simple rendering of three-dimensional text can be done using a pfString. A pfString is an array of font indices stored as 8-bit bytes, 16-bit shorts, or 32-bit integers. Each element of the array contains an index to a particular character of a pfFont structure. A pfString can not be drawn until it has been associated with a pfFont object via a call to **pfStringFont()**. To render a pfString once it references a pfFont, call the function **pfDrawString()**.

pfStrings support the notion of ‘flattening’ to trade off memory for faster processing time. This will cause individual, non-instanced geometry to be used for each character, eliminating the cost of translating the text cursor between each character when drawing the pfString.

Example 8-2 Setting Up and Drawing a pfString

```

/* Create a string and rotate it for 2.5 seconds */
void
LoadAndDrawString(const char *text)
{
    pfFont *myfont = ReadMyFont();
    pfString *str = pfNewString(NULL);
    pfMatrix mat;
    float start,t;

    /* Use myfont as the 3-d font for this string */
    pfStringFont(str, fnt);
}

```

```
/* Center String */
pfStringMode(str, PFSTR_JUSTIFY, PFSTR_MIDDLE);

/* Color String is Red */
pfStringColor(str, 1.0f, 0.0f, 0.0f, 1.0f);

/* Set the text of the string */
pfStringString(str, text);

/* Obtain a transform matrix to place this string */
GetTheMatrixToPlaceTheString(mat);
pfStringMat(str, &mat);

/* optimize for draw time by flattening the transforms */
pfFlattenString(str);

/* Twirl text for 2.5 seconds */
start = pfGetTime();
do
{
    pfVec4 clr;
    pfSetVec4(clr, 0.0f, 0.0f, 0.0f, 1.0f);

    /* Clear the screen to black */
    pfClear(PFCL_COLOR|PFCL_DEPTH, clr);

    t = (pfGetTime() - start)/2.5f;
    t = PF_MIN2(t, 1.0f);

    pfMakeRotMat(mat, t * 315.0f, 1.0f, 0.0f, 0.0f);
    pfPostRotMat(mat, mat, t * 720.0f, 0.0f, 1.0f, 0.0f);

    t *= t;
    pfPostTransMat(mat, mat, 0.0f,
        150.0f * t + (1.0f - t) * 800.0f, 0.0f);

    pfPushMatrix();
    pfMultMatrix(mat);

    /* DRAW THE INPUT STRING */
    pfDrawString(str);

    pfPopMatrix();
}
```

```

        pfSwapWinBuffers(pfGetCurWin());
    } while(t < 2.5f);
}

```

Table 8-6 lists the key routines used to manage pfStrings.

Table 8-6 pfString Routines

Function	Description
pfNewString	Create a new pfString
pfDelete	Delete a pfString.
pfStringFont	Set the pfFont to use when drawing this pfString.
pfStringString	Set the character array that this pfString will represent/render.
pfDrawString	Draw this pfString
pfFlattenString	Flatten all positional translations and the current specification matrix into individual pfGeoSets so that more memory is used, but no matrix transforms or translates have to be done between each character of the pfString.
pfStringColor	Set the color of the pfString.
pfStringMode	Specify a particular mode for this pfString. Valid Modes to set: PFSTR_JUSTIFY — set the line justification and has the following possible values: PFSTR_FIRST or PFSTR_LEFT , PFSTR_MIDDLE or PFSTR_CENTER , and PFSTR_LAST or PFSTR_RIGHT . PFSTR_CHAR_SIZE — set the number of bytes per character in the input string and has the following possible values: PFSTR_CHAR , PFSTR_SHORT , PFSTR_INT .
pfStringMat	Specify a transform matrix that will affect the entire character string when the pfString is drawn
pfStringSpacing Scale	Specify a scale factor for the escapement translations that happen after each character is drawn. This routine is useful for changing the spacing between characters and even between lines.

Chapter 9

“Graphics State”

The chapter describes the graphics state, which contains all of the fields that together define the shape and appearance of a geometry.

Graphics State

The graphics state is a class of fields that define everything about the shape and texture of an object in a IRIS Performer scene. Fields include such things as transparency, shading, reflectance, and texture. The graphics state is set globally for all objects in the scene graph. Individual objects, however, can override graphics state settings. The cost, however, is efficiency. For performance reasons, therefore, it is important to set the fields in the graphics state to satisfy the greatest number of objects in the scene.

This chapter describes in detail all of the fields in the graphics state.

Immediate Mode

The graphics libraries are immediate-mode state machines; if you set a mode, all subsequent geometry is drawn in that mode. For the best performance, mode changes need to be minimized and managed carefully. *libpr* manages a subset of graphics library state and identifies bits of state as *graphics state elements*. Each state element is identified with a PFSTATE token, e.g., PFSTATE_TRANSPARENCY corresponds to the transparency state element. State elements are loosely partitioned into three categories: modes, values and attributes.

Modes are the graphics state variables, such as transparency and texture enable, that have simple values like ON and OFF. An example of a mode command is **pfTransparency(mode)**.

Values are not modal, rather they are real numbers which signify a threshold or quantity. An example of a value is the reference alpha value specified with the **pfAlphaFunc()** command.

Attributes are references to encapsulations (structures) of graphics state. They logically group the more complicated elements of state, such as textures and lighting models. Attributes are structures that are modified through a procedural interface and must be applied to have an effect. For example, **pfApplyTex(tex)** applies the texture map, *tex*, to subsequently drawn geometry.

In *libpr*, there are three methods of setting state:

- immediate mode
- display list mode
- pfGeoState mode

Like the graphics libraries, *libpr* supports the notion of both immediate and display-list modes. In immediate mode, graphics mode changes are sent directly to the Geometry Pipeline, i.e., they have immediate effect. In display-list mode, graphics mode changes are captured by the currently active pfDispList, which can be drawn later. *libpr* display lists differ from graphics library objects because they capture only *libpr* commands and are reusable. *libpr* display lists are useful for multiprocessing applications in which one process builds up the list of visible geometry and another process draws it. “Display Lists” on page 285 describes *libpr* display lists.

A pfGeoState is a structure that encapsulates all the graphics modes and attributes that *libpr* manages. You can individually set the state elements of a pfGeoState to define a *graphics context*. The act of applying a pfGeoState with **pfApplyGState()** configures the state of the Geometry Pipeline according to the modes, values, and attributes set in the pfGeoState. For example, the following code fragment shows equivalent ways (except for some inheritance properties of pfGeoStates described later) of setting up some lighting parameters suitable for a glass surface:

```
/* Immediate mode state specification */
pfMaterial *shinyMtl;
pfTransparency(PFTR_ON);
pfApplyMtl(shinyMtl);
pfEnable(PFEN_LIGHTING);

/* is equivalent to: */

/* GeoState state specification */
pfGeoState *gstate;
pfGStateMode(gstate, PFSTATE_TRANSPARENCY, PFTR_ON);
pfGStateAttr(gstate, PFSTATE_FRONTMTL, shinyMtl);
pfGStateMode(gstate, PFSTATE_ENLIGHTING, PF_ON);
pfApplyGState(gstate);
```

In addition, pfGeoStates have unique state inheritance capabilities that make them very convenient and efficient; they provide independence from ordered drawing. pfGeoStates are described in the “pfGeoState” section of this chapter.

Libpr routines have been designed to produce an efficient structure for managing graphics state. You can also set graphics state directly through the GL. However, *libpr* will have no record of these settings and will not be able to optimize them and may make incorrect assumptions about current graphics state if the resulting state does not match the *libpr* record when *libpr* routines are called. Therefore, it is best to use the *libpr* routines whenever possible to change graphics state and to restore *libpr* state if you go directly through the GL.

The following sections will describe the rendering geometry and state elements in detail. There are three types of state elements: modes, values and attributes. Modes are simple settings that take a set of integer values that include values for enabling and disabling the mode. Modes may also have associated values that allow a setting from a defined range. Attributes are complex state structures that encapsulate a related collection of modes and values. Attribute structures will not include in their definition an enable or disable as the enabling or disabling of a mode is orthogonal to the particular related attribute in use.

Rendering Modes

libpr manages a subset of the rendering modes found in the graphics libraries. In addition, *libpr* abstracts certain concepts like transparency, providing a higher-level interface that hides the underlying implementation mechanism.

libpr provides tokens that identify the modes that it manages. These tokens are used by `pfGeoStates` and other state-related functions like `pfOverride()`. The following table enumerates the `PFSTATE_` tokens of supported modes, each with a brief description and default value.

Table 9-1 lists and describes the mode tokens.

Table 9-1 pfGeoState Mode Tokens

Token Name	Description	Default Value
PFSTATE_TRANSPARENCY	Transparency modes	PFTR_OFF
PFSTATE_ALPHAFUNC	Alpha function	PFAF_ALWAYS
PFSTATE_ANTIALIAS	Antialiasing mode	PFAA_OFF
PFSTATE_CULLFACE	Face culling mode	PFCF_OFF
PFSTATE_DECAL	Decaling mode for coplanar geometry	PFDECAL_OFF
PFSTATE_SHADEMODEL	Shading model	PFSM_GOURAUD
PFSTATE_ENLIGHTING	Lighting enable flag	PF_OFF
PFSTATE_ENTEXTURE	Texturing enable flag	PF_OFF
PFSTATE_ENFOG	Fogging enable flag	PF_OFF
PFSTATE_ENWIREFRAME	pfGeoSet wireframe mode enable flag	PF_OFF
PFSTATE_ENCOLORTABLE	pfGeoSet colortable enable flag	PF_OFF
PFSTATE_ENHIGHLIGHTING	pfGeoSet highlighting enable flag	PF_OFF
PFSTATE_ENLPOINTSTATE	pfGeoSet light point state enable flag	PF_OFF
PFSTATE_ENTEXGEN	Texture coordinate generation enable flag	PF_OFF

The mode control functions described in the following sections should be used in place of their graphics library counterparts so that IRIS Performer can correctly track the graphics state. Use **pfGStateMode()** with the appropriate PFSTATE token to set the mode of a pfGeoState.

Transparency

You can control transparency using **pfTransparency()**. Possible transparency modes are:

Table 9-2 pfTransparency Tokens

Transparency mode	Description
PFTR_OFF	Transparency disabled.
PFTR_ON PFTR_FAST	Use the fastest, but not necessarily the best, transparency provided by the hardware.
PFTR_HIGH_QUALITY	Use the best, but not necessarily the fastest, transparency provided by the hardware.
PFTR_MS_ALPHA	Use screen-door transparency when multisampling. Fast but limited number of transparency levels.
PFTR_BLEND_ALPHA	Use alpha-based blend with background color. Slower but high number of transparency levels.

In addition, the flag `PFTR_NO_OCCLUDE` may be logically OR-ed into the transparency mode in which case geometry will not write depth values into the frame buffer. This will prevent it from occluding subsequently rendered geometry. Enabling this flag improves the appearance of unordered, blended transparent surfaces.

There are two basic transparency mechanisms: screen-door transparency which requires hardware multisampling and blending. Blending offers very high quality transparency but for proper results requires that transparent surfaces be rendered in back-to-front order after all opaque geometry has been drawn. When using transparent texture maps to “etch” geometry or if the surface has constant transparency, screen-door transparency is usually good enough. Blended transparency is usually required to avoid “banding” on surfaces with low transparency gradients like clouds and smoke.

Shading Model

Selects flat shading or Gouraud (smooth) shading. **pfShadeModel()** takes one of two tokens: `PFSM_FLAT` or `PFSM_GOURAUD`. On some graphics hardware flat shading can offer a significant performance advantage.

Alpha Function

pfAlphaFunc() is an extension of the IRIS GL function **afunction(3g)** and the OpenGL function **glAlphaFunc()**; it allows IRIS Performer to keep track of the hardware mode. The alpha function is a pixel test that compares the incoming alpha to a reference value and uses the result to determine whether or not the pixel is rendered. The reference value must be specified in the range [0, 1]. For example, a pixel whose alpha value is 0 is not rendered if the alpha function is PFAF_GREATER and the alpha reference value is also 0. Note that rejecting pixels based alpha can be faster than using transparency alone. A common technique for improving the performance of filling polygons is to set an alpha function that will reject pixels of low (possibly non-zero) contribution. Alpha function is typically used for see-through textures like trees.

Decals

On Z-buffer based graphics hardware, coplanar geometry can cause unwanted artifacts due to the finite numerical precision of the hardware which cannot accurately resolve which surface has visual priority. This can result in *flimmering*, a visual “tearing” or “twinkling” of the surfaces. **pfDecal()** is used to accurately draw coplanar geometry on IRIS platforms and it supports two basic implementation methods, each with its advantages:

The *stencil decaling* method uses a hardware resource known as a stencil buffer and requires that a single stencil plane (see IRIS GL **stencil()** and OpenGL **glStencilOp()** man pages) be available for IRIS Performer. This method offers the highest image quality but requires that geometry be coplanar and rendered in a specific order which reduces opportunities for the performance advantage of sorting by graphics mode.

A potentially faster method is the *displace decaling* method. In this case, each layer is displaced towards the eye so it “hovers” slightly above the preceding layer. Displaced decals need not be coplanar, can be drawn in any order but the displacement may cause geometry to incorrectly “poke through” other geometry.

The specification of a decal plane can improve the displace decaling method. The object geometry will be projected onto the specified plane and if the same plane is specified for base and layer geometry, the base and layer polygons will be generated with identical depth values. If the objects are drawn in priority order, no further operation is necessary. Otherwise, displace can be applied to the planed geometry for a superior result. Decal planes can be specified on **pfGeoSets** with **pfGSetDecalPlane()**, on a **pfGeoState** with the PFASTATE_DECALPLANE attribute to **pfGStateAttr()**, or globally with **pfApplyDecalPlane()**.

Decals consist of *base geometry* and *layer geometry*. The base defines the depth values of the decal while layer geometry is simply “inlaid” on top of the base. Multiple layers are supported but limited to 8 when using displaced decals. Realize that these layers imply superposition; there is no limit to the number of polygons in a layer, only to the number of distinct layers.

The decal mode indicates whether the subsequent geometry is base or layer and the decal method to use. For example, a mode of PFDECAL_BASE_STENCIL means that subsequent geometry is to be considered as base geometry and drawn using the stencil method. All combinations of base/layer and displace/stencil modes are supported but you should make sure to use the same method for a given base-layer pair.

Example 9-1 illustrates the use of **pfDecal()**.

Example 9-1 Using pfDecal() to Draw Road With Stripes

```
pfDecal(PFDECAL_BASE_STENCIL);

/* ... draw underlying geometry (roadway) here ...*/

pfDecal(PFDECAL_LAYER_STENCIL);

/* ... draw coplanar layer geometry (stripes) here ... */

pfDecal(PFDECAL_OFF);
```

Note: *libpf* applications can use the pfLayer node to include decals within a scene graph.

Frontface / Backface

pfCullFace() controls which side of a polygon (if any) is discarded in the Geometry Pipeline. Polygons are either front-facing or back-facing. A front-facing polygon is described by a counterclockwise order of vertices in screen coordinates, and a back-facing one has a clockwise order. **pfCullFace()** has four possible arguments:

PF_CF_OFF	Disable face-orientation culling
PF_CF_BACK	Cull back-facing polygons
PF_CF_FRONT	Cull front-facing polygons
PF_CF_BOTH	Cull both front- and back-facing polygons

In particular, backface culling is highly recommended since it offers a significant performance advantage for databases where polygons are never be seen from both sides (databases of “solid” objects or with constrained eyepoints).

Antialiasing

pfAntialias() is used to turn the antialiasing mode of the hardware on or off. Currently, antialiasing is implemented differently by each different graphics system. Antialiasing can produce artifacts as a result of the way IRIS Performer and the active hardware platform implement the feature. See the reference page **pfAntialias()** for implementation details.

Rendering Values

Some modes may also have associated values. These values are set through **pfGStateVal()**. Table 9-3 lists and describes the value tokens.

Table 9-3 pfGeoState Value Tokens

Token Name	Description	Range	Default Value
PFSTATE_ALPHAREF	Set the alpha function reference value.	0.0 - 1.0	0.0

Enable / Disable

pfEnable() and **pfDisable()** control certain rendering modes. Certain modes do not have effect when enabled but require that other attribute(s) be applied. Table 9-4 lists and describes the tokens and also lists the attributes required for the mode to become truly active.

Table 9-4 Enable and Disable Tokens

Token	Action	Attribute(s) Required
PFEN_LIGHTING	Enable or disable lighting.	pfMaterial pfLight pfLightModel
PFEN_TEXTURE	Enable or disable texture.	pfTexEnv pfTexture

Table 9-4 (continued) Enable and Disable Tokens

Token	Action	Attribute(s) Required
PFEN_FOG	Enable or disable fog.	pfFog
PFEN_WIREFRAME	Enable or disable pfGeoSet wireframe rendering.	none
PFEN_COLORTABLE	Enable or disable pfGeoSet colortable mode.	pfColortable
PFEN_HIGHLIGHTING	Enable or disable pfGeoSet highlighting.	pfHighlight
PFEN_TEXGEN	Enable or disable automatic texture coordinate generation.	pfTexGen
PFEN_LPOINTSTATE	Enable or disable pfGeoSet light points	pfLPointState

By default all modes are disabled.

Rendering Attributes

Rendering attributes are state structures that are manipulated through a procedural interface. Examples include pfTexture, pfMaterial, and pfFog. *libpr* provides tokens that enumerate the graphics attributes it manages. These tokens are used by pfGeoStates and other state-related functions like **pfOverride()**. Table 9-5 lists and describes the tokens.

Table 9-5 Rendering Attribute Tokens

Attribute Token	Description	Apply Routine
PFSTATE_LIGHTMODEL	Lighting model	pfApplyLModel
PFSTATE_LIGHTS	Light source definitions	pfLightOn
PFSTATE_FRONTMTL	Front-face material	pfApplyMtl
PFSTATE_BACKMTL	Back-face material	pfApplyMtl
PFSTATE_TEXTURE	Texture	pfApplyTex
PFSTATE_TEXENV	Texture environment	pfApplyTEnv
PFSTATE_FOG	Fog model	pfApplyFog
PFSTATE_COLORTABLE	Color table for pfGeoSets	pfApplyCtab

Table 9-5 (continued) Rendering Attribute Tokens

Attribute Token	Description	Apply Routine
PFSTATE_HIGHLIGHT	Definition of pfGeoSet highlighting style	pfApplyHlight
PFSTATE_LPOINTSTATE	pfGeoSet light point definition	pfApplyLPState
PFSTATE_TEXGEN	Texture coordinate generation definition	pfApplyTGen

Rendering attributes control which attributes are applied to geometric primitives when they're processed by the hardware. All IRIS Performer attributes consist of a control structure, definition routines, and an apply function, **pfApply*** (except for lights which are "turned on").

Each attribute has an associated **pfNew*()** routine that allocates storage for the control structure. When sharing attributes across processors in a multiprocessor application, you should pass the **pfNew*()** routine a shared memory arena from which to allocate the structure. If you pass NULL as the arena, the attribute is allocated from the heap and isn't sharable in a non-shared address space (**fork()**) multiprocessing application.

All attributes can be applied directly, referenced by a pfGeoState or captured by a display list. When changing an attribute, that change isn't visible until the attribute is reapplied. Detailed coverage of attribute implementation is available in the reference pages.

Texture

IRIS Performer supports texturing through pfTextures and pfTexEnvs, which provide encapsulated support for graphics library textures (see **texdef2d()** for IRIS GL, or **glTexImage2D()** for OpenGL) and texture environments (see IRIS GL's **tevdef(3g)** or OpenGL's **glTexEnv()**). A pfTexture defines a texture image, format, and filtering. A pfTexEnv specifies how the texture should interact with the colors of the geometry it's applied to. You need both to display textured data, but you don't need to specify them both at the same time. For example, you could have pfGeoStates each of which had a different texture specified as an attribute and still use an overall texture environment specified with **pfApplyTEnv()**.

A pfTexture is created by calling **pfNewTex()**. If the desired texture image exists as a disk file in IRIS libimage format (the file often has a ".rgb" suffix) or in the IRIS Performer fast loading image format (a ".pfi" suffix), you can call **pfLoadTexFile()** to load the image into CPU memory and completely configure the pfTexture

```
pfTexture *tex = pfLoadTexFile("brick.rgba");
```

Otherwise, **pfTexImage()** lets you directly provide a GL-ready image array in the same external format as specified on the pfTexture and as expected by **texdef2d()** in IRIS GL and **glTexImage2D()** in OpenGL.

```
void pfTexImage(pfTexture* tex, uint* image,
               int comp, int sx, int sy, int sz);
```

IRIS GL and OpenGL both expect packed texture data with each row beginning on a long word boundary. However, IRIS GL and OpenGL expect the individual components of a texel to be packed in opposite order. For example, IRIS GL expects four component texels to be packed as ABGR OpenGL expects the texels to be packed as RGBA. If you provide your own image array in a multiprocessing environment, it should be allocated from shared memory (along with your pfTexture) to allow different processes to access it. A basic example demonstrating loading a image file and placing the resulting pfTexture on scene graph geometry is at `/usr/share/Performer/src/pguide/libpf/C/texture..c`.

Note: The size of your texture must be an integral power of two on each side. IRIS GL scales up your textures to the next power of two, making them take up to four times more space in hardware texture memory! OpenGL simply refuses to accept badly sized textures. You can rescale your texture images with the *izoom* or *imgworks* programs (shipped with IRIX 5.3 in the `eo2.sw.imagetools` and `imgtools.sw.tools` subsystems; and with IRIX 6.2 in the `eo2.sw.imagetools` and `imgworks.sw.tools` subsystems).

Your texture source does not have to be a static image. **pfTexLoadMode()** can be used to set one of the sources listed in Table 9-6 with `PFTEX_LOAD_SOURCE`. Note that sources other than CPU memory may not be supported on all graphics platforms, or may have some special restrictions. There are several sample programs that demonstrate paging sequences of texture from different texture sources. For paging from host memory there are:

- `/usr/share/Performer/src/pguide/libpr/C/texlist.c`
- `/usr/share/Performer/src/pguide/libpr/C/mipmap.c`
- `/usr/share/Performer/src/pguide/libpfutil/movietex.c`

These examples demonstrates the use of different texture sources for paging textures, and `libpufitl` utilities for managing texture resources. One thing these examples do is use `pfTexLoadImage()` to update the pointer to the image data to avoid the expensive reformatting the texture. This requires that the provided image data be the same size as the original image data, as well as same number of components and same formats.

Table 9-6 Texture Image Sources

PFTEX_SOURCE_ Token	Texture image is take from:
IMAGE	CPU memory location specified by <code>pfTexLoadImage()</code> or <code>pfTexImage()</code> .
FRAMEBUFFER	framebuffer location offset from window origin as specified by <code>pfTexLoadOrigin()</code> .
VIDEO	Default video source on the system.

Video Texturing

The source of texture image data can be live video input. IRIS Performer supports the video input mechanisms of Sirius Video on RealityEngine and InfiniteReality, DIVO on Onyx2/InfiniteReality, and O2 and OCTANE video input. IRIS Performer includes a sample program that features video texturing:

`/usr/share/Performer/src/pguide/libpf/movietex.c`. This example demonstrates all video initialization, including the creation of video library resources, is done in the draw process, as required by the video library. Part of that initialization includes setting the proper number of components on the `pfTexture` and choosing a texture filter and potentially internal format. Those basic operations are discussed further in this section.

IRIS Performer will automatically download the frame of video when the texture object is applied through the referencing `pfGeoState`. Alternatively, you may want to schedule this download to happen at the beginning or end of the rendering frame and can force it with token with `pfLoadTex()`.

Textures must be created with sizes that are powers of two the input video frame is usually not in powers of two. The `[0,1]` texture coordinate range can be scaled into the valid part of the `pfTexture` with a texture matrix. This matrix can be applied directly to the global state with `pfApplyTMat()` to affect all `pfGeoSets`, or can be set on a `pfGeoState` with the `PFSTATE_TEXMAT` attribute to `pfGStateAttr()`.

Texture Management

Texture storage is limited only by virtual memory, but for real-time applications you must consider the amount of texture storage the graphics hardware supports. Textures that don't fit in the graphics subsystem will be paged as needed when **pfApplyTex()** is called. *Libpr* provides routines for managing hardware texture memory so that a real-time application does not have to get a surprise texture load. **pfIsTexLoaded()**, called from the drawing process, will tell you if the pfTexture is currently properly loaded in texture memory. The initially required textures of an application, or all of the textures if they will fit, can be pre-loaded into texture memory as part of application initialization. **pfuMakeSceneTexList()** will make a list of all textures referenced by a scene graph and **pfuDownloadTexList()** will load a list of textures into hardware texture memory (and must be called in the draw process). The *perfly* sample program does this as part of its initialization and displays the textures as it pre-loads them.

There are additional routines to assist with the progressive loading and unloading of pfTextures. **pfIdleTex()** can be used to free up the hardware texture memory owned by a pfTexture. f texture paging, GL host and hardware texture memory resources can be freed with **pfDeleteGLHandle()** from the drawing process. IRIS Performer will automatically re-allocate those resources if the pfTexture is used again. For an example of management of texture resources, see the example program `/usr/share/Performer/src/pguide/libpfutil/txmem.c` that uses the pfuTextureManager from *libpfutil* for basic texture paging support.

pfLoadTex(), called from the drawing process, can be used to explicitly load a texture into graphics hardware texture memory (which will include doing any necessary formatting of the texture image). By default, **pfLoadTex()** will load the entire texture image, including any required minification or magnification levels, into texture memory. **pfSubloadTex()** and **pfSubloadTexLevel()** can also be used in the drawing process to do an immediate load of texture memory managed by the given pfTexture and these routines allow you to specify all loading parameters (source, origin, size, etc.). This is useful for loading different images for the same pfTexture in different graphics pipelines. **pfSubloadTex()** allows you to load a subsection of the texture tile by tile.

A special **pfTexFormat()** formatting mode, PFTEX_SUBLOAD_FORMAT, allows part or all of the image in texture memory owned by the pfTexture to be replaced via **pfApplyTex()**, **pfLoadTex()**, or **pfSubloadTex()**, without having to go through the expensive reformatting phase. This allows you to quickly update the image of a pfTexture in texture memory. The PFTEX_SUBLOAD_FORMAT used with an appropriate **pfTexLoadSize()** and **pfTexLoadOrigin()** allows you to control what part of the texture will be loaded by subsequent calls to **pfLoadTex()** or **pfApplyTex()**. There are

also different loading modes that cause **pfApplyTex()** to automatically reload or subload a texture from a specified source. If you want the image of a **pfTexture** to be updated upon every call to **pfApplyTex()**, you can set the loading mode of the **pfTexture** with **pfTexLoadMode()** to be **PFTEX_BASE_AUTO_REPLACE**. **pfTexLoadImage()** allows you to continuously update the memory location of an **IMAGE** source texture without triggering any reformatting of the texture.

Note: In IRIS GL, the **SUBLOAD** format (same as the **FAST_DEFINE** format on old versions of IRIS Performer) can only be used on non-MIPmapped textures. The fast texture loading uses the IRIS GL **subtexload()** and OpenGL **glTexSubImage()** calls. In IRIS GL, subload sizes must be integral multiples of 32.

Hint: There are texture formatting modes that can improve texture performance and these are the modes that are used by default by IRIS Performer. Of most importance is the 16-bit texel internal formats. These formats cause the resulting texels to have 16 bits of resolution instead of the standard 32. These formats can have dramatically faster texture fill performance and cause the texture to take up half the hardware texture memory. Therefore, they are strongly recommended and are used by default. There are different formats for each possible number of components to give a choice of how the compression is to be done. These formats are described in the **pfTexFormat(3pf)** reference page.

There may also be formatting modes for internal or external image formats that IRIS Performer does not have a token for. However, the GL value can be specified. Specifying GL values will make your application GL specific and may also cause future porting problems, so it should only be done if absolutely necessary.

pfTextures also allow you to define a set of textures that are mutually exclusive, should always be applied to the same set of geometry, and thus that can share the same location in hardware texture memory. With **pfTexList(tex, list)** you can specify a list of textures to be in a texture set managed by the base texture, *tex*. The base texture is what gets applied with **pfApplyTex()**, or assigned to geometry through **pfGeoStates**. With **pfTexFrame()**, you can select a given texture from the list (-1 selects the base texture and is the default). This allows you to define a texture movie where each image is the frame of the movie. You can have an image on the base texture to display when the movie is not playing.

There are additional loading modes for **pfTexLoadMode()** described in Table 9-7 to control how the textures in the texture list share memory with the base texture.

Table 9-7 Texture Load Modes

PFTEX_LOAD_modeToken	Load Mode Values	Description
SOURCE	SOURCE_IMAGE, SOURCE_FRAMEBUFFER PFTEX_SOURCE_VIDEO PFTEX_SOURCE_DMBUF PFTEX_SOURCE_DMVIDEO	Source of image data is host memory image, framebuffer, default video source, digital media buffer, or a video library digital media buffer.
BASE	BASE_APPLY BASE_AUTO_SUBLOAD	Loading of image for pfTexture is done as required for pfApply, or automatically subloaded upon every pfApply.
LIST	LIST_APPLY LIST_AUTO_IDLE LIST_AUTO_SUBLOAD	Loading of list texture image is as separate apply, causes freeing of previous list texture in hardware texture memory, or is subloaded into memory managed by the base texture.
VIDEO_INTERLACED	OFF, INTERLACED_ODD, INTERLACED_EVEN,	video input is interlaced or not and if so, which field (even or odd) is spatially higher.

Texture list textures can share the exact graphics texture memory as the base texture but this has the restriction that the textures must all be the exact same size and format as the base texture. Texture list textures can also indicate that they are mutually exclusive which will cause the texture memory of previous textures to be freed before applying the new texture. This method has no restrictions on the texture list, but is less efficient than the previous method. Finally, texture list textures can be treated as completely independent textures that should all be kept resident in memory for rapid access upon their application.

IpfTexFilter() sets a desired filter to a specified filtering method on a pfTexture. The minification and magnification texture filters are described with bitmask tokens. If filters are partially specified, IRIS Performer will fill in the rest with machine dependent fast defaults. The PFTEX_FAST token can be included in the bitmask to allow IRIS Performer to make machine dependent substitutions where there are large performance differences.

There are a variety of texture filter functions that can improve the look of textures when they are minified and magnified. By default, textures use MIPmapping when minified (though this costs an extra 1/3 in storage space to store the minification levels). Each level of minification or magnification of a texture is twice the size of the previous level. Minification levels are indicated with positive numbers and magnification levels are indicated with non-positive numbers. The default magnification filter for textures is bilinear interpolation. The use of detail textures and sharpening filters can improve the look of magnified textures. Detailing actually uses an extra detail texture that you provide that is based on a specified level of magnification from the corresponding base texture. The detail texture can be specified with the **pfTexDetail()** command. By default, MIPmap levels are generated for the texture automatically. OpenGL operation allows for the specification of custom MIPmap levels. Both MIPmap levels and detail levels can be specified with **pfTexLevel()**. The level number should be a positive number for a minification level and a non-positive number for a magnification (detail) level. If you are providing your own minification levels, you must provide all $\log_2(\text{MAX}(\text{texSizeX}, \text{texSizeY}))$ minification levels. There is only one detail texture for a pfTexture.

The magnification filters use spline functions to control their rate of application as a function of magnification, and specified level of magnification for detail textures. These splines can be specified with **pfTexSpline()**. The specification of the spline is a set of control points that are pairs of non-decreasing magnification levels (specified with non-positive numbers) and corresponding scaling factors. Magnification filters can be applied to all components of a texture, only the RGB components of a texture, or to just the alpha components. OpenGL does not allow different magnification filters (between detail and sharpen) for RGB and alpha channels.

Note: The specification of detail textures may have GL dependencies and magnifications filters may not be available on all hardware configurations. The pfTexture reference page describes these details.

Texture Formats

The format in which an image is stored in texture memory is defined with **pfTexFormat()**:

```
void pfTexFormat(pfTexture *tex, int format, int type)
```

format specifies which format to set. Valid formats and their basic types include:

- `PFTEX_INTERNAL_FORMAT`— specifies how many bits per component are to be used in internal hardware texture memory storage. The default is 16 bits per full texel and is based on the number of components and external format.
- `PFTEX_IMAGE_FORMAT`—describes the type of image data and must match the number of components, such as `PFTEX_LUMINANCE`, `PFTEX_LUMINANCE_ALPHA`, `PFTEX_RGB`, and `PFTEX_RGBA`. The default is the token in this list that matches the number of components. Other OpenGL selections can be specified with the GL token.
- `PFTEX_EXTERNAL_FORMAT`—specifies the format of the data in the `pfTexImage` array. The default is packed 8 bits per component. There are special fast-loading hardware ready formats, such as `PFTEX_UNSIGNED_SHORT_5_5_5_1`.
- `PFTEX_SUBLOAD_FORMAT`—a boolean to specify if the texture will be a sub-loadable paging texture. Default is `FALSE`.

In general you will just need to specify the number of components in `pfTexImage()`. You may want to specify a fast loading hardware-ready external format, such as `PFTEX_UNSIGNED_SHORT_5_5_5_1`, in which case IRIS Performer will automatically choose a matching internal format. See the `pfTexFormat(3pf)` reference page for more information on texture configuration details.

Controlling Texture LOD with `pfTexLOD`

You can control the levels of detail (LODs) of a texture that are accessed and used with `pfTexLOD` to force higher or lower MIPmap levels to be used when minifying. You can use this to give the graphics hardware a hint about what levels can be accessed (IMPACT hardware takes great advantage of such a hint) and you can use this to have multiple textures sharing a single MIPmap pyramid in texture memory. For example, a distant object and a close one may use different LODs of the same `pfTexture` texture. The `pfGeoStates` of those `pfGeoSets` would have different `pfTexLOD` objects that referenced the proper texture LODs. `pfTexLevel()` would be used to specify and update the proper image for each LOD in the `pfTexture`. You can use LODs to specify to yourself and the GL which LODs of texture should be loaded from disk into main memory. For example, if the viewer is in one LOD, most of the texture in that LOD can often be viewed and, consequently, should be paged into texture memory. You can set LOD parameters on a `pfTexture` directly or use `pfTexLOD`.

To use a `pfTexLOD` object, you

1. Set the ranges of the LOD, using `pfTLODRange()`, and their corresponding minimum and maximum resolution MIPmap. Because the minimum and maximum limits can be floating point values, new levels can be smoothly blended in when they become available to avoid popping from one LOD to another.
2. Optionally, set the bias levels, using `pfTLODBias()`, to force blurring of a texture to simulate motion blur and depth of field, or to force a texture to be sharper, or to compensate for asymmetric minification of a MIPmapped texture.

Note: Any LOD settings on `pfTexture` take priority over current `pfTexLOD` settings.

3. Enable LOD control over texture by using the following methods:

```
pfEnable(PFEN_TEXLOD);  
pfGeoState::pfGStateMode(myTxLOD, PFSTATE_ENTEXLOD, ON);
```

where `myTxLOD` is an instance of `pfTexLOD`, and `ON` is a non-zero integer.

4. Apply the LOD settings to the texture using `pfApplyTLOD()`.

See the sample program `/usr/share/Performer/src/pguide/libpr/C/textlod.c` for an example of using a `pfTexLOD`.

Note: You can only control the LOD of a texture when using OpenGL.

Setting the Texture Environment with `pfTexEnv`

The environment specifies how the colors of the geometry, potentially lit, and the texture image interact. This is described with a `pfTexEnv` object. The mode of interaction is set with `pfTEnvMode()` and valid modes include:

- `PFTE_MODULATE`—the gray scale of the geometry is mixed with the color of the texture (the default).

This option multiplies the shaded color of the geometry by the texture color. If the texture has an alpha component, the alpha value modulates the geometry's transparency, for example, if a black and white texture, such as text, is applied to a green polygon, the polygon remains green and the writing appears as dark green lettering.

- `PFTE_DECAL`—the texture alpha component acts as a selector between 1.0 for the texture color and 0.0 for the base color to decal an image onto geometry.

- **PFTE_BLEND**—the alpha acts as a selector between 0.0 for the base color and 1.0 for the texture color modulated by a constant texture blend color specified with **pfTEEnvBlendColor()**. The alpha/intensity components are multiplied.
- **PFTE_ADD**—the RGB components of the base color are added to the product of the texture color modulated by the current texture environment blend color. The alpha/intensity components are multiplied.

Automatic Texture Coordinate Generation

Automatic texture coordinate generation is provided with the **pfTexGen** state attribute. **pfTexGen** closely corresponds to IRIS GL's **texgen()** and OpenGL's **glTexGen()** functions. When texture coordinate generation is enabled, a **pfTexGen** applied with **pfApplyTGen()** will automatically generate texture coordinates for all rendered geometry. Texture coordinates are generated from geometry vertices according to the texture generation mode set with **pfTGenMode()**. Available modes and their function are listed in Table 9-8. Some modes refer to a plane which is set with **pfTGenPlane()** and to a line that is specified as a point and direction with **pfTGenPoint()**.

Table 9-8 Texture Generation Modes

PFTG_ Mode Token	Texture coordinates are calculated as...
OBJECT_PLANE	distance of vertex from plane in object coordinates
EYE_PLANE	distance of vertex from plane in eye coordinates. The plane is transformed by the inverse of the ModelView matrix when the pfTexGen is applied.
EYE_PLANE_IDENT	distance of vertex from plane in eye coordinates. The plane is not transformed by the inverse of the ModelView matrix when the pfTexGen is applied
SPHERE_MAP	an index into a 2D reflection map based on vertex position and normal. Specifics of the calculation are found in the graphics libraries' man pages.
OBJECT_DISTANCE_TO_LINE	distance in object space from vertex to specified line
EYE_DISTANCE_TO_LINE	distance in eye space from eye to a specified vector through the vertex

Lighting

IRIS Performer lighting is an extension of graphics library lighting (see **lmdef(3g)** for IRIS GL or **glLight()** and related functions in OpenGL), but IRIS Performer divides the actions of **lmdef()** into lights and light models, just as OpenGL does. The light embodies the color, position, and type (for example, infinite or spot) of the light. The light model specifies the environment for infinite (the default) or local viewing, and two-sided illumination..

The lighting model describes the type of lighting operations to be considered, including local lighting, two-sided lighting, and light attenuation. The fastest light model is infinite single-sided lighting. A **pfLightModel** state attribute object is created with **pfNewLModel()**. A light model also allows you to specify ambient light for the scene, such as might come from the Sun, with **pfLModelAmbient()**.

pfLights are created by calling **pfNewLight()**. A light has color and position. The light colors are specified with **pfLightColor()**:

```
void pfLightColor(pfLightSource* lsource, int which, float r,
                 float g, float b);
```

which specifies one of three light colors:

- PFLT_AMBIENT
- PFLT_DIFFUSE
- PFLT_SPECULAR

You position the light source using **pfLightPos()**:

```
void pfLightPos(pfLight* light, float x, float y,
               float z, float w);
```

w is the distance between the location in the scene defined by (*x*, *y*, *z*) and the light source, *lsource*. If *w* equals zero, *lsource* is infinitely far away and (*x*, *y*, *z*) defines a vector pointing from the origin in the direction of *lsource*; if *w* equals one, *lsource* is located at the position, (*x*, *y*, *z*). The default position is (0, 0, 1, 0): directly overhead, infinitely far away.

pfLights are attached to a **pfGeoState** through the **PFSTATE_LIGHTS** attribute.

The transformation matrix that is on the matrix stack at the time the light is applied controls the interpretation of the light source direction:

1. To attach a light to the viewer (like a miner's head-mounted light), call **pfLightOn()** only once with an identity matrix on the stack.
2. To attach a light to the world (like the sun or moon), call **pfLightOn()** every frame with only the viewing transformation on the stack.
3. To attach a light to an object (like the headlights of a car), call **pfLightOn()** every frame with the combined viewing and modeling transformation on the stack.

The number of lights you can have turned on at any one time is limited by `PF_MAX_LIGHTS`, just as is true with the graphics libraries.

Note: In IRIS GL, attenuation is also part of the light model definition. In OpenGL, attenuation is defined per-light. There is separate *libpr* API for setting each of these: **pfLModelAtten()** for IRIS GL and **pfLightAtten()** for OpenGL. You can use **pfQueryFeature()** with a feature specifier value of `PFQFTR_LMODEL_ATTENUATION` or `PFQFTR_LIGHT_ATTENUATION` to find out which is supported in the current run-time environment.

Note: *libpf* applications can include light sources in a scene graph with the `pfLightSource` node.

Materials

IRIS Performer materials are an extension of graphics library materials (see **lmdef(3g)** for IRIS GL or **glMaterial()** for OpenGL). `pfMaterials` encapsulate the ambient, diffuse, specular, and emissive colors of an object as well as its *shininess* and transparency. A `pfMaterial` is created by calling **pfNewMtl()**. As with any of the other attributes, a `pfMaterial` can be referenced in a `pfGeoState`, captured by a display list, or invoked as an immediate mode command.

`pfMaterials`, by default, allow object colors to set the ambient and diffuse colors. This allows the same `pfMaterial` to be used for objects of different colors, removing the need for material changes and thus improving performance. This mode can be changed with **pfMtlColorMode(mtl, side, PFMTL_CMODE_*)**. IRIS GL only supports the front material tracking the current color while OpenGL allows front or back materials to track the current color. If the same material is used for both front and back materials, there is no difference in functionality.

With the method, **pfMtlSide()**, you can specify whether to apply the the material on the side facing the viwer (PFMTL_FRONT), the side not facing the viewer (PFMTL_BACK), or both.(PFMTL_BOTH). Back-sided lighting will only take affect if there is a two-sided lighting model active. Two sided lighting typically has some significant performance cost.

Object materials only have effect when lighting is active.

Color Tables

A pfColortable substitutes its own color array for the normal color attribute array (PFGS_COLOR4) of a pfGeoSet. This allows the same geometry to appear differently in different views simply by applying a different pfColortable for each view. By leaving the selection of color tables to the global state, you can use a single call to switch color tables for an entire scene. In this way, color tables can simulate time-of-day changes, infrared imaging, psychedelia, and other effects.

pfNewCtab() creates and returns a handle to a pfColortable. As with other attributes, you can specify which color table to use in a pfGeoState or you can use **pfApplyCtab()** to set the global color table, either in immediate mode or in a display list. For an applied colortable to have effect, colortable mode must also be enabled.

Fog

A pfFog is created by calling **pfNewFog()**. As with any of the other attributes, a pfFog can be referenced in a pfGeoState, captured by a display list, or invoked as an immediate mode command. Fog is the atmospheric effect of aerosol water particles that occlude vision over distance. The IRIS hardware can simulate this phenomenon in several different fashions. A fog color is blended with the resultant pixel color based on the range from the viewpoint and the fog function. pfFog supports several different fogging methods. Table 9-9 lists the pfFog tokens and their corresponding actions.

Table 9-9 pfFog Tokens

pfFog Token	Action
PFFOG_VTX_LIN	Compute fog linearly at vertices.
PFFOG_VTX_EXP	Compute fog exponentially at vertices (e^x).
PFFOG_VTX_EXP2	Compute fog exponentially at vertices (e^{x^2}).
PFFOG_PIX_LIN	Compute fog linearly at pixels.
PFFOG_PIX_EXP	Compute fog exponentially at pixels (e^x).
PFFOG_PIX_EXP2	Compute fog exponentially at pixels (e^{x^2}).
PFFOG_PIX_SPLINE	Compute fog using a spline function at pixels.

pfFogType() uses these tokens to set the type of fog. A detailed explanation of fog types is given in the reference page `pfFog(3pf)` and in the IRIS GL `fogvertex(3g)` and OpenGL `glFog(3g)` reference pages.

You can set the near and far edges of the fog with **pfFogRange()**. For exponential fog functions, the near edge of fog is always zero in eye coordinates. The near edge is where the onset of fog blending occurs, and the far edge is where all pixels are 100% fog color.

The token `PFFOG_PIX_SPLINE` selects a spline function to be applied when generating the hardware fog tables. This is further described in the `pfFog(3pf)` reference page. Spline fog allows the user to define an arbitrary fog ramp that can more closely simulate real-world phenomena like horizon haze.

For best fogging effects the ratio of the far to the near clipping planes should be minimized. In general, it's more effective to add a small amount to the near plane than to reduce the far plane.

Highlights

IRIS Performer provides a mechanism for highlighting geometry with alternative rendering styles, useful for debugging and interactivity. A `pfHighlight`, created with `pfNewHlight()`, encapsulates the state elements and modes for these rendering styles. A `pfHighlight` can be applied to an individual `pfGeoSet` with `pfGSetHlight()`, or can be applied to multiple `pfGeoStates` through a `pfGeoState` or `pfApplyHlight()`. The highlighting effects are added to the normal rendering phase of the geometry. `pfHighlights` make use of special outlining and fill modes and have a concept of a foreground color and a background color that can both be set with `pfHlightColor()`. The available rendering styles can be combined by OR-ing together tokens for `pfHlightMode()` and are described in Table 9-10.

Table 9-10 `pfHlightMode()` Tokens

PFHL_Mode Bitmask Token	Description
LINES	Outlines the triangles in the highlight foreground color according to <code>pfHlightLineWidth()</code> .
LINESPAT LINESPAT2	Outlines triangles with patterned lines in the highlight foreground color, or in two colors using the background color.
FILL	Draws geometry with the highlight foreground color. Combined with <code>SKIP_BASE</code> , this is a fast highlighting mode.
FILLPAT FILLPAT2	Draws the highlighted geometry as patterned with one or two colors.
FILLTEX	Draw highlighting fill pass with a special highlight texture.
LINES_R FILL_R	Reverses the highlighting foreground and background colors for lines and fill, respectively.
POINTS	Renders the vertices of the geometry as points according to <code>pfHlightPntSize()</code> .
NORMALS	Displays the normals of the geometry with lines according to <code>pfHlightNormalLength()</code> .
BBOX_LINES BBOX_FILL	Displays the bounding box of the <code>pfGeoSet</code> as outlines and/or filled box. Combined with <code>PFHL_SKIP_BASE</code> , this is a fast highlighting mode.
SKIP_BASE	Causes the normal drawing phase of the <code>pfGeoSet</code> to be skipped. This is recommended when using <code>PFHL_FILL</code> or <code>PFHL_BBOX_FILL</code> .

For a demonstration of the highlighting styles, see the sample program, `/usr/share/Performer/pguide/src/libpr/C/hlcube.c`.

Graphics Library Matrix Routines

IRIS Performer provides extensions to the standard graphics library matrix-manipulation functions. These functions are similar to their graphics library counterparts, with the exception that they can be placed in IRIS Performer display lists. Table 9-11 lists and describes the matrix manipulation routines.

Table 9-11 Matrix Manipulation Routines

Routines	Action
<code>pfScale</code>	Concatenate a scaling matrix.
<code>pfTranslate</code>	Concatenate a translation matrix.
<code>pfRotate</code>	Concatenate a rotation matrix.
<code>pfPushMatrix</code>	Push down the matrix stack.
<code>pfPushIdentMatrix</code>	Push the matrix stack and load an identity matrix on top.
<code>pfPopMatrix</code>	Pop the matrix stack.
<code>pfLoadMatrix</code>	Add a matrix to the top of the stack.
<code>pfMultMatrix</code>	Concatenate a matrix.

Sprite Transformations

A sprite is a special transformation used to efficiently render complex geometry with axial or point symmetry. A classic sprite example is a tree which is rendered as a single, texture-mapped quadrilateral. The texture image is of a tree and has an alpha component whose values which “etches” the tree shape into the quad. In this case, the sprite transformation rotates the quad around the tree trunk axis so that it always faces the viewer. Another example is a puff of smoke which again is a texture-mapped quad but is rotated about a point to face the viewer so it appears the same from any viewing angle. The `pfSprite` transformation mechanism supports both these simple examples as well as more complicated ones involving arbitrary 3D geometry.

A `pfSprite` is a structure which is manipulated through a procedural interface. It is different from “attributes” like `pfTexture` and `pfMaterial` since it affects transformation, rather than state related to appearance. A `pfSprite` is activated with `pfBeginSprite()`. This enables “sprite mode” and any `pfGeoSet` that is drawn before sprite mode is ended with `pfEndSprite()` will be transformed by the `pfSprite`. First, the `pfGeoSet` is translated to the location specified with `pfPositionSprite()`. Then, it is rotated, either about the sprite position or axis depending on the `pfSprite`’s configuration. Note that `pfBeginSprite()`, `pfPositionSprite()` and `pfEndSprite()` are display listable and this will be captured by any active `pfDispList`.

A `pfSprite`’s rotation mode is set by specifying the `PFSPRITE_ROT` token to `pfSpriteMode()`. In all modes, the Y axis of the geometry is rotated to point to the eye position. Rotation modes are listed below.

Table 9-12 `pfSprite` Rotation Modes

<code>PFSPRITE_</code> Rotation Token	Rotation Characteristics
<code>AXIAL_ROT</code>	Geometry’s Z axis is rotated about the axis specified with <code>pfSpriteAxis()</code> .
<code>POINT_ROT_EYE</code>	Geometry is rotated about the sprite position with the object coordinate Z axis constrained to the window coordinate Y axis, i.e., geometry’s Z axis stays “upright”.
<code>POINT_ROT_WORLD</code>	Geometry is rotated about the sprite position with the object coordinate Z axis constrained to the sprite axis.

Rather than using the graphics hardware's matrix stack, `pfSprites` transform small `pfGeoSets` on the CPU for improved performance. However, when a `pfGeoSet` contains a certain number of primitives it becomes more efficient to use the hardware matrix stack. While this threshold is dependent on the CPU and graphics hardware used, you may specify it with the `PFSPRITE_MATRIX_THRESHOLD` token to **`pfSpriteMode()`**. The corresponding value is the minimum vertex requirement for hardware matrix transformation. Any `pfGeoSet` with fewer vertices will be transformed on the CPU. If you want a `pfSprite` to affect non-`pfGeoSet` geometry you should set the matrix threshold to zero so that the `pfSprite` will always use the matrix stack. When using the matrix stack, **`pfBeginSprite()`** pushes the stack and **`pfEndSprite()`** pops the matrix stack so the sprite transformation is limited in scope.

`pfSprites` are dependent on the viewing location and orientation and the current modeling transformation. You can specify these with calls to **`pfViewMat()`** and **`pfModelMat()`** respectively. Note that *libpf*-based applications need not call these routines since *libpf* does it automatically.

Display Lists

libpr supports display lists, which can capture and later execute *libpr* graphics commands. **`pfNewDList()`** creates and returns a handle to a new `pfDispList`. A `pfDispList` can be selected as the current display list with **`pfOpenDList()`**, which puts the system in display list mode. Any subsequent *libpr* graphics commands, such as **`pfTransparency()`**, **`pfApplyTex()`**, or **`pfDrawGSet()`**, are added to the current display list. Commands are added until **`pfCloseDList()`** returns the system to immediate mode. It is not legal to have multiple `pfDispLists` open at a given time but a `pfDispList` may be reopened in which case commands are appended to the end of the list.

Once a display list is constructed, it can be executed by calling **`pfDrawDList()`**, which traverses the list and sends commands down the Geometry Pipeline.

`pfDispLists` are designed for multiprocessing, where one process builds a display list of the visible scene and another process draws it. The function **`pfResetDList()`** facilitates this by making `pfDispLists` reusable. Commands added to a reset display list overwrite any previously entered commands. A display list is typically reset at the beginning of a frame and then filled with the visible scene.

pfDispLists support concurrent multiprocessing, where the producer and consumer processes simultaneously write and read the display list. The PFDL_RING argument to **pfNewDList()** creates a ring buffer or FIFO-type display list. pfDispLists automatically ensure ring buffer consistency by providing synchronization and mutual exclusion to processes on ring buffer full or empty conditions.

For more information and the application of display lists, see Chapter 10, “ClipTextures.”

Combining Display Lists

The contents of one pfDispList may be appended to a second pfDispList by using the function, **pfAppendDList()**. All pfDispList elements in *src* are appended to the pfDispList *dlist*.

Alternately, you can append the contents of one pfDispList to a second pfDispList by using the function **pfDispList::append()**. All pfDispList elements in *src* are appended to the pfDispList on which the append method is invoked.

State Management

pfState is a structure that represents the entire *libpr* graphics state. A pfState maintains a stack of graphics states that can be pushed and popped to save and restore state. The top of the stack describes the current graphics state of a window as it's known to IRIS Performer.

pfInitState() initializes internal *libpr* state structures and should be called at the beginning of an application before any pfStates are created. Multiprocessing applications should pass a **usinit()** semaphore arena pointer to **pfInitState()**, such as **pfGetSemaArena()**, so IRIS Performer can safely manage state between processes. **pfNewState()** creates and returns a handle to a new pfState, which is typically used to define the state of a single window. If using pfWindows, discussed in Chapter 11, “Windows,” a pfState is automatically created for the pfWindow when the window is opened and the current pfState is switched when the current pfWindow changes. **pfSelectState()** can be used to efficiently switch a different complete pfState. **pfLoadState()** will force the full application of a pfState.

Pushing and Popping State

pfPushState() pushes the state stack of the currently active *pfState*, duplicating the top state. Subsequent modifications of the state through *libpr* routines are recorded in the top of stack. Consequently, a call to **pfPopState()** restores the state elements that were modified after **pfPushState()**.

The code fragment in Example 9-2 illustrates how to push and pop state.

Example 9-2 Pushing and Popping Graphics State

```
/* set state to transparency=off and texture=brickTex */
pfTransparency(PFTR_OFF);
pfApplyTex(brickTex);

/* ... draw geometry here using original state ... */

/* save old state. establish new state */
pfPushState();
pfTransparency(PFTR_ON);
pfApplyTex(woodTex);

/* ... draw geometry here using new state ...*/

/* restore state to transparency=off and texture=brickTex */
pfPopState();
```

State Override

pfOverride() implements a global override feature for *libpr* graphics state and attributes. **pfOverride()** takes a mask that indicates which state elements to affect and a value specifying whether the elements should be overridden. The mask is a bitwise OR of the state tokens listed previously.

The values of the state elements at the time of overriding become fixed and cannot be changed until **pfOverride()** is called again with a value of zero to release the state elements.

The code fragment in Example 9-3 illustrates the use of **pfOverride()**.

Example 9-3 Using **pfOverride()**

```
pfTransparency(PFTR_OFF);
pfApplyTex(brickTex);

/*
 * Transparency will be disabled and only the brick texture
 * will be applied to subsequent geometry.
 */
pfOverride(PFSTATE_TRANSPARENCY | PFSTATE_TEXTURE, 1);
/* Draw geometry */

/* Transparency and texture can now be changed */
pfOverride(PFSTATE_TRANSPARENCY | PFSTATE_TEXTURE, 0);
```

pfGeoState

A **pfGeoState** encapsulates all the rendering modes, values, and attributes managed by *libpr*. See “Rendering Modes” on page 261, “Rendering Values” on page 266, and “Rendering Attributes” on page 267 for more information. **pfGeoStates** provide a mechanism for combining state into logical units and define the appearance of geometry. For example, you can set a brick-like texture and a reddish-orange material on a **pfGeoSet** and use it when drawing brick buildings.

You can specify texture matrices on **pfGeoSets**.

Local and Global State

There are two levels of rendering state: local and global. A record of both is kept in the current **pfState**. The local state is that defined by the settings of the current **pfGeoState**. The rendering state and attributes of a **pfGeoState** can be either locally set or globally inherited. If all state elements are set locally, a **pfGeoState** becomes a full graphics context—that is, all state is then defined at the **pfGeoState** level. Global state elements are set with *libpr* immediate mode routines like **pfEnable()**, **pfApplyTex()**, **pfDecal()**, **pfTransparency()** or by drawing a **pfDispList** containing these commands with **pfDrawDList()**. Local state elements for subsequent **pfGeoSets** are set by applying a **pfGeoState** with **pfApplyGState()** (note that **pfDrawGSet()** automatically calls **pfApplyGState()** if the **pfGeoSet** has an attached **pfGeoState**). The state elements applied by a **pfGeoState** are those modes, enables, and attributes that are explicitly set on the

pfGeoState. Those settings revert back to the pfState settings for the next call to **pfApplyGState()**. A pfGeoState can be explicitly loaded into a pfState to affect future pfGeoStates with **pfLoadGState()**.

Note: By default, all state elements are inherited from the global state. Inherited state elements are evaluated faster than values that have been explicitly set.

While it can be useful to have all state defined at the pfGeoState level, it usually makes sense to inherit most state from global default values and then explicitly set only those state elements that are expected to change often.

Examples of useful global defaults are lighting model, lights, texture environment, and fog. Highly variable state is likely to be limited to a small set such as textures, materials, and transparency. For example, if the majority of your database is lighted, simply configure and enable lighting at the beginning of your application. All pfGeoStates will be lighted except the ones for which you explicitly disable lighting. Then attach different pfMaterials and pfTextures to pfGeoStates to define specific state combinations.

Note: Caution should be used when enabling modes in the global state. These modes may have cost even when they have no visible effect. Therefore, geometry that cannot use these modes should have a pfGeoState that explicitly disables the mode. Modes to be especially careful of include the texturing enable and transparency.

You specify that a pfGeoState should inherit state elements from the global default with **pfGStateInherit(gstate, mask)**. *mask* is a bitmask of tokens that indicates which state elements to inherit. These tokens are listed in the “Rendering Modes”, “Rendering Values”, and “Rendering Attributes” sections of this chapter. For example, `PFSTATE_ENLIGHTING | PFSTATE_ENTEXTURE` makes *gstate* inherit the enable modes for lighting and texturing.

A state element ceases to be inherited when it is set in a pfGeoState. Rendering modes, values, and attributes are set with **pfGStateMode()**, **pfGStateVal()**, and **pfGStateAttr()**, respectively. For example, to specify that *gstate* is transparent and textured with *treeTex*, use

```
pfGStateMode(gstate, PFSTATE_TRANSPARENCY, PFTR_ON);
pfGStateAttr(gstate, PFSTATE_TEXTURE, treeTex);
```

Applying pfGeoStates

Use **pfApplyGState()** to apply the state encapsulated by a **pfGeoState** to the Geometry Pipeline. The effect of applying a **pfGeoState** is similar to applying each state element individually. For example, if you set a **pfTexture** and enable a decal mode on a **pfGeoState**, applying it essentially calls **pfApplyTex()** and **pfDecal()**. If in display-list mode, **pfApplyGState()** is captured by the current display list.

State is (logically) pushed before, and popped after, **pfGeoStates** are applied, so that **pfGeoStates** don't inherit state from each other. This is a very powerful and convenient characteristic since as a result, **pfGeoStates** are order-independent, and you don't have to worry about one **pfGeoState** corrupting another. The code fragment in Example 9-4 illustrates how **pfGeoStates** inherit state.

Example 9-4 Inheriting State

```
/* gstateA should be textured */
pfGStateMode(gstateA, PFSTATE_ENTEXTURE, PF_ON);

/* gstateB inherits the global texture enable mode */
pfGStateInherit(gstateB, PFSTATE_ENTEXTURE);

/* Texturing is disabled as the global default */
pfDisable(PFEN_TEXTURE);

/* Texturing is enabled when gstateA is applied */
pfApplyGState(gstateA);
/* Draw geometry that will be textured */

/* The global texture enable mode of OFF is restored
so that gstateB is NOT textured. */
pfApplyGState(gstateB);
/* Draw geometry that will not be textured */
```

The actual **pfGeoState** pop is a lazy pop that doesn't happen unless a subsequent **pfGeoState** requires the global state to be restored. This means that the actual state between **pfGeoStates** isn't necessarily the global state. If a return to global state is required, call **pfFlushState()** to restore the global state. Any modification to the global state made using *libpr* functions—**pfTransparency()**, **pfDecal()**, and so on—becomes the default global state.

For best performance, set as little local `pfGeoState` state as possible. You can accomplish this by setting global defaults that satisfy the majority of the requirements of the `pfGeoStates` being drawn. By default, all `pfGeoState` state is inherited from the global default.

pfGeoSets and pfGeoStates

There is a special relationship between `pfGeoSets` and `pfGeoStates`. Together they completely define both geometry and graphics state. You can attach a `pfGeoState` to a `pfGeoSet` with `pfGSetGState()` to specify the appearance of geometry. Whenever the `pfGeoSet` is drawn with `pfDrawGSet()`, the attached `pfGeoState` is first applied using `pfApplyGState()`. If a `pfGeoSet` does not have a `pfGeoState`, its state description is considered undefined. To inherit all values from the global `pfState`, a `pfGeoSet` should have a `pfGeoState` with all values set to inherit, the default.

This combination of routines allows the application to combine geometry and state in high-performance units which are unaffected by rendering order. To further increase performance, sharing `pfGeoStates` among `pfGeoSets` is encouraged.

pfGeoState Routines

Table 9-13 lists and describes the `pfGeoState` routines.

Table 9-13 `pfGeoState` Routines

Function	Description
<code>pfNewGState</code>	Create a new <code>pfGeoState</code> .
<code>pfCopy</code>	Make a copy of the <code>pfGeoState</code> .
<code>pfDelete</code>	Delete the <code>pfGeoState</code> .
<code>pfGStateMode</code>	Set a specific state mode.
<code>pfGStateVal</code>	Set a specific state value.
<code>pfGStateAttr</code>	Set a specific state attribute.
<code>pfGStateInherit</code>	Specify which state elements are inherited from the global state.
<code>pfApplyGState</code>	Apply <code>pfGeoState</code> 's non-inherited state elements to graphics.

Table 9-13 (continued) pfGeoState Routines

Function	Description
pfLoadGState	Load pfGeoState's settings into the pfState, inherited by future pfGeoStates.
pfGetCurGState	Return the current pfGeoState in effect.
pfGStateFuncs	Assign pre/post callbacks to pfGeoState
pfApplyGStateTable	Specify table of pfGeoStates used for indexing.

pfGeoState Structure

Figure 9-1 diagrams the conceptual structure of a pfGeoState.

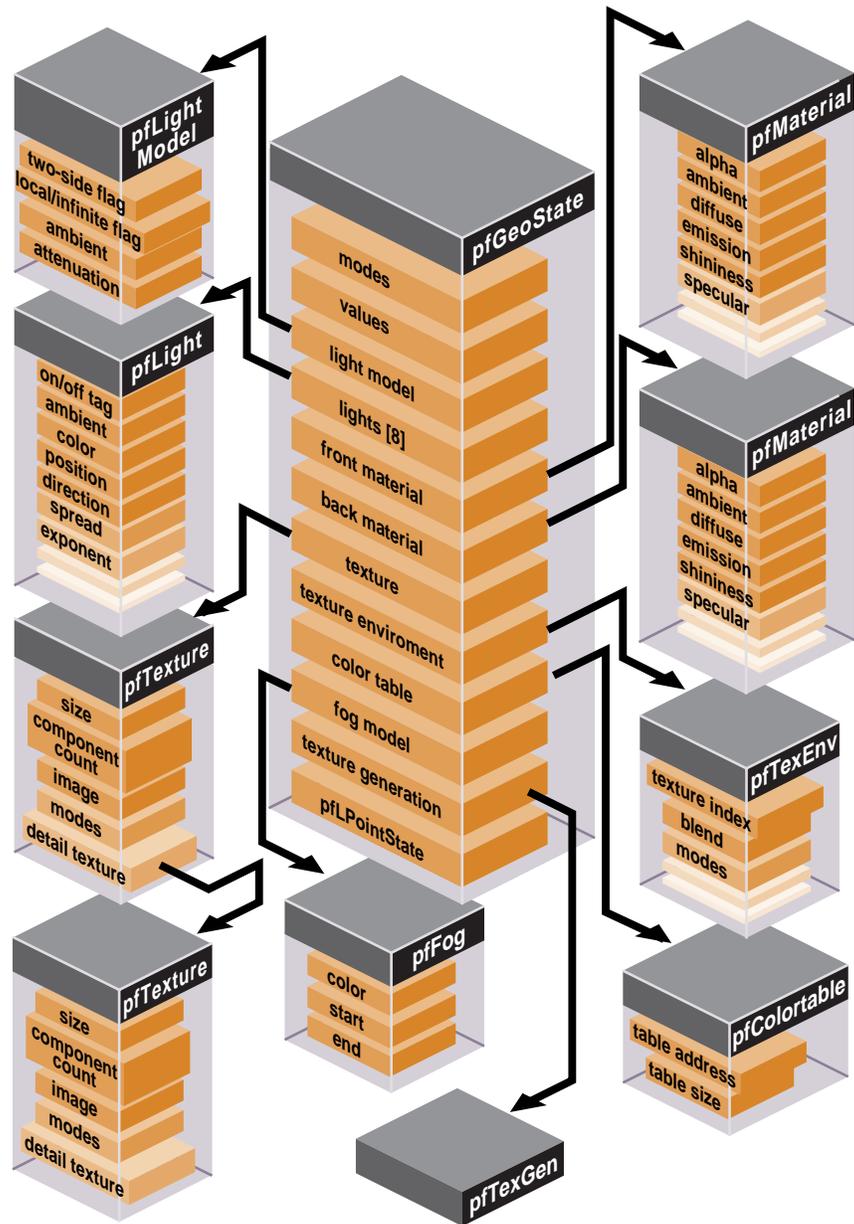


Figure 9-1 pfGeoState Structure

Chapter 10

“ClipTextures”

This chapter describes how to work with large, high-resolution textures.

ClipTextures

As CPUs get faster and storage gets cheaper, applications are moving away from scenes with small, synthetic textures to large textures, taken from real environments, giving the viewer realistic renderings of actual locations.

There has customarily been a trade-off between the complexity of a texture and the area it covers: if a texture covers a large area, its resolution must be limited so that it can fit into texture memory; high-resolution textures are limited to small regions for the same reason.

A cliptexture allows you to circumvent many of these system resource restrictions by virtualizing MIPmapped textures. Only those parts of the texture needed to display the textured geometry from a given location are stored in system and texture memory. IRIS Performer provides support for this technique, called *cliptexturing*, through a subclass of a `pfTexture` called a `pfClipTexture`. This functionality allows you to display textures too large to fit in texture memory, or even in system memory; you can put the entire world into a single texture.

IRIS Performer supports texture load management from disk to system memory and from system to texture memory, synchronizing clipped regions with the viewpoint, and many the other tasks needed to virtualize a texture relative to the viewer location.

This chapter describes cliptextures in the following parts:

- “Overview” on page 298
- “Cliptexture API” on page 313
- “Preprocessing ClipTextures” on page 313
- “Cliptexture Configuration” on page 316
- “Configuration API” on page 317
- “Post-Scene Graph Load Configuration” on page 339
- “Manipulating Cliptextures” on page 347
- “Using Cliptextures” on page 361

Overview

Cliptexturing avoids the size limitations of normal MIPmaps by clipping the size of each level of a mipmap texture to a fixed area, called the clip region. A MIPmap contains a range of levels, each four times the size of the previous one. If the clip region is larger than a particular level, the entire level is kept in texture memory. Levels larger than the clip region are clipped to the clip region's size. The clip region is set by the application, trading off texture memory consumption against image quality. The clip region size is set through the clip size, which is the length of the sides (in texels) of the clip region's sides.

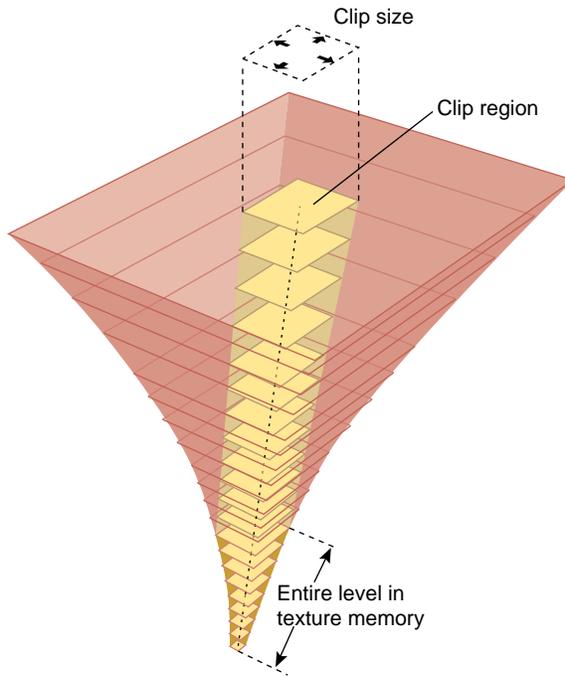


Figure 10-1 Cliptexture Components

The clip region positioned so as to be centered about the clip center, or as close as possible to the clipcenter while remaining entirely within the cliptexture. The clipcenter is set by the application, usually to the location on the texture corresponding to the location closest to the viewer on the cliptextured geometry. The clipcenter is specified in texel coordinates, which is the texture coordinates (s and t values, ranging from 0.0 to 1.0, scaled by the dimensions of the finest level of the cliptexture, level 0).

Cliptexture Levels

Texture memory contains the MIPmap levels, the larger ones clipped to the clip region size; the rectangle of texture memory corresponding to each clipped level is called a tex region. As the viewer moves relative to the cliptextured geometry, the clipcenter must be updated. When this happens, the clipped mipmap levels must have their texture data updated, in order to represent the area closest to the center. This updating usually must happen every frame, and is done by IRIS Performer image caches.

To facilitate loading only portions of the texture at a time, the texture data must first be subdivided into a contiguous set of rectangular areas, called tiles. These tiles can then be loaded individually from disk into texture memory.

Texture memory must be loaded from system memory; it can't be loaded directly from disk. In order to improve the performance of texel downloading, the region in system memory is made larger than the destination texture memory and organized into a lookahead cache, called the mem region.

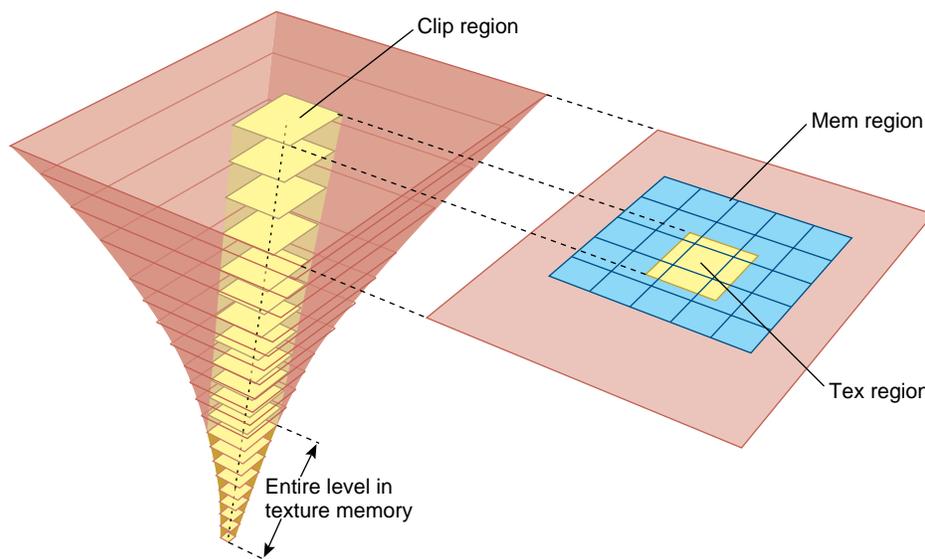


Figure 10-2 Image Cache Components

Image caches must know three things in order to update clipped texture levels:

- Where and how the data is stored on disk, so they can retrieve it,
- Location and size of system memory cache, called the mem region,
- The texture memory they are responsible to update when the cilpcenter moves (the tex region).

Cliptexture Assumptions

For the cliptexture algorithm to work seamlessly, applications must abide by the following assumptions:

- An application can only view a clip region's worth of high resolution texel data on its textured geometry from any viewpoint.
- The application views the texture from one location at a time. Multiple views require multiple cliptextures.
- The viewer must move smoothly relative to the cliptextured geometry; no "teleporting" (abrupt changes in position).

Given these assumptions, your application can maintain a high-resolution texture by keeping only those parts of the texture closest to the viewer in texture memory; the remainder of the texture is on disk and cached in system memory.

Why Do These Assumptions Work?

Only the textured geometry closest to the viewer needs a high-resolution texture. Far away objects are smaller on the screen, so the texels used on that object also appear smaller (cover a smaller screen area). In normal MIPmapping, coarser MIPmap levels are chosen as the texel size gets smaller relative to the pixel size. These coarser levels contain less texels, since each texel covers a larger area on the textured geometry.

Cliptextures take advantage of this facts by storing only part of each large MIPMap level in texture memory, just enough so that when you look over the geometry, the MIPmap algorithm starts choosing texels from a lower level (because the texels are getting small on the screen) before you run out of texels on the clipped level. Because coarser levels have texels that cover a larger area, at a great enough distance, MIPmapping is choosing texels from the unclipped, smaller levels.

When a clip size is chosen, cliptexture levels can be thought of as belonging to one of two categories:

- Clipped levels, which are texture levels that are larger than the clip size.
- Non-clipped levels, which are small enough to fit entirely within the clip region.

The non-clipped levels are viewpoint independent; each non-clipped texture level is complete. Clipped levels, however, must be updated as the viewer moves relative to the textured geometry.

Image Cache

The image cache organizes its system memory as a grid of fixed size texture tiles. This grid of texture data forms a lookahead cache, called the mem region. The cache automatically anticipates texture download requirements, updating itself with texture tiles it expects to use soon.

Image caches update texture memory by transferring image data from disk files. The data is transferred in two steps. Data is moved from disk files a tile at a time into the mem region in system memory. The mem region is updated so that it always contains the image data corresponding to the tex region and its immediate surroundings. The border of extra surrounding data allows the image cache to update the tex region as necessary without having to wait for tiles to be loaded into the mem region from disk.

The image cache also contains a tex region, the rectangle of texel data in a given level's texture memory. This rectangle of data is in texture memory, and is being updated from a corresponding rectangle of data in the memregion. As the center moves, the tex region being loaded into texture memory can get close to the edge of the mem region. When this happens, tiles in the mem region are updated with new data from disk so that the tex region is moved closer to the center of the image data.

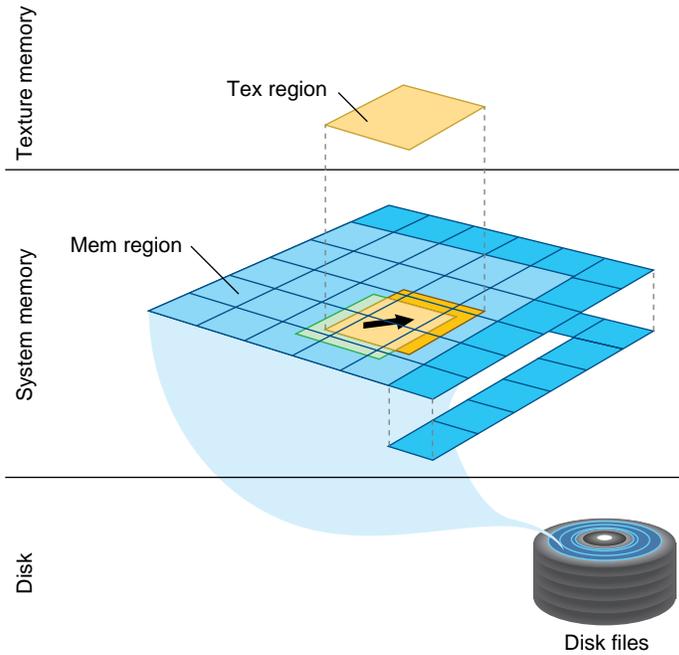


Figure 10-3 Mem Region Update

As the center moves, the clipped region on each clipped level of the image cache shifts position. The clipped regions on each level move at different rates; each coarser level only moves at one half the speed of the level above it. The image cache reflects the change on its level by tracking the position of the clipped region with its tex region. Data in texture memory must be updated to match the texel data in the translated tex region.

This updating is done by copying rectangles of texel data from the shifted tex region area in the mem region to the appropriate locations in texture memory. The amount of updating is minimized by only updating the portions of the texture memory that actually need new data. The majority of the tex region data only has to shift position in texture memory; this is done by translating texture coordinates, and taking advantage of the wrap mode when accessing texels from texture memory.

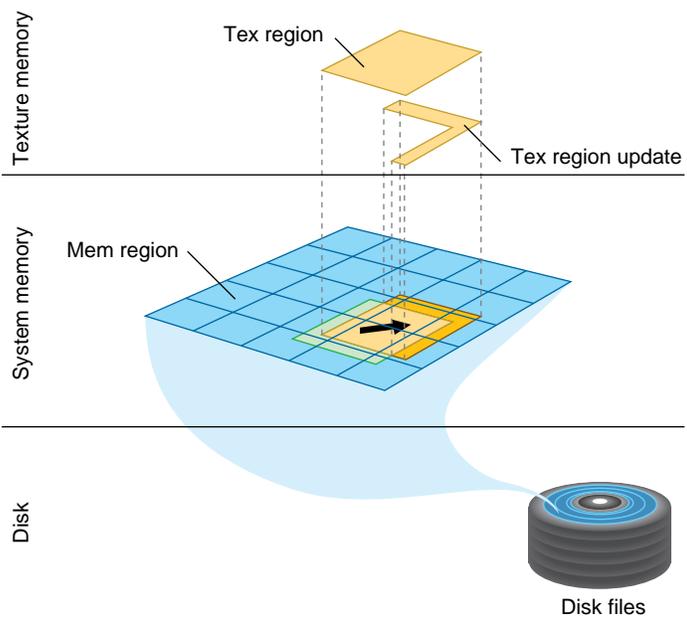


Figure 10-4 Tex Region Update

By loading textures to system memory before they're needed in texture memory, the latency caused by waiting for tiles downloading from a disk is reduced.

1. Texture data on disk is cached into system memory in an image cache's mem region.
2. Texture data in the tex region part of the mem region is used to update texture memory.

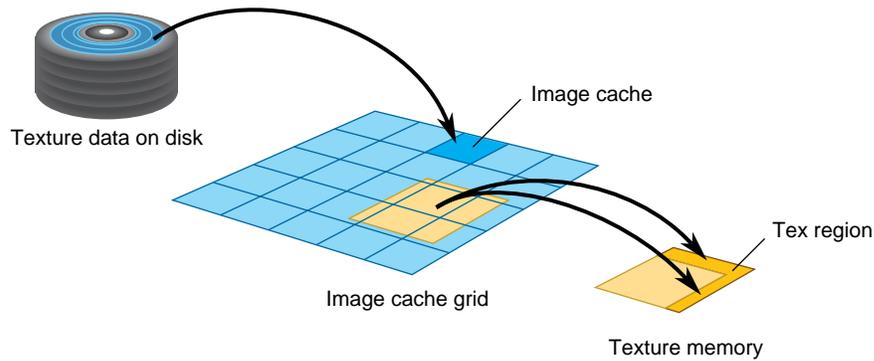


Figure 10-5 Cliptexture Cache Hierarchy

Toroidal Loading

In order to minimize the bandwidth required to download texels from system to texture memory, the image cache's tex regions are updated using *toroidal loading*. A toroidal load assumes that changes in the contents of the clip region are incremental, such that the update consists of:

- New texels that need to be loaded.
- Texels that are no longer valid.
- Texels that are still in the clip region, but have shifted position.

Toroidal loading minimizes texture downloading by only updating the part of the texture region that needs new texels. Shifting texels that remain visible isn't necessary, since the coordinates of the clip region wrap around to the opposite side.

Invalid Borders

Being able to impose alignment requirements to the regions being downloaded to texture memory improves performance. Cliptextures support the concept of an *invalid border* to provide this feature. It is the area around the perimeter of a clip region that can't be used. The invalid border shrinks the usable area of the clip region, and can be used to dynamically change the effective size of the clip region. Shrinking the effective clipsize can be a useful load control technique.

When texturing requires texels from a portion of an invalid border at a given MIPmap level, the texturing system moves down a level, and tries again. It keeps going down to coarser levels until it finds texels at the proper coordinates that are not in the invalid region. This is always guaranteed to happen, since each level covers the same area with less texels (coarser level texels cover more area on textured geometry). Even if the required texel is clipped out of every clipped level, the unclipped pyramid levels will contain it.

You can use an invalid border to force the use of lower levels of the MIPmap to:

- Reduce the abrupt discontinuity between MIPmap levels if the clip region is small: using coarser LODs blends MIPmap levels over a larger textured region.
- Improve performance when a texture must be roamed very quickly.

Since the invalid border can be adjusted dynamically, it can reduce the texture and system memory loading requirements at the expense of a blurrier image.

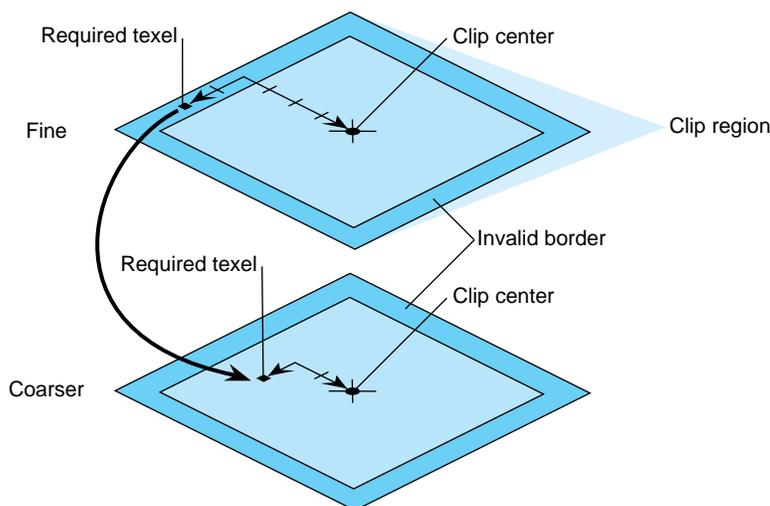


Figure 10-6 Invalid Border

Updating the Clipcenter

To figure out what part of the texture must be loaded in each of the clipped levels, you must know where the viewer is relative to the geometry being textured. Often this position is computed by finding the location of the cliptextured geometry that is closest to the viewer, and converting that to a location on the texture. This position is called the cliptexture center and it must be updated every frame as the viewer moves relative to the cliptextured geometry.

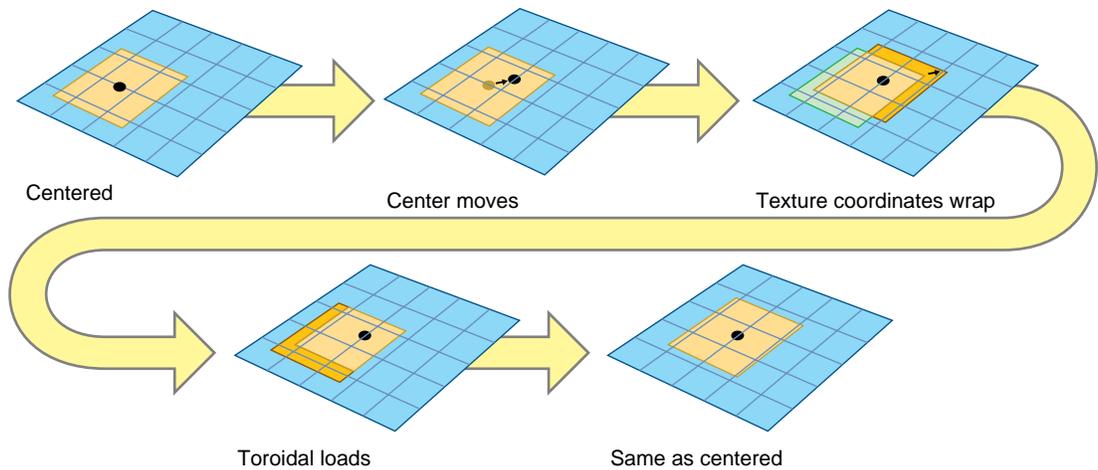


Figure 10-7 Clipcenter Moving

The clipcenter is set by the application for level 0, The cliptexture code then derives the clipcenter location on all MIPmap levels. As the viewer roams over a cliptexture, the centers of each MIPmap level move at a different rate. For example, moving the clipcenter one unit corresponds to the center moving one half that distance in each dimension in the next-coarser MIPmap level.

Most of the work of cliptexturing is updating the center properly and updating the texture data in the clipped levels reliably and efficiently each frame.

Virtual Cliptextures

Cliptextures save texture memory by limiting the extent of texture levels. Every level in the mipmap is represented in texture memory, and can be accessed as the geometry is textured. There are limits to the number of levels the cliptexturing hardware can access while rendering, which restricts the cliptextures maximum size.

This limit can be exceeded by only accessing a subset of all the MIPmap's levels in texture memory on each piece of geometry, "virtualizing" the cliptexture. The virtual offset sets a virtual "level 0" in the MIPmap, while the number of effective levels indicates how many levels starting from the new level 0 can be accessed. The minlod and maxlod parameters are used to ensure that only valid levels are displayed. The application typically divides the cliptextured terrain into pieces, using the relative position of the viewer and the terrain to update the parameter values as each piece is traversed.

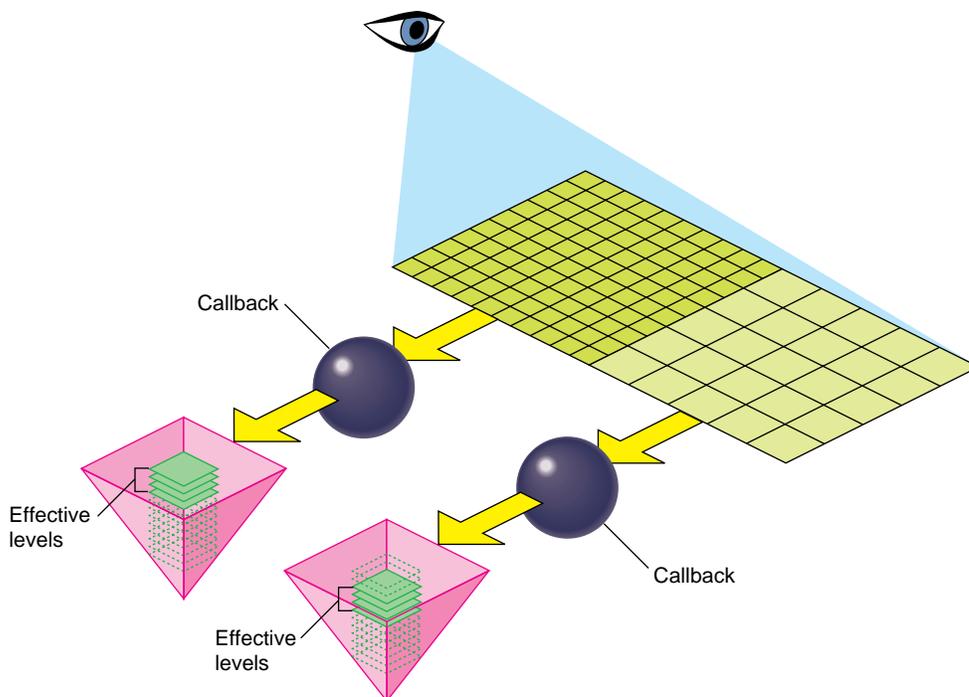


Figure 10-8 Virtual Cliptexture Concepts

For more information about virtual cliptextures, see "Virtual ClipTextures" on page 353.

Cliptexture Support Requirements

Ideally, pfClipTextures would be interchangeable with pfTextures in IRIS Performer. Unfortunately, this is only partially true. The following sections describe some of the differences between IRIS Performer textures and cliptextures.

Centering

Every level is complete in a regular texture. Cliptextures have clipped levels, where only the portion of the level near the cliptexture center is complete. In order to look correct, a cliptextures center must be updated as the channel's viewport moves relative to the cliptextured geometry.

Cliptextures require functionality that recalculates the center position whenever the viewer moves (essentially each frame). This means that a relationship has to exist between the cliptexture and a channel.

Applying

Textures only need to be applied once. Cliptextures must be applied every time the center moves (essentially each frame). In order to apply at the right time, cliptextures need to be connected to a pfPipe.

Texel Data

A texture does not know where its data comes from. The application just supplies it as a pointer to region of system memory when the texture is applied.

Cliptextures need to update their contents as the center moves and they are reapplied each frame. As a result, they need to know where their image data resides on the disk. In order to maximize performance, cliptextures also cache their texel data in system memory. As a result, cliptextures are a lot more work to configure, since you have to tell them how to find their data on disk, and how you want the data cached in system memory.

Special Features

Since cliptexture levels are so large, IRIS Performer offers additional features not available to regular textures.

Insets

With certain restrictions, cliptexture levels can be partially populated, containing “islands” of high resolution data. This can be useful if the application only needs high-resolution texel data in relatively small, widely scattered areas of a large cliptexture. A example of this might be an airline flight simulator, where high resolution data is only needed in the vicinity of the airports used by the simulator.

For more information about insets, see “Cliptexture Insets” on page 361.

Virtualization

To further increase the size of cliptextures that IRIS Performer can use, the levels themselves can be virtualized; It then selects a subset of all the available texture levels to be loaded into memory. This requires additional support by the application. Virtual cliptextures are described in detail in “Virtual ClipTextures” on page 353.

Multiple Pipe Support

Since cliptextures require both system and texture memory resources, IRIS Performer has provided functionality to share the system memory resources when a cliptexture is used in a multipipe application. “Slave” cliptextures and a “master” cliptexture share system memory resources, but have their own classes and texture memory.

How Cliptextures Interact with the Rest of the System

As a result of their special requirements, cliptextures are used differently than pfTextures with many different IRIS Performer classes. The following sections describe these differences.

Geostates

When everything is configured properly, a pfClipTexture is interchangeable with a pfTexture when used in a geostate.

Pipes

A pfClipTexture can be connected to a pfMPClipTexture, a multiprocessing component, which is connected to a pfPipe. From the pipe's point of view, a pfMPClipTexture is something it can apply to.

Channels

Some functionality must be supplied to update a cliptexture's center as the channel moves with respect to the cliptextured geometry. This functionality can be supplied by the application, or IRIS Performer can do it automatically if the application uses clipcenter nodes.

A clipcenter node is added to the scenegraph and is traversed by the APP process just like every other node in the scenegraph. pfMPClipTexture, which contains the cliptextured geometry, should be a child node of the clipcenter node. When the clipcenter node is traversed by a channel, the clipcenter node computes the relationship between the cliptextured geometry and the channel's eyepoint, and updates the cliptexture's center appropriately.

Cliptexture Support in IRIS Performer

Cliptexture is a large and diverse piece of functionality. As a result, cliptexture support is found in nearly every major library in IRIS Performer.

libpr Support

The pfImageCache class defines image caches which manage the updating of clipped levels, pfImageTile classes are used to define non-clipped cliptexture levels and define pieces of clipped levels downloaded from disk to system memory. The pfQueue class supports read queues, which manage the read requests from disk to system memory in image caches, while the pfClipTexture class itself defines cliptextures themselves, virtual mipmaps composed of image caches and image tile levels. The pfTexLoad class defines download requests when image caches download texels from system to texture memory.

libpf Support

libpf adds multiprocessing support for using cliptextures in scene graphs. the pfMPClipTexture class ties together pfClipTextures, pfPipes, cliptexture centering

functionality (often `pfuClipCenterNode` nodes) and the application itself in a multiprocessing environment. additional functionality in the `pfPipe` class ensures that cliptextures are applied properly.

libpfutil Support

libpfutil provides easy to use clipcentering functionality through the `pfuClipCenterNode` class, a subclass of the `pfGroup` class. This library also provides traversals to simplify the work of finding cliptextures in a scene graph using `pfuFindClipTextures()`, code for post loader configuration, where `pfMPClipTextures` are created, and attached to pipes and clipcenter nodes using `pfuProcessClipCenters()` and `pfuProcessClipCentersWithChannel()`. The `pfuAddMPClipTextureToPipes()` and `pfuAddMPClipTexturesToPipes()` routines connect `pfMPClipTextures` to the proper pipes, handling multipipe issues in a clean way. Load time configuration is simplified using the `pfuInitClipTexConfig()`, `pfuMakeClipTexture()`, and `pfuFreeClipTexConfig()` along with the appropriate callbacks for image caches and image tiles. Image cache configuration is supported with `pfuInitImgCacheConfig()`, `pfuMakeImageCache()`, and `pfuFreeImgCacheConfig()` routines.

libpfdu Support

The cliptexture configuration file parsers are supported here; `pfdLoadClipTexture()` and `pfdLoadClipTextureState()` work with cliptexture configuration files to simplify the creation and configuration of cliptextures. The companion programs that create and configure `pfdLoadImageCache()` and `pfdLoadImageCacheState()`. All of these parsers use the `pfuMakeClipTexture()` and `pfuMakeImageCache()` configuration routines.

libpfdb Support

Example cliptexture loaders, including the *libpfim* example cliptexture loader, the *libpfct* demo loader and *libpfvct* virtual pseudo loader are all included here.

Cliptexture Manipulation

While the scene graph is being viewed, the application may want to dynamically alter the appearance or performance characteristics of the cliptexture. The `mpcliptexture` provides functionality to support parameter changes in the APP process, providing frame-accurate updating. Here are some of the parameters that might be changed.

Load Control

The DTR functionality (described in detail elsewhere in this chapter) is largely automatic. Some high performance applications may need to adjust DTR parameters to improve appearance performance trade-offs.

Invalid Border

The invalid border can be adjusted at runtime to shrink the effective size of the clip region. This might be done to provide additional load control beyond the per-level control that DTR provides.

Share Masks

When operating master and slave cliptextures in a multipipe application, the application may want to change the sharemask, which controls the synchronization of parameters between master and slave cliptextures.

Read Function

The image cache creates requests to read image tiles from disk to the image cache's system memory cache. The read function processes these requests and actually does the data transfer. IRIS Performer provides set of read functions that attempts to do direct-io reads for speed, but falls back to normal reads if direct-IO is not possible.

The application can replace the IRIS Performer default function with its own custom read function. This could be useful for implementing special functionality, such as dynamic decompression of cliptexture data.

Read Queue Sorting

The read queue provides dynamic sorting of the read requests to improve performance and minimize latency. The application can provide custom sorting routines.

Cliptexture API

Cliptexturing has a large API. Not only is there are lot of cliptexture functionality scattered throughout the library, but there is often more than one way to use a particular piece of functionality. In order to make things clearer, and make it easier to use the API described here, the cliptexture API is grouped and ordered in the same way an application writer would use it.

The API is grouped into four sections:

- Preprocessing the cliptexture data.
- Configuring cliptextures and image caches.
- Post-load-time configuration.
- Run-time manipulation.

Preprocessing ClipTextures

Before using cliptextures, large textures must be preprocessed, as follows:

1. Start with the highest-resolution version of the image (texture) and build a MIPmap of the image.
2. Choose a clip size.
3. Tile each MIPmap level.

Every image that is larger than the clip size must be cut into tiles. All of the tiles in one MIPmap level must be equal in size. You generally choose a tile size that's about 1/4 of the clip size or less.

4. Divide the levels into separate files to maximize download performance.
The files should be named properly so that the image caches can access them.
5. If the configuration parsers are used, cliptexture configuration files are also created at this time.

The following sections describe the steps in this procedure in greater detail.

Building a MIPmap

Building a MIPmap of an image requires an algorithm that performs the following tasks:

1. Start with the highest-resolution version of the image (texture). The image dimensions in pixels must be in powers of 2, for example, 8192 X 8192.
2. Average every four adjacent texels of a high resolution image into a single texture (essentially blurring it and shrinking it by a factor of two in both dimensions).
3. Save the result as a new, blurrier, smaller image.
4. Convert the MIPmaps into a compatible format.
5. Repeat the first two steps with each blurrier image until you have a single texel whose color is the average of all the texel colors in the original image.

Each successive reduction is called a level of detail (LOD). The more the reduction, the higher the level of detail, the coarser the image.

There are a variety of tools that tile textures. IRIS Performer provides some simple ones available in the `/usr/share/Performer/src/tools` directory. They are listed in Table 10-1.

Table 10-1 Tiling Algorithms

Program	Description
rsets	Shrinks and tiles one or more .rgb image files recursively. rsets stops tiling when it reaches the clip size you give it. rsets assumes that the original image is square.
rgb2raw	Converts .rgb images into a raw format that can be downloaded directly into texture memory. Files should be in a raw format to avoid conversions at download time.
shrink	Is a subset of rsets functionality; makes a tree-like structure of LOD images from an .rgb image.
to5551	Converts from .rgb to the 5551 raw format.
to888	Converts from .rgb to the 888 raw format.
to8888	Converts from .rgb to the 8888 raw format.
viewtile	Enables the user to view a raw format image tile.

For more information about MIPmaps, see the *OpenGL Programming Guide*.

Formatting Image Data

The texel data must be in a format that can be used in IRIS Performer textures. This means the texels must have contiguous color components, whose size and type match a supported format. Keep in mind that these texels will be loaded dynamically, on an as-needed basis, so the smaller the size of each texel, the better the performance of the cliptexture. You should choose the smallest texel format that provides acceptable color quality. A good choice might be RGBA 5551, which takes up 16 bits per texel. IRIS Performer provides some tools for converting from rgb format to 5551 or 888 RGBA. They are named *to5551* and *to888* and are found in */usr/share/Performer/src/tools*.

For more information about file formats, see “Building a MIPmap” on page 314.

Tiling an Image

Dividing a texture into tiles allows you to look at a subset of all texels in the texture. In this way, you can selectively download from disk into the texture memory only those texels that the user is viewing and those they might soon look at. Since downloading texture tile files from disk to texture memory takes a long time, the image caches decide which tiles a viewer might need next and download them in advance.

Note: In the highest resolution LOD, one texel corresponds to one pixel.

Texel tiles in each level are loaded into memory separately, from coarsest to finest. The high-resolution tiles take longer to download than the coarser tiles. If a viewer advances through a scene so quickly that the high-resolution tiles cannot download from disk into texture memory in time, lower-resolution tiles are displayed instead. The effect is that if the viewer goes too fast, the tiles become blurry. When the viewer slows down, the tiles displayed are less coarse.

Using lower instead of higher-resolution levels is controlled by cliptexture’s load control mechanism, DTR. Without DTR, IRIS Performer waits for *all* of the levels to download before displaying any one of them. DTR removes this restriction, displaying the levels that have been downloaded.

If you want to break up a rgb image into tiles, IRIS Performer provides the *subimg* program in */usr/share/Performer/src/tools*.

Tile Size

Small tiles, while less efficient, are better at load leveling, since the time it takes to load a new tile into system memory is smaller. It also means that the total size of an image cache in system memory can be smaller. We've found that tile sizes of 512 x 512 and 1024 x 1024 provide a good trade-off between download efficiency and low latency, but download performance is very sensitive to system configuration. Experimenting is the best way to find a good tile size.

Cliptexture Configuration

After preprocessing the texture data, you need to configure cliptextures. Configuration is actually a two step process; the configuration that can be done by the scenegraph loader, and the configuration that requires pfPipes and pfChannels to be present. We'll discuss the first stage of configuration here.

Configuration Considerations

An application must configure the cliptexture in two steps:

- Loader—when the scene graph is constructed.
- Post-loading—when the channel and pipes are known to the application.

This process is complex. IRIS Performer supplies a number of utilities to make the job easier.

To manipulate cliptexture parameters, the application makes calls to the pfMPClipTexture in the APP process. The pfMPClipTexture updates the cliptexture in a frame-accurate manner.

Load-Time Configuration

This is the time the scene graph is being constructed. Geostates are pointed to cliptextures; the cliptextures themselves are created and configured using the cliptexture configuration files and the libpfdu parsers. If the application does its own configuration, it should use the libpfutil routines to simplify the process and to ensure adequate error checking. If the application opts to use IRIS Performer clipcentering support, clipcenter nodes are inserted into the scenegraph at the root of the cliptextured geometry and connected to the corresponding cliptexture.

Post-Load-Time Configuration

At this stage the scene graph has been created and the channels and pipes have been defined. The libpfutil traversers (**pfuProcessClipCenters()** or **pfuProcessClipCentersWithChannel()**) are used to create pfMPClipTextures, connecting them with the appropriate cliptextures and clipcenter nodes. These routines return a list of pfMPClipTextures, which can be used to with **pfuAddMPClipTextureToPipes()** and **pfuAddMPClipTexturesToPipes()** to attach the pfMPClipTextures to the appropriate pfPipes. These routines can be used for single pipe and multipipe applications with little or no change to the calling sequence.

Configuration API

Since cliptexture configuration is complex, we provide three different cliptexture configuration API layers, allowing different trade-offs between flexibility and simplicity.

libpr Functionality

The lowest layer, using the libpr calls, is the most complex and difficult. A cliptexture has the same configuration requirements as a MIPmapped pfTexture, where texel format, type and texture dimensions must be configured. In addition, cliptextures have to know about system memory caching, the file configuration of the texture data, load control, read queue, and other cliptexture specific configurations.

Using the libpr layer directly is not recommended, since it is error prone and does not buy much flexibility compared to the libpfutil configuration routines. Here is a list of the libpr calls you must consider when configuring a cliptexture directly:

These are the functions needed to configure the cliptexture itself. The cliptexture contains two types of levels: image cache levels and image tile levels. Image caches support clipped levels in a cliptexture. They know where their texture data resides on disk, they understand clip regions, and setup system memory caching and updating. Every properly-configured image cache points to an image tile, called a proto tile, which contains global information about the texel format, size, and file information about the image tiles the image cache uses to update clipped texture levels.

Configuring an Image Cache Level

Image tiles can be used by themselves to represent unclipped levels. Essentially the unclipped level is represented by a single tile covering the entire level. Because image tiles do not understand clip regions and can not do dynamic updating, image tiles cannot be used to represent clipped levels.

To configure an image cache level, use the following calls:

- `pfNewClipTexture`
- `pfTexName`
- `pfClipTextureVirtualSize`
- `pfClipTextureClipSize`
- `pfTexImage`
- `pfTexFormat`
- `pfClipTextureInvalidBorder`
- `pfClipTextureEffectiveLevels`
- `pfClipTextureAllocatedLevels`
- `pfClipTextureLevel`

Configuring an Image Cache Proto Tile

There are also image tile calls in this sequence. They are used to configure the image cache's proto tile, which is used as a template for the tiles the image cache will use to load texel data from disk to system memory cache.

To configure an image cache proto tile, use the following calls:

- `pfNewImageTile`
- `pfImageTileReadFunc`
- `pfGetImageTileMemInfo` (page size)
- `pfImageTileMemInfo`
- `pfImageTileReadQueue`
- `pfImageTileHeaderOffset`

- `pflmageTileNumFileTiles`
- `pflmageTileSize`
- `pflmageTileFileName`
- `pflmageTileFileImageType`
- `pflmageTileMemImageType`

Configuring an Image Cache

To configure an image cache, use the following calls:

- `pflmageCacheName`
- `pflmageCacheTexRegionOrigin`
- `pflmageCacheMemRegionOrigin`
- `pflmageCacheImageSize`
- `pflmageCacheMemRegionSize`
- `pflmageCacheTileFileNameFormat`
- `pflmageCacheTexRegionSize`
- `pflmageCacheMemRegionSize`
- `pflmageCacheTex`
- `pflmageCacheTexSize`
- `pflmageCacheFileStreamServer`
- `pflmageCacheProtoTile`—copies the information into the image cache's proto tile.
- `pfDelete (tmp proto tile)`—now that it's copied into the image cache, you can delete it.

Configuring a pfTexture

Image caches can be used independently of `cliptextures`, if they are, they need to be associated with a `pfTexture`, and that texture needed to be configured.

To configure a pfTexture, use the following calls:

- pfTexImage
- pfTexFormat

Configuring the Default Tile

Image caches can have a default tile defined, which is the tile to use if a tile on disk can't be found. Default tiles can be useful for "filling in" border regions of a cliptexture level. Default tiles are covered in more detail in section "default_tile" on page 332.

To configure the default tile, use the following calls:

- pfNewImageTile
- pfCopy (proto to default)
- pfImageTileFileName
- pfImageTileReadQueue
- pfImageTileDefaultTile

Configuring Image Tiles

Image tiles need their own configuration, since they need to know about the file they should load from, texel formats, etc.

To configure an image tile, use the following calls:

- pfNewImageTile
- pfImageTileMemImageFormat
- pfImageTileFileImageFormat
- pfImageTileMemImageType
- pfImageTileSize
- pfImageTileHeaderOffset
- pfClipTextureLevel
- pfLoadImageTile

Configuration Utilities

Using the libpr calls to configure a cliptexture is difficult and error prone. IRIS Performer provides utilities to make cliptexture configuration easier and more robust. The configuration utility API is broken into two groups. One group is used to configure cliptextures, the other configures image caches. Each group contains three functions, an init function, a config function, and a free function. These functions work with a structure that the application fills in.

The init function initializes the optional fields in the structure with default values, and the mandatory fields with illegal values. Configuring the structure allows the configuration function to do more error checking, and to allow the application to avoid the tedium of filling in optional field. The application then sets fields in the structure to parameterize how the cliptexture or image cache should be configured. The application then calls the configuration function on the filled in structure. The free function is then called with the structure to ensure that all allocated values are freed.

Cliptexture Configuration

Methods to configure the cliptexture include:

`pfuInitClipTexConfig(pfuClipTexConfig *config)`

Initialize the values of the `pfuClipTexConfig` structure that has been allocated by the application.

`pfuMakeClipTexture(pfuClipTexConfig *config)`

Return a cliptexture configured as directed by the values in the `pfuClipTexConfig` structure.

`pfuFreeClipTexConfig(pfuClipTexConfig *config)`

Free any malloc'd structures that the application or the init function may have created.

Image Cache Configuration

Methods to configure the image cache include:

`pfuInitImgCacheConfig(pfuImgCacheConfig *config)`

Initialize the values of the `pfuClipTexConfig` structure that has been allocated by the application.

`pfuMakeImageCache(pfuImgCacheConfig *config)`

Return a `cliptexture` configured as directed by the values in the `pfuClipTexConfig` structure.

`pfuFreeImgCacheConfig(pfuImgCacheConfig *config)`

Free any `malloc`'d structures that the application or the `init` function may have created.

All of these functions are defined in `libpfutil/cliptexture.c`. The structures themselves are defined in `pfutil.h`.

Filling in the Structures

Filling the `pfuImgCacheConfig` structure to create and configure the image cache is considerably simpler than setting fields in the `pfuClipTexConfig` structure. This is because the `cliptexture` configuration fields must also create and configure image cache and image tiles to populate its levels. The configuration code does this supplying a function pointer to configure the image cache levels and a function pointer for configuring image tile levels. Each function pointer also has a void data pointer so you can pass data to the functions. The function pointers expect functions with the following forms:

```
pfImageCache *exampleICacheConfigFunction(pfClipTexture *ct,  
    int level, struct _pfuCilpTexConfig *icInfo)
```

```
pfImageTile *exampleITileConfigFunction(pfClipTexture *ct,  
    int level, struct _pfuClipTexConfig *icInfo)
```

The `cliptexture` and image cache configuration parsers, described in the next section, use the configuration utilities. You can look at the parsers as example code. For example, you may want to look at `pdfLoadImageTileFormat()` and `pdfLoadImageCache()` formats for example functions for the function pointers. The parsers are in the `/usr/share/Performer/src/lib/libpfd/pfdLoadImage.c` file.

Configuration Files

The easiest and most commonly used method to configure cliptextures is to create cliptexture and image cache configuration files, then use the configuration parsers to create and configure cliptextures. The configuration files can be created and stored along with the texture data files. Configuration files allow an application or loader to simply call a single function to create and configure cliptextures.

Configuration files are ascii text files containing a token parameter format. Values are separated by white space and the token parameter sequences can be placed in the file in arbitrary order. Comments can also be added to the configuration files, making them self-documenting.

Using Configuration Files

Four parser functions are available to create and configure cliptextures and image caches using configuration files:

```
pfClipTexture *pfdLoadClipTexture(const char *fileName)
```

```
pfImageCache *pfdLoadImageCache(const char *fileName)
```

These parser functions take a configuration file name, and use it to configure and create a cliptexture or an image cache respectively. The cliptexture configuration file may refer to image cache configuration files, which will be searched for and used automatically.

Two other versions of these parsers also take a pointer to a configuration utility structure. This allows the user to pre-configure using the configuration structure, then finish with the parser and configuration files.

```
pfClipTexture *pfdLoadClipTextureState(const char *fileName,  
                                       pfuClipTexConfig *state)
```

```
pfImageCache *pfdLoadImageCacheState(const char *fileName,  
                                       pfuImgCacheConfig *state)
```

The parsers use IRIS Performer's **pfFindFile()** functionality to search for the configuration files. The parsers support environment variable expansion and relative pathnames to make it simpler to create configuration files that refer to other configuration or data files.

Creating Configuration Files

To successfully use cliptextures, you must first prepare the texture data and create the configuration files:

1. Create an image cache configuration file for each level using an image cache in the cliptexture.

The configuration file should describe the:

- Format and tiling of the texture data.
- Location and names of the files containing the texture data.
- Size of the tex region in texture memory.
- Size and layout of the mem region in system memory.

2. Create a cliptexture configuration file.

It contains the:

- Name and location of each image cache configuration file.
- Names and locations of the texture data for each image tile level in the cliptexture. Remember, image tile levels can't be clipped levels, so they can only be used in the pyramid levels. Image cache levels can be used anywhere.
- General properties of the cliptexture.
- Look at the example cliptexture configuration files in the */usr/share/Performer/data/clipdata* directory. The cliptexture configuration files use the .ct suffix. The image cache configuration files use .ic for their suffixes.

3. Test the image cache configuration files individually, using the *pguide/libpr/C/icache* program.
4. Test the cliptexture configuration file using the */pguide/libpr/C/cliptex* or the */pguide/libpf/C/cliptex* programs
5. When the configuration and data files are complete and tested, your application can create and configure a cliptexture by calling **pfdLoadClipTexture(fname)** using the name of the cliptexture configuration file. If more control is needed, you can use **pfdLoadClipTextureState(fname, state)** initializing and configuring the configuration utility cliptexture structure, *pfuClipTexConfig*.

Configuration File Tips

Unfortunately, cliptexture configuration is not trivial, even with documentation and example programs. Success in creating working configuration files requires a two prong approach:

- Keep them simple: set the minimum number of fields possible. Take advantage of default value. Try to find a similar example configuration file to copy from.
- Work bottom-up: create and test image cache configuration files first, gradually building up to the cliptexture configuration file.

We've found that parameterized naming of the image caches and tile files works the best. If you've named your files consistently, this can be easy. If things don't work, you can fall back and name your file explicitly as a sanity check. Read the error messages carefully; they try to point out where in the configuration file the parser found problems. If you need more information, try re-running the program with PFNFYLEVEL set to 5 or 9.

A number of example configuration files and cliptextures are available on the IRIS Performer release. Working from one of them can save a lot of time. Some places to look are:

- *data/clipdata/hunter*
- *data/clipdata/moffett*
- *data/asddata*

Cliptexture Loaders

Finally, your application might be able to take advantage of some of the cliptexture loaders. The libpfim loader supports loading a cliptexture, and updating its center as a function of viewposition. The libpfct loader creates a cliptexture with simple terrain. Virtual cliptextures, mentioned in "Virtual ClipTextures" on page 353, can also be created using the libpfspherepatch or libpfvct loaders. These loaders can be used as examples if you need to write your own loader that supports cliptextures.

Image Cache Configuration File Details

Image cache configuration files supply the following information to IRIS Performer:

- Format of the texel data.
- Size of the entire texture at a particular MIPmap level.
- How to find the files containing the texel data for this image cache.
- Size and layout of image cache tiles in memory.
- Size of the image cache that should be kept in texture memory.
- A default image tile to use if one is missing.
- The size each level should be clipped to
- The amount of border that should be invalidated at each level
- How to find the image cache configuration files
- How to find the tiles consisting the levels that aren't image caches

Configuration Fields

Configuration fields are either tokens or parameter values, as listed in Table 10-2. All fields are character strings and all parameters must be separated by white space. The token names marked with an asterisk (*) are optional, and default to reasonable values.

Table 10-2 Image Cache Configuration File Fields

Token Name	Parameters	Description
ic_version2.0	no data field	Starts image cache config files: type and version
*tex_size	3 integers	area of tex memory for level if not tex_region_size
*header_offset	integer	beginning of file to skip over in bytes
*tiles_in_file	3 integers	dimensions of grid of tiles stored in each file
*s_streams	filepath list	list of streams used to access files in S dimension
*t_streams	filepath list	list of streams used to access files in T dimension
*r_streams	filepath list	list of streams used to access files in R dimensions
*default_tile	filepath string	tile to use if expected tile isn't available

Table 10-2 (continued) Image Cache Configuration File Fields

Token Name	Parameters	Description
*page_size	integer	system page size; memory allocation alignment
*read_func	1 or 2 strings	custom read function; library, func or func in app
*lookahead	integer	extra tiles in mem region for lookahead caching
ext_format	string	External format of stored texels
int_format	string	Internal format used by graphics hw
img_format	string	Image format of stored texels
icache_size	3 integers	size of complete image level in texels
tex_region_size	3 integers	area to load in texture memory; matches clip size
mem_region_size	3 integers	dimensions of system memory cache in tiles
tile_size	3 integers	dimensions of each file in texels
tile_format	scanf-style string	parameterized path to tile files
tile_params	list of symbols	parameter types in order in tile_format string

Image Cache Configuration File Description

The `ic_version2.0` token must be first in an image cache configuration file. This token identifies the file as an image cache configuration file and what version the configuration file is formatted in.

Next the parser looks for tokens and any associated data values. In general, the order of the tokens in the file must follow the sequence specified in the table above. The tokens marked with an asterisk are optional. Optional tokens have default values, which are used if the token and value are omitted. Tokens can have:

- No arguments.
- A fixed number of arguments.
- A variable number of arguments.

If a token has a fixed number of arguments, the token must be followed by a white space-separated list containing the specified number of arguments. If the token has a variable number of arguments, one of its arguments specifies the number of arguments used.

Any time a token is expected by the parser, a comment can be substituted. A comment can't be put anywhere in the file, however. For example, if a token expects arguments, you can't place a comment between any of them; you have to place it after all of the previous tokens arguments. There are a variety of supported comment tokens; they are interchangeable. The comment tokens are `#`, `//`, `;`, `comment`, or `rem`.

ext_format, int_format, and img_format

One of the first things that must be specified in an image cache is the format of the texel data. This includes the external format (`ext_format`), internal format (`int_format`) and image format (`img_format`). The arguments expected by these format parameters are the ascii string names of the format's enumerates. For example, a valid external format would be `ext_format PFTex_FLOAT`. Consult the pTexture man pages for a list of the valid formats of each type.

icache_size, mem_region_size, and tex_region_size

The next set of parameters that must be specified in the image cache configuration file is its size on disk, in system memory, and in texture memory. The `icache_size` token requires the size of the image cache. This means the dimensions, in texels, in the *s*, *t*, and *r* dimensions of the complete texture at this level. Since three dimensional textures are not currently supported, the *r* parameter will always be 1.

An image cache's texels are organized into a set of fixed sized pieces, called tiles. Both in system memory and on disk, the texels are broken up this way. At any given time, an array of these texel tiles are cached in system memory. They are arranged as an array in system memory. If the center of the image cache nears the edge of this array, the most distant tiles are dropped out, and new tiles are read in from disk. The larger the array of tiles in system memory, the more of the complete texture is cached there, and the less likely new tiles may need to be swapped in. The benefit is offset by the cost of tying up more system memory to hold the texel tiles.

The arrangement and dimensions of tiles in system is defined for each image cache, and is set with the `mem_region_size` token. This token expects three arguments which determine the number of tiles in the *s*, *t*, and *r* dimensions of the grid. Since three dimensional textures aren't currently supported, the *r* dimension is always 1.

A subset of the texels in system memory are cached in the texture memory itself. These texels are arranged in a rectangular region. The dimensions of this region are defined by the `tex_region_size` token. It expects three arguments, the number of texels in the *s*, *t*, and *r* dimensions. Again, since three dimensional textures aren't supported, the *r* value is always 1.

The image cache configuration file allows some leeway in the arrangement of texel tiles on disk. There can be one or more tiles on each disk file, and the file itself could contain non-texel information at the beginning of the file. The tiles themselves can have user-specified dimensions. While there is some flexibility in how tiles are stored in files on disk, there are restrictions also. Any header must be the same size for every file in an image cache. The same is true for the tile size, and the number and layout of tiles in each file. If there is more than one tile in a file, the tiles must be arranged in row-major order. In other words, as you pass from the first tile to the last, the *s* dimension must be incrementing fastest.

tile_format and tile_params

The image cache texel data is stored in one or more files. The configuration file provides a way for IRIS Performer to find these files. The files usually have similar names, varying in a predictable way, such as by tile position in the image cache array and size of the image cache. The files themselves are grouped in on or more directories. The file name and file path information is divided into a number of groups within the configuration file. There is a scanf-style string specifying the path to find image cache files. There are a number of parameters in the string that vary as a function of the tile required, and characteristics of the image cache.

The next group of tokens describes the location of the configuration files defining the location of the texture data tiles for the image cache. You can define the texture tile configuration filenames with a scanf-style string containing parameter values, as is done with image caches. To create parameterized image cache names, you must define the `tile_format` and `tile_params` tokens.

The `tile_format` token is followed by a scanf-style string describing the filepath and filename of the image cache configuration files. The argument contains constant parts, interspersed with `%d` or `%s` parameters. The number of parameters must match the number of symbols supplied as parameters to the `tile_params` token. If the `tile_format` string starts with the pattern `ENVNAME`, `{ENVNAME}` or `(ENVNAME)`, then the value of `ENVNAME` will be assumed to be an environment variable, and expanded into the `basename`.

The possible values of the image tile file name parameters is given in the table below.

Table 10-3 Image Tile Filename Tokens

Image Tile Filename Tokens	Description
PFIMAGECACHE_TILE_FILENAMEARG_VSIZE_S	Virtual size S width
PFIMAGECACHE_TILE_FILENAMEARG_VSIZE_T	Virtual size T width
PFIMAGECACHE_TILE_FILENAMEARG_VSIZE_R	Virtual size R width
PFIMAGECACHE_TILE_FILENAMEARG_TILENUM_S	Tiles from origin in S
PFIMAGECACHE_TILE_FILENAMEARG_TILENUM_T	Tiles from origin in T
PFIMAGECACHE_TILE_FILENAMEARG_TILENUM_R	Tiles from origin in R
PFIMAGECACHE_TILE_FILENAMEARG_TILEORG_S	Texels from origin in S
PFIMAGECACHE_TILE_FILENAMEARG_TILEORG_T	Texels from origin in T
PFIMAGECACHE_TILE_FILENAMEARG_TILEORG_R	Texels from origin in R
PFIMAGECACHE_TILE_FILENAMEARG_STREAMSERVERNAME	From streams
PFIMAGECACHE_TILE_FILENAMEARG_CACHENAME	The <code>tile_base</code> value
PFIMAGECACHE_TILE_FILENAMEARG_FILENUM_S	Files from origin in S
PFIMAGECACHE_TILE_FILENAMEARG_FILENUM_T	Files from origin in T
PFIMAGECACHE_TILE_FILENAMEARG_FILENUM_R	Files from origin in R

header_offset, tiles_in_file, and tile_size

The `header_offset` argument specifies the size of the file's header in bytes. This many bytes will be skipped over as a file is read. The `tiles_in_file` token requires three arguments, specifying the number of tiles in the s, t, and r dimensions. The r dimension must always be 1, since 3d textures aren't supported. The `tile_size` parameter defines the texel dimensions of each tile in s, t, and r. Again, r must be 1. Both the `header_offset` and the `tiles_in_file` tokens are optional. They default to the values 0 and 1 1 1 respectively, specifying no header and a single tile in each file.

One of the major bottlenecks to sustained cliptexture performance is the speed of copying texels from disk to system memory. Cliptextures can be configured to maximize the bandwidth of this transfer, by distributing image tiles over multiple disks, and downloading them in parallel. The streams section of the configuration file is used for this purpose.

num_streams, s_streams, t_streams, and r_streams

A stream, short for stream device, can be thought of as a separate disk that can be accessed in parallel with other disks. Each disk is mounted in a file system, and therefore has a unique filepath segment. The streams tokens allow the user to identify these stream filepath segments, and how the image tiles are distributed among them. The stream devices are arranged in a three dimensional grid, with s, t, and r dimensions, just like the image tiles are in memory. The stream device is accessed by taking the position of the tile, counting tiles from the origin in the s, t, and r directions, and generating a coordinate, modulo the number of stream devices in the corresponding s, t, and r directions. The s, t, and r values generated are used to look up the appropriate stream device. If the stream server name is part of the tile file name format string, it effects which disk is used to find the tile.

Stream servers improve bandwidth at the expense of duplicating image tiles over multiple disks. You must insure that the proper image tiles are available for any disk which is addressed by the tile's s, t, and r coordinates modulo the available number of stream servers for each of those dimensions. The stream server tokens are optional. The `s_streams` token is followed by a list of filepaths. These are the names that will be indexed from the list by taking the s coordinate of the tile's position in the image cache grid, modulo the number of s stream devices. The names in the `s_stream` list do not have to be unique.

The `t_streams` and `r_streams` tokens work in exactly the same way, in the t and r directions, respectively.

Sometimes only a subregion of the entire cliptexture is of interest to the application. This is especially true when you consider that the number of tiles in the s, t, and r directions must all be a power of two. To save space, improve performance, and make creating image caches more convenient, a default tile can be defined, and tiles of no interest can simply be omitted. If a tile can't be found, and a default tile is defined, then the default one is used in place of the missing one.

default_tile

Unlike normal tiles, which are read from disk as they are needed, the default tile is loaded as part of the configuration process. The tile is named in the configuration file as the argument to the `default_tile` token. The argument is a filepath to the default tile. If the `tile_base` token has been defined, it is pre-pended to the file path, otherwise it is used as-is.

Cliptexture Configuration File Details

Image cache configuration files supply the following information to IRIS Performer:

- Format of the texel data.
- Size of the entire texture at a particular MIPmap level.
- How to find the files containing the texel data for this image cache.
- Size and layout of image cache tiles in memory.
- Size of the image cache that should be kept in texture memory.
- A default image tile to use if one is missing.
- The size each level should be clipped to
- The amount of border that should be invalidated at each level
- How to find the image cache configuration files
- How to find the tiles consisting the levels that aren't image caches

Configuration Fields

Configuration fields are either tokens or parameter values, as listed in Table 10-4. All fields are character strings and all parameters must be separated by white space.

Table 10-4 Cliptexture Configuration File Fields

Token Name	Parameters	Description
# or // or ; or comment	<i>comment</i>	comment symbols; comment to end of line
ct_version2.0	no data field	Starts file: type and version
ext_format	string	External format of stored texels
int_format	string	Internal format used by graphics hw
img_format	string	Image format of stored texels
virt_size	3 integers	size of complete texture at level 0 (finest level)
clip_size	<i>integer</i>	size of clip region square for clipped levels
*invalid_border	integer	width of clip region perimeter to not use
*tile_size	3 integers	size of tiles (used when if no icache config files)
*smallest_ichache	3 integers	smallest icache level dimensions
*lookahead	integer	extra tiles in mem region
*ichache_format	scanf string	ichache fnames: no field? list files
*effective_levels	integer	levels used for texturing in virtual cliptexture
*ichache_params	string list	format tokens in order
*ichache_files	list of filenames	only if ichache_format is default
*tile_files	list of filenames	pyramid; only if tile_format default
*effective_levels	integer	levels used for texturing in virtual cliptexture
*allocated_levels	integer	total virtual cliptexture levels in texture memory
*header_offset	1 integer	Byte offset to skip user's file header
*tiles_in_file	3 integers	Image tile arrangement in each file
*read_func	1 or 2 strings	custom read function; lib & func or func in app

Table 10-4 (continued) Cliptexture Configuration File Fields

Token Name	Parameters	Description
*tile_format	scanf string	Tile filename format
*tile_params	string list	Format parameter tokens in order
*page_size	integer	system page size; memory allocation alignment

Cliptexture Configuration File Description

The `ct_version2.0` token must be first in an cliptexture configuration file. This token identifies the file as an cliptexture configuration file and what version the configuration file is formatted in.

Next the parser looks for tokens and any associated data values. In general, the order of the tokens in the file must follow the sequence specified in the table above. The tokens marked with an asterisk are optional. Optional tokens have default values, which are used if the token and value are omitted.

Tokens can have:

- No arguments.
- A fixed number of arguments.
- A variable number of arguments.

If a token has a fixed number of arguments, the token must be followed by a white space-separated list containing the specified number of arguments. If the token has a variable number of arguments, one of its arguments specifies the number of arguments used.

Any time a token is expected by the parser, a comment can be substituted. A comment can't be put anywhere in the file, however. For example, if a token expects arguments, you can't place a comment between any of them; you have to place it after all of the previous tokens arguments. There are a variety of supported comment tokens; they are interchangeable. The comment tokens are `#`, `//`, `;`, `comment`, or `rem`.

ext_format, int_format, and img_format

One of the first things that must be specified in a cliptexture is the format of the texel data. This includes the external format (`ext_format`), internal format (`int_format`) and image format (`img_format`). The arguments expected by these format parameters are the ascii string names of the format's enumerates. For example, a valid external format would be `ext_format PFTEX_FLOAT`. Consult the `pfTexture` man pages for a list of the valid formats of each type.

virt_size and clip_size

The next group of tokens characterizes the image cache itself. The `virt_size` token expects three integer arguments. They define the s, t, and r dimensions of the level 0 layer of the cliptexture in texels. The `clip_size` token describes the size of each layer that exists in texture memory. It also takes three integers, describing the s, t, and r dimensions of the clipped region. This value is the same for all levels of a cliptexture. If the image cache configuration files' `clip_size` differs from this value, the cliptexture overrides it.

invalid_border

The `invalid_border` defines the region of each clipped level that shouldn't be used. If a texel is needed in that region, the next level down is used instead. If the invalid border is large, the system may have to go down multiple levels, or even down to the pyramidal, unclipped part of the MIPmap. The invalid border argument is a single integer, describing the width of the border in texels.

smallest_ocache

The `smallest_ocache` token describes the s, t, and r dimensions of the lowest level that is described as an image cache. This parameter is needed because the unclipped, pyramidal part of the MIPmap can also be configured as image caches. This is an optional token. If it isn't included in the file, the last clipped level is considered the smallest image cache in the cliptexture.

ocache_files, ocache_format and ocache_params

The next group of tokens describes the location of the configuration files defining the image cache levels of the cliptexture. There are two methods of describing where the image cache configuration files. You can explicitly list the filenames in order with `ocache_files`.

The other method is to define the image cache configuration filenames with a scanf-style string containing parameter values, as is done with image caches. This is usually the preferred method. To create parameterized image cache names, you must define the `icache_format` and `icache_params` tokens. If the format string starts with the pattern `$(ENVNAME)`, `{ENVNAME}` or `$(ENVNAME)`, then the value of `ENVNAME` will be assumed to be an environment variable, and expanded into the basename.

The `icache_format` token is followed by a scanf-style string describing the filepath and filename of the image cache configuration files. The argument contains constant parts, interspersed with `%d` or `%s` parameters. The number of parameters must match the integer given with the `num_icache_params` token. The tile parameters themselves follow the `icache_params` token.

icache_files

The number of parameters must match the number of parameters in `icache_format`. All of these parameters are optional. The list of available parameter tokens is given in Table 10-5.

Table 10-5 Parameter Tokens

Parameter Token Name	Description
<code>PFCLIPTEX_FNAMEARG_LEVEL</code>	Cliptexture level (top is 0)
<code>PFCLIPTEX_FNAMEARG_LEVEL_SIZE</code>	Largest value of level's virtual size
<code>PFCLIPTEX_FNAMEARG_IMAGE_CACHE_BASE</code>	Value of <code>icache_base</code>
<code>PFCLIPTEX_FNAMEARG_TILE_BASE</code>	Value of <code>tile_base</code>

The parameter values are used to construct the name of the image cache configuration file; uniquely naming that file for each level of the cliptexture.

Near the bottom of the cliptexture, the size of lower levels are too small to warrant image caches. These levels are specified directly, referring to a single filename containing a single image tile for each level. The filenames for these tile files are specified in exactly the same way as the image cache configuration files are. Instead of `icache_base`, `icache_format`, `num_icache_parameters`, and `icache_parameters`, `tile_base`, `tile_format`, `num_tile_parameters`, and `tile_parameters` are used. The parameters available for use in the `tile_format` string are identical to the ones used for `icache_format`.

tile_files

If image cache configuration files and/or image tiles are to be explicitly named, they are listed in order, from the top (largest) level to the bottom, using the `icache_files` and `tile_files` tokens. These tokens can only be used if the corresponding format, `num_parameters`, and `parameter` tokens aren't. The number of filenames listed after `icache_files` and `tile_files` must exactly match the number of cached and uncached levels, respectively, in the `cliptexture`.

header_offset, tiles_in_file, and tile_size

The `header_offset` argument specifies the size of the file's header in bytes. This many bytes will be skipped over as a file is read. The `tiles_in_file` token requires three arguments, specifying the number of tiles in the s, t, and r dimensions. The r dimension must always be 1, since 3d textures aren't supported. The `tile_size` parameter defines the texel dimensions of each tile in s, t, and r. Again, r must be 1. Both the `header_offset` and the `tiles_in_file` tokens are optional. They default to the values 0 and 1 1 1 respectively, specifying no header and a single tile in each file.

The image cache texel data is stored in one or more files. The configuration file provides a way for IRIS Performer to find these files. The files usually have similar names, varying in a predictable way, such as by tile position in the image cache array and size of the image cache. The files themselves are grouped in on or more directories. The file name and file path information is divided into a number of groups within the configuration file. There is a `scanf`-style string specifying the path to find image cache files. There are a number of parameters in the string that vary as a function of the tile required, and characteristics of the image cache.

tile_base, tile_format and tile_params

The `tile_format` token expects a `scanf`-style argument. If the string starts with the pattern `$(ENVNAME)`, `${ENVNAME}` or `$(ENVNAME)`, then the value of `ENVNAME` will be assumed to be an environment variable, and expanded into the basename.

The argument contains constant parts, interspersed with `%d` or `%s` parameters. The tile parameters themselves follow the `tile_params` token. The number of parameters must match the number of parameters in `tile_format`.

The possible values of the image tile file name parameters is given in the table below.

Table 10-6 Image Tile Filename Tokens

Image Tile Filename Tokens	Description
PFIMAGECACHE_TILE_FILENAMEARG_VSIZE_S	Virtual size S width
PFIMAGECACHE_TILE_FILENAMEARG_VSIZE_T	Virtual size T width
PFIMAGECACHE_TILE_FILENAMEARG_VSIZE_R	Virtual size R width
PFIMAGECACHE_TILE_FILENAMEARG_TILENUM_S	Tiles from origin in S
PFIMAGECACHE_TILE_FILENAMEARG_TILENUM_T	Tiles from origin in T
PFIMAGECACHE_TILE_FILENAMEARG_TILENUM_R	Tiles from origin in R
PFIMAGECACHE_TILE_FILENAMEARG_TILEORG_S	Texels from origin in S
PFIMAGECACHE_TILE_FILENAMEARG_TILEORG_T	Texels from origin in T
PFIMAGECACHE_TILE_FILENAMEARG_TILEORG_R	Texels from origin in R
PFIMAGECACHE_TILE_FILENAMEARG_STREAMSERVERNAME	From streams
PFIMAGECACHE_TILE_FILENAMEARG_CACHENAME	The tile_base value
PFIMAGECACHE_TILE_FILENAMEARG_FILENUM_S	Files from origin in S
PFIMAGECACHE_TILE_FILENAMEARG_FILENUM_T	Files from origin in T
PFIMAGECACHE_TILE_FILENAMEARG_FILENUM_R	Files from origin in R

Optional Image Cache Configuration Files

If the cliptexture has a very regular structure from level to level, the cliptexture configuration file can be augmented with some extra fields, and the image cache configuration files dispensed with. We recommend you start with the image cache configuration files, however, because it makes it easier to gradually create and test your configuration files using the icache and cliptex utilities in the */usr/share/Performer/src/pguide/libpr/C* directory.

Image cache configuration files can be removed if the image caches of the cliptexture are essentially the same, and configuration of each image cache is simple. The image caches should only differ in size between levels; the tile size, formats, tile filename format, etc. should be the same. Also image cache configuration files aren't optional when features like streams are configured.

To stop using image cache configuration files, you should add a `TILE_SIZE` token to the cliptexture configuration file, and be sure to have `TILE_FORMAT` and `TILE_PARAMS` specified. The tile specification in the cliptexture configuration file will be used for all tile files the ones used by the image caches and the ones in representing pyramid levels.

In order to make the parser stop using the image cache configuration files, remove the entries referring to them such as `icache_format`, `icache_params`, or `icache_tiles`.

An example of a cliptexture configuration file that doesn't use image cache configuration files is `/usr/share/Performer/data/clipdata/hunter/hl.noic.ct`.

Post-Scene Graph Load Configuration

There are a number of cliptexture configuration steps that can't be completed until the IRIS Performer application's pipes and channels have been created. This configuration stage centers around configuring cliptextures to be properly applied and centered each frame.

Two jobs must be accomplished. Each cliptexture must be attached to a pipe through its own `pfMPClipTexture` so it can be applied each frame, and a centering callback must be established to update the cliptexture as the channel's viewpoint moves with respect to the cliptextured geometry.

MPClipTextures

`pfMPClipTexture` is a multiprocess wrapper for a `pfClipTexture`. A `pfMPClipTexture` allows you to:

- Change the center of the `pfClipTexture` in the APP process.
- Automatically perform the necessary texture downloading (applying) in the CULL process.
- Control the cliptexture parameters in the APP process.

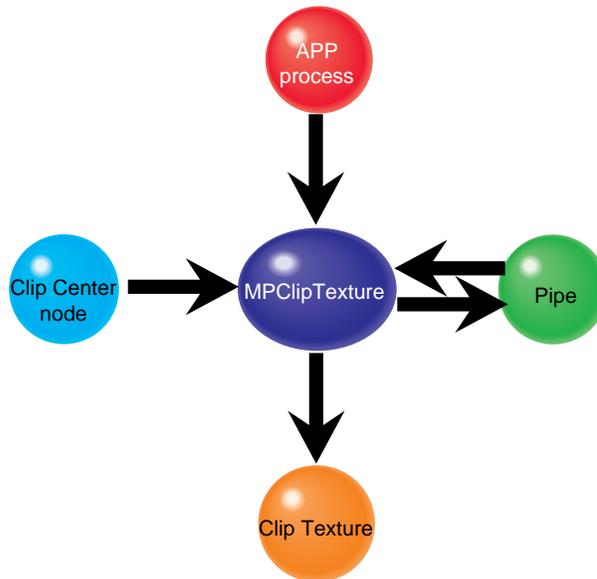


Figure 10-9 pfMPClipTexture Connections

Connecting MPcliptextures to pfPipes

To automatically apply of the pfClipTexture at the correct times and in the correct processes, you must:

1. Create a pfMPClipTexture object.
2. Attach the pfMPClipTexture to the cliptexture you want to control.
3. Attach the pfMPClipTexture object to a pfPipe using the pfPipe.

Note: If you use pfMPClipTexture, you should never call either pfUpdateMPClipTexture or pfApplyMPClipTexture the pfPipe should do the applying.

When you attach a pfMPClipTexture to a pfPipe using **pfAddMPClipTextureToPipes()**, or **pfAddMPClipTexturesToPipes()** pfPipe automatically updates and applies pfClipTexture at the correct time. The functions take three arguments, an pfMPClipTexture or list of pfMPClipTextures, a pipe to attach to, called the master pipe, and a list of other pipes the application wants to use with the pfMPClipTextures.

- **pfAddMPClipTextureToPipes(pfMPClipTexture, masterpipe, pipe_list)**
- **pfAddMPClipTexturesToPipes(pfMPClipTexture_list, masterpipe, pipe_list)**

The pipe_list is used for multipipe applications. It is the list of pipes that slave pfMPClipTextures should be attached to. Setting pipe_list is NULL is equivalent to adding slave pfMPClipTextures to every other pipe in the application.

There are additional libpf routines that can be useful:

- **pfRemoveMPClipTexture()** detaches a pfMPClipTexture from a pfPipe. If a pfMPClipTexture is removed that is the master of other pfMPClipTextures, the slaves will be removed from their pipes as well.
- **pfGetNumMPClipTextures()** returns the number of pfMPClipTextures attached to a pfPipe.
- **pfGetMPClipTexture()** returns a pointer to the pfMPClipTexture that is attached to a pfPipe.

libpf Functionality

You can do this directly with the libpf API using the following calls:

- **pfNewMPClipTexture**—create a new pfMPClipTexture.
- **pfMPClipTextureClipTexture**—attach the pfMPClipTexture to the cliptexture.
- **pfAddMPClipTexture - (a pfPipeCall)**—attach the pfMPClipTexture to a pipe.
- **pfMPClipTexturePipe**—tell the pfMPClipTexture what pipe it's attached to.

pfMPClipTexture Utilities

IRIS Performer provides utilities to make it easy to attach pfMPClipTextures to pipes, and to automatically do pfMPClipTexture centering as well. As a bonus, the utility code requires little or no changes to convert a single pipe application to a multipipe one.

To use the pfMPClipTexture utilities, you need to use IRIS Performer's clipcenter nodes to center the pfMPClipTexture. clipcenter nodes are a subclass of pfGroup nodes. They have additional functionality that allows them to connect to a pfMPClipTexture, the cliptextured geometry (through their child nodes), and properly update the pfMPClipTexture's center each frame. At load time, clipcenter nodes are placed at the

root of the subtree containing the cliptextured geometry. All the cliptextures in the scene are created configured and attached to the clipcenter node at this time as well.

Once you have a scenegraph with geometry, cliptextures, and clipcenter nodes, it's easy to make pfMPClipTextures, attach them to pipes and to centering callbacks. The function **pfuProcessClipCenters()** traverses the scene graph, looking for clipcenter nodes. As each node is encountered, the function creates an MP cliptexture, attaches it to the associated cliptexture and the clipcenter node, and saves a pointer to the MP cliptexture in a pfList. When the function returns, it provides the list of MP cliptextures that were created. The **pfuProcessClipCentersWithChannel()** routine performs the same operations, but also sets a channel pointer in the clipcenter node. When the channel pointer is set, the clipcenter node only will update a pfMPClipTexture center when that channel traverses it. This is useful for multichannel applications.

Clipcenter Node

In order for cliptextures to be rendered correctly, the clipcenter must move along with the viewer. IRIS Performer has made this task simpler by providing a special node for the scene graph that does this calculation and applies it to the cliptexture each frame. This node, called the *clipcenter node*, is a subclass of a pfGroup node. In addition to pfGroup functionality, pfuClipCenterNode's can do the following:

- Points to the cliptexture. This allows cliptextures to be attached to clipcenter nodes at load time.
- Points to the geometry textured by the clipcenter node's cliptexture. The clipcenter node is assumed rooted in the subtree containing the cliptextured geometry.
- Points to an optional simplified version of the cliptextured geometry to make centering calculations go faster.
- Points to the pfMPClipTexture attached to the cliptexture. The node also has API to automatically create an pfMPClipTexture and attach it to the cliptexture.
- Contains a replaceable post-APP callback function for updating a pfMPClipTexture's center.
- Can point to a pfChannel, and only update the pfMPClipTexture center only when that pfChannel traverses the clipcenternode.

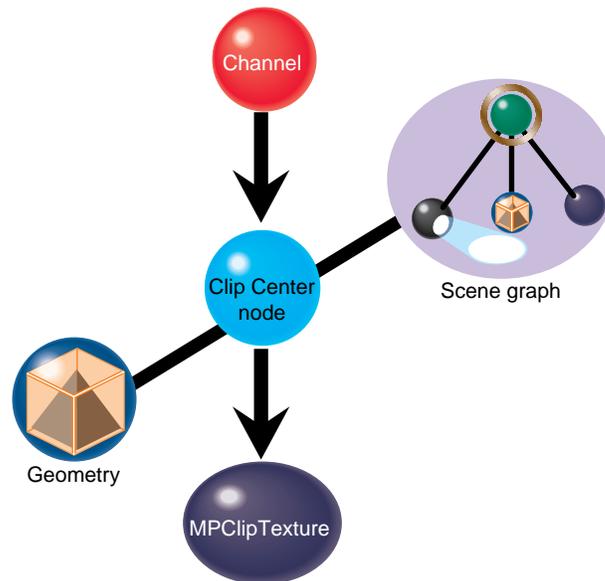


Figure 10-10 pfuClipCenterNode Connections

The clipcenter node uses a simple algorithm, setting the cliptexture center to be the point on the textured geometry closest to the viewer. Other algorithms can be substituted by replacing the callback function.

Clipcenter nodes can be created by calling the utility routine `pfuNewClipCenterNode()`. There are set and get functions to attach cliptextures, channels, custom centering callbacks, simplified cliptextured geometry, as well as a get to return the `pfMPClipTexture`. See the `pfuClipCenterNode` man page for details on the API.

The clipcenter node source code is available in `pfuClipCenterNode.C` and `pfuClipCenterNode.h`, in the `/usr/share/Performer/src/lib/libputil` directory. It is implemented as a C++ class with C++ and C API. It also has example code illustrating to subclass the clipcenternode further to customize it.

If the configuration has been done properly, and if `pfuClipCenterNodes` have been used for centering, most of the per-frame operations for cliptextures is automatic. Centering is computed and applied by the clipcenter nodes during the APP traversal, and cliptexture application is automatically handled by the `pfPipes` attached to the `pfMPClipTextures`.

Using Cliptextures with Multiple Pipes

Cliptextures use a lot of texture memory, system memory (for their caches) and disk i/o bandwidth. Many multipipe applications produce multiple views from the same location, looking in different directions. It would be very inefficient to create a completely separate cliptexture for each pipe: although there is separate texture memory and graphics hardware from each pipe, the system memory and disk resources are shared by the entire system.

Cliptextures have been designed to support multipipe rendering without excessive drain on system memory and disk i/o bandwidth. Cliptextures that are to be used in multiple pipes can be split into *master* and *slave* cliptextures. The master cliptexture is complete; it contains an image cache and a region of texture memory to control. A slave cliptexture points to its master, and shares its image cache, using it to download into its own texture memory. All the slave cliptextures share their master's system memory cache and disk i/o resources, reducing the load on the system.

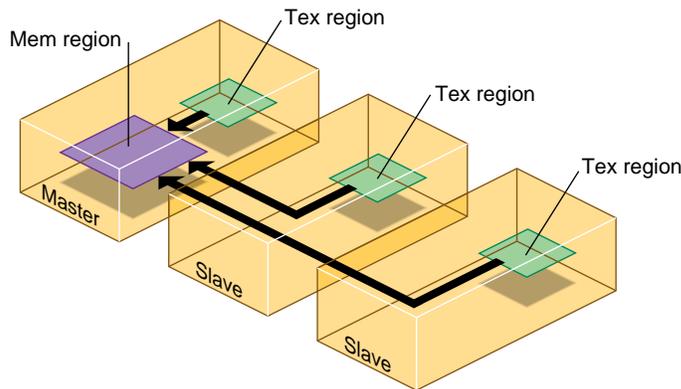


Figure 10-11 Master and Slave Cliptexture Resource Sharing

Making Masters and Slaves

Master and slave relationships can be established between image caches, cliptextures, and pfMPClipTextures. The process starts with an object already configured the way you want it. Then another object of the same type is created, and is set to be a slave of the configured object. This is done with the `setMaster()` function. When an object is made the slave of another object, it automatically configures itself to match its master. It also makes all the connections necessary to share its master's resources.

If two cliptextures are made into a master and slave, all of their image caches must have the same master/slave relationship. This is done automatically. This is also true for pfMPClipTextures. The pfMPClipTextures that will be the master and slave must be connected to cliptextures. Only the masters have to be configured, however. When the other pfMPClipTexture becomes a slave, it configures its cliptexture, and makes it and its image caches slaves as well.

Multipipe Cliptexture API

IRIS Performer tries to make multipipe cliptexturing as transparent as possible. Simply call setmaster on a cliptexture, passing it a pointer to the cliptexture that should be its master.

(master_mct is a pfMPClipTexture that's already configured)

- **pfMPClipTexture *slave_mct = pfNewMPClipTexture()**
- **pfClipTexture *slave_ct = pfNewClipTexture()**
- **pfMPClipTextureClipTexture(slave_mct, slave_ct)**
- **pfMPClipTextureMaster(slave_mct, master_mct)**

At this point, slave_mct and master_mct are connected; slave_mct is configured to match master_mct and shares its image cache resources. The cliptextures and image caches are also configured and linked. To make pfClipTextures or pfImageCaches masters and slaves, use the same procedure.

When you attach a pfMPClipTexture to a pfPipe with **pfAddMPClipTexture()** provides automatic multipipe support. If a pfMPClipTexture is added to a pipe that is already connected to another pipe, the function silently creates a new pfMPClipTexture, makes it a slave of the pfMPClipTexture that is already connected to another pipe, and adds the slave to the pipe in place of the one passed as an argument to the function.

Multipipe Utilities

Although it isn't difficult to set up master and slave cliptextures directly, it's usually not necessary. The previously described utility routines, **pfuAddMPClipTextureToPipes()** and **pfuAddMPClipTexturesToPipes()** can take multiple pipe arguments. A master pipe and a list of slave pipes is specified. The routine makes the pfMPClipTexture a master and attaches it to the master pipe. It then creates slave pfMPClipTextures, attaches them to the master cliptexture, and attaches a slave cliptexture to each pipe in the

slave_pipes list. This routine does extra checking of pipe and cliptexture state, and is guaranteed not to generate errors, even if the function is applied more than once.

Master/Slave Share Masks

A group of cliptextures grouped by master/slave relationships can do more than share mem region resources. By default, slave cliptextures also track a number of their master's attribute values. This means changing a master's center, for example, automatically causes the slaves to change their center locations to match their master's. The attributes that a slave can track are divided into groups called *share groups*. The application can control which groups are shared by setting a slave's *share mask*. Changing the sharing of a slave only affects that slave's sharing with its master. Changing the master share mask has no effect. The share mask is set with the following call:

```
pfMPClipTextureShareMask(uint mask)
```

The mask can be set using one or more of the following values:

- PFMPCLIPTEXTURE_SHARE_CENTER—slave track the master's center.
- PFMPCLIPTEXTURE_SHARE_DTR—slave tracks DTR; DTR mode, tex load time (actual or calculated), fade count, and blur margin.
- PFMPCLIPTEXTURE_SHARE_EDGE—slaves track texture level parameters; LODbias invalid border.
- PFMPCLIPTEXTURE_SHARE_LOD—slaves track minLOD and maxLOD.
- PFMPCLIPTEXTURE_SHARE_VIRTUAL—slaves track lodOffset and num effective levels.
- PFMPCLIPTEXTURE_SHARE_DEFAULT—a bitwise 'or' of all the masks listed above.

PFMPCLIPTEXTURE_SHARE_DEFAULT is the default sharemask value, which provides maximum sharing between master and slave cliptextures. If an application would like to control one or more slaves independently, it needs to change the slave's sharemask, then start setting the slaves parameters directly as needed.

Texture Memory and Hardware Support Checking

At the first application or formatting of a cliptexture, IRIS Performer compares the expected size of the cliptexture texel data in texture memory against the systems texture memory size. If it looks like the cliptexture won't fit into texture memory, it shrinks the clip size by two and tries again. It will keep shrinking the clip size until either the cliptexture will fit or the clip size is zero. The system taking into account texture memory banking and paging, to come up with a more accurate estimate.

Note that the resizing mechanism doesn't take into account other textures or cliptextures in use by the application. You should adjust your application so that IRIS Performer doesn't have to auto-shrink the cliptexture. See "Estimating Cliptexture Memory Usage" on page 365 for calculating cliptexture system memory and texture memory usage.

During the checking phase, IRIS Performer also checks to see if cliptextures are supported in hardware on the system. To cliptexture properly, the clipped levels need hardware support. If cliptexturing isn't supported, then the cliptexture is reconfigured so only the unclipped, pyramid levels are loaded, and indicates to the system that the texture is a normal MIPmap. The rest of the cliptexture support is unchanged. This means that image caches in the pyramid levels will still work. This feature allows the application writer to run and do some testing of cliptexturing applications even if the system it's run on doesn't support cliptexturing.

Manipulating Cliptextures

Once cliptextures have been configured and connected into the application, they can be manipulated by the application in the APP process. Applying and centering cliptextures happens each frame, and is usually an automatic process, set up during post-load configuration. Other parameters that can be adjusted include load control parameters, min and max LOD levels, and virtual cliptexture control. Some of these parameters may only need to be set once in the application, others, like the parameter setting for virtual cliptextures, need to happen multiple times per frame.

Cliptexture Load Control

The virtualization of pfTextures into pfClipTextures, allowing very large texture maps, comes at a price. As the clipcenter moves, cliptextures have to download data from disk to system memory, and from system memory to texture memory. Because of these download requirements, cliptextures are sensitive to available system bandwidth. Without some sort of download load control, a fast moving center would cause a cliptextures to “freeze”, waiting for the system to catch up with its updates.

While mem region updates happen asynchronously, tex region updates must happen in the DRAW process, competing with geometry rendering and individual texture loading. Real time applications require that cliptextures, like other IRIS Performer features, must be controlled in a way such that an upper bound can be set on their use of resources. IRIS Performer’s cliptexture load control, called Dynamic Texture Resolution (DTR), provides this functionality.

Dynamic Texture Resolution

Dynamic Texture Resolution (DTR) is similar to Dynamic Visual Resolution (DVR): the bandwidth requirements are adjusted to meet system limitations by lowering the resolution of the texture data displayed by the cliptexture.

DTR controls bandwidth by analyzing the cliptexture in the CULL process. It checks each cliptexture level, ensuring that the mem region contains updated tiles corresponding to the tex region, and that there is enough time to update the tex region within the download time limit.

This checking goes from level to level, from coarser levels to finer ones. When a level is found that can’t be displayed, DTR adjusts the cliptexture parameters so that no levels above the finest complete level are displayed. At that point, DTR stops checking levels until the next frame. In order not to waste CULL processing time on levels that aren’t visible, DTR will not try to sharpen more than one level beyond the current minLOD and virtualLODoffset values. It will go one level beyond these values so that it can react quickly if the values change.

This way the cliptexture updating will always keep up with the movement of the clipcenter, and will never display invalid data. When the center moves too quickly, DTR will “blur down” to coarser complete levels, then “sharpen up” to finer levels when the center slows down and the system can catchup. In this way DTR can trade visual quality against updating bandwidth. The visual result: the faster a viewer goes, the less time there is to download texture, the blurrier the texture data gets.

The nature of cliptexturing makes load control work. When the clipcenter moves, this change is reflected at every clipped level of the cliptexture. But because each texel in a level covers four times the geometry of the texel in the next finer level, the clipcenter only moves half the distance each time you go down a level. This translates into less demanding texture download requirement.

DTR has other features, such as read queue sorting, which prioritize the order in which read requests are done to improve mem region update performance. The rate at which levels are blurred and sharpened can also be controlled to minimize visual artifacts.

Load Control API

DTR controls three aspects of load control, which can be turned on and off independently: tex region updating (from the mem region in system memory), mem region updating (loading from disks), and read queue sorting (reducing the latency of read requests for downloads from disk to the mem region).

pfMPClipTextureDTRMode(DTRMode)

DTRMode is a bitmask; if a bit is set, that DTR feature is enabled. It has the following bits defined:

- **PF_DTR_MEMLOAD** - enable mem region load control from disk
- **PF_DTR_TEXLOAD** - enable tex region load control; DRAW download time
- **PF_DTR_READSORT** - enable priority sorting of the read queue

All three bits are enabled by default, which means that DTR has all modes enabled. Besides the bitmask to control what parts of DTR are enabled, there are parameters to available to adjust load control performance. The DTR parameters, and how they affect DTR functionality are discussed below:

Download Time

The memload component of DTR is relatively simple; it computes whether all the tiles in a level's mem region that cover the tex region are valid. If any are not, the tex region can't be updated and DTR invalidates that level. If the texload component of DTR is enabled, DTR must also compute the time it takes to download from the mem region to the tex region. The application provides the load control with a total download time in milliseconds:

```
pfMPClipTextureTexLoadTime(float _msec)
```

This is the total time DTR has available to update the cliptexture's texture memory each frame. As DTR analyzes each cliptexture level that needs updating, it computes all the regions in the level's texture memory that need updating. If a level can be updated, DTR determines whether there is enough download time left to update the level. If there is, DTR marks that level valid, subtracts the time needed to download that level from the total, and starts analyzing the next finest level in the cliptexture.

Cost Tables

IRIS Performer contains texture download *cost tables*, which DTR uses to estimate the time it will take to carry out those texture subloads. These tables are a 2D array of floating point values, indexed by width and height of the texture rectangle being subloaded. The cost tables themselves are indexed by machine type, and can be read by the application. The application can also define its own cost tables and configure the system to use it. The cost table API is shown below:

```
pfPerf(int type, void *table)
pfQueryPerf(int type, void **table)
```

The text field indicates whether the cost table should be the one chosen by the system:

- **PFQPERF_DEFAULT_TEXLOAD_TABLE** - the one supplied by the application
- **PFQPERF_USER_TEXLOAD_TABLE** - or the one currently in use
- **PFQPERF_CUR_TEXLOAD_TABLE** - The default table is the current one unless a application supplies a cost table, then the application's cost table takes precedence.

For more details on cost tables, see the man pages for **pfPerf()** and **pfQueryPerf()**. The cost table structure is named `pfTexSubloadCostTable`, defined in `/usr/include/Performer/pr.h`.

Changing Levels

The DTR load control system is designed to minimize visual artifacts as it adjusts for different download demands. Instead of abruptly sharpening the texture as new levels with valid texture data become available, DTR blurs in new levels over a number of frames, making the process of load control less noticeable. The application can control the rate at which newly valid levels are displayed. The application sets a *fade count*, which controls the number of frames it takes to fade in a new level. Each frame, the cliptexture will sharpen $1/\text{fadecount}$ of the way from its current (possible fractional) level to the next level. This process is repeated each frame, resulting in an exponential fade-in function. If the fade count is 0, then fading is disabled, and DTR will show new levels immediately.

```
pfMPClipTextureFadeCount(int _frames)
```

If the clipcenter roaming speed leaves barely enough bandwidth to bring in a new cliptexture level, a distracting “LOD flicker” between to cliptexture LOD levels can result. Since DTR must blur immediately if a level becomes invalid, the only way to prevent flicker is to be conservative when sharpening, building in a hysteresis factor. There is a parameter, called *blur margin* which helps determine when DTR should sharpen.

The *blurmarg* parameter also helps cliptextures blur smoothly when DTR can’t keep up. It is a floating point value, which can be interpreted as a fraction of the cliptexture’s tex load time. When blurmarg isn’t zero, DTR will load all the levels it can within the texload time, but not display all of them. Instead it will only sharpen to the level that would have been reached if the texload time was scaled by the blurmarg. This leaves a cushion of extra time that can be used up before DTR will be forced to blur to a coarser level. The default blurmarg value of .5 usually causes the finest level displayed to be one level coarser than the finest level loaded. The application can adjust the blurmarg by calling:

```
pfMPClipTextureBlurMargin(float margin)
```

DTR needs this cushion in order to fade smoothly. A cliptexture can only fade between two valid levels; if it waits until its current level is invalid, the cliptexture must immediately jump to the next coarser level or it will show invalid data. This abrupt blurring is very noticeable. The blur margin allows the DTR system to anticipate when it will lose a level, and smoothly fade to the next coarser level over a number of frames.

Total Texload Time and Texload Time Fraction

Using the texload time, blur margin, and fade count parameters is sufficient to control a single cliptexture from a pipe, but the interface is awkward if multiple cliptextures are applying from the same pipe. Since each pipe has the same amount of DRAW process time available per frame, no matter how many cliptextures are applied from it, it would be more convenient to provide a total amount of download time, then divide it among the cliptextures using the pipe.

IRIS Performer provides this interface using the total texload time and texload time fraction parameters. The application can set the total texture download time available on a pipe, then assign fractional values for each cliptexture, indicating how the download time should be divided. The total texload time is a `pfPipe` call, while the fractional values are set on `pfMPClipTextures`:

```
pfPipeTotalTexLoadTime(float msec)  
pfMPClipTextureTexLoadTimeFrac(float frac)
```

The fractional values should indicate the relative priority of each `pfMPClipTexture` on the pipe. The fractional values don't have to add up to 1; the DTR code will normalize them against the sum of all the fractional values set on the pipe's `pfMPClipTextures`.

The total tex load time on the pipe is scaled by the normalized fractional value on each cliptexture. The scaled tex load time is then used as the cliptexture's texture download time. Explicitly setting the tex load time on a `pfMPClipTexture` will override the computed fractional time.

Read Queue Sorting

When the clipcenter moves quickly, the number of read requests for texture data tiles that move into the clipped levels mem regions can grow much faster than the read function can service them. If there isn't enough bandwidth to display a particular level, *itsread* requests may become "stale", becoming obsolete as the location of the requested tile moves into, then passes out of a level's mem region. For DTR to be robust, the read queue must be culled and sorted to remove stale read requests, and move the requests for tiles closest to the clipcenter to the front of the queue. The cliptexture's read queue is a sorting queue, which means that a function can process the elements of the queue asynchronously. DTR uses the read queue to cull read requests for tiles that are no longer in their mem region, and to prioritize the other requested tiles as a function of level and distance from the clipcenter. Sophisticated applications can provide their own sorting function.

Invalidating Cliptextures

Sometimes an application may want to force a cliptexture to completely reload itself. For example, The `pfuGridifyClipTexture()` function modifies the cliptexture's texel data in system memory with a system of grid marks to make debugging and analysis easier. It modifies the read function to add a grid to every tile as it's loaded into system memory, then invalidates the cliptexture. For more information on gridify, look at the source code in the `/usr/share/Performer/src/lib/libpfutil/gridify.C` file.

Invalidating a cliptexture forces it to completely reload its texture memory. Invalidating is only supported for cliptextures, not MPcliptextures. This means that an application cannot call invalidate from the APP process. Instead, it must call invalidate from the CULL process, usually in a pre-cull callback. The invalidate call itself is simple:

```
pfInvalidateClipTexture(pfClipTexture *cliptex)
```

Invalidation is not needed for normal operation, but it is useful as a way to immediately update a cliptexture's texture memory.

Virtual Cliptextures

Regular cliptextures limit the size of each level but do not restrict the number of levels you can access. Virtual cliptextures take the virtualization a step further by allowing you to use only a subset of all the levels you have data for.

Although InfiniteReality supports cliptextures of virtual size up to $8M \times 8M = 2^{23} \times 2^{23}$ texels (i.e. 24 levels), the hardware is only capable of addressing a region of at most $32K \times 32K = 2^{15} \times 2^{15}$ texels (i.e. 16 levels). By limiting the set of texture MIPMap levels, the cliptextures can be enlarged. A larger, virtual, cliptexture is defined just like a normal cliptexture, except that the size of the cliptexture can exceed the 32K X 32K maximum level size dictated by the hardware.

Virtual cliptextures do use more texture memory and require more callbacks in the CULL process, but they allow enormous cliptextures that are limited only by the precision of the texture coordinates. Cliptextures over one million texels on a side have been demonstrated.

Although virtual cliptextures require dividing the cliptextured geometry into sections for a given MIPmap *levelrange*, the division is much coarser and less restrictive than texture tiling. Cliptextured geometry usually doesn't need to be clipped to sectional boundaries, for example, since there is a lot of leeway when there are more MIPmap levels available than are needed for a given section of geometry.

For a sample application implementing virtual cliptextures, see */usr/share/Performer/src/pguide/libpf/C/virtcliptex.c*.

Selecting the Levels

The application is responsible for choosing which 16 (or less) levels can be accessed at any given time by setting two parameters: *virtualLODOffset* and *numEffectiveLevels*. Most applications make *numEffectiveLevels* the maximum number allowed by the hardware, 16 on InfiniteReality. Smaller values may be chosen in some cases to improve stability. *VirtualLODOffset* sets the initial level in the cliptexture where 0 is the finest level.

For example, if *numEffectiveLevels* = 16 and *virtualLODOffset* = 0 then the texels the hardware can access are limited to the 32Kx32K region surrounding the current clipcenter, measured in finest-level texels (actually somewhat less than this; see the file */usr/share/Performer/doc/clipmap/IRClipmapBugs.html* or */usr/share/Performer/doc/clipmap/IRClipmapBugs.txt* for details on cliptexture limitations on InfiniteReality graphics); attempting to access outside this range results in the value of the nearest texel in the good region; i.e. the texels forming the border of the 32Kx32K area will appear to be "smeared" out to fill the virtual cliptexture.

Increasing *virtualLODOffset* from 0 to 1 doubles the size of the accessible region in both S and T (so that it's 32Kx32K level 1 texels, which are twice as big as level 0 texels), but makes the finest level inaccessible.

The maximum *virtualLODOffset* allowable is $\text{numVirtualLevels} - \text{numEffectiveLevels}$; when set to that value, the entire S,T range of the virtual cliptexture is accessible, and the finest level from which texels are available is the 32Kx32K level.

In general, it is appropriate to choose a large value of *virtualLODOffset* when the viewpoint is far away from the scene and more S,T area is visible; smaller values of *virtualLODOffset* are appropriate as the eye moves closer to the scene, gaining needed higher resolution at the expense of range in S,T.

Changing *virtualLODOffset* and *numEffectiveLevels* has no effect on the contents of texture memory nor any effect on the texture coordinates stored in the geosets and passed to the graphics: the texture coordinates, as well as the clipcenter, are always expressed in the space of the entire virtual cliptexture rather than the smaller “effective” cliptexture of up to 16 levels within it. (In contrast, changing the clipcenter requires texture downloading; thus it is a much more expensive operation and therefore it is not practical to change the clipcenter more than once per frame, whereas *virtualLODOffset* and *numEffectiveLevels* can be changed multiple times per frame, as we will see below.)

How to Set Virtual Cliptexture Parameters

IRIS Performer supports two different methods for managing *virtualLODOffset* and *numEffectiveLevels* of a cliptexture. The simpler of the two methods allows the parameters to be set and changed at most once per frame; the more sophisticated method allows them to be changed multiple times per frame (different values for different parts of the scene). In addition to *virtualLODOffset* and *numEffectiveLevels* described above, the parameters minLOD, maxLOD, LODBiasS and LODBiasT often need to be set in the same way, so we will show how to set those as well.

Per-Frame Setting of Virtual Cliptexture Parameters

The easy way to manage the virtual cliptexture parameters is to set the values of the parameters on the pfMPClipTexture controlling the pfClipTexture:

```
int LODOffset, numEffectiveLevels;
float minLOD, maxLOD;
float LODBiasS, LODBiasT, LODBiasR;
...
mpcliptex->setVirtualLODOffset(LODOffset);
mpcliptex->setNumEffectiveLevels(numEffectiveLevels);
mpcliptex->setLODRange(minLOD, maxLOD);
mpcliptex->setLODBias(LODBiasS, LODBiasT, LODBiasR);
```

You make these calls in the APP process, either in the main program loop, a channel APP func, or a pre- or post-node APP func. The last value you give during the APP in a particular frame will be used for rendering that frame and all subsequent frames, until you change the value again.

This simple technique is the one that is used by the *clipfly* program when you manipulate the LODOffset and EffectiveLevels sliders (when using a naive scene loader such as the .im loader that doesn't do its own management of *virtualLODOffset* and *numEffectiveLevels*): clipfly makes these calls in its channel pre-APP function.

This technique is also used by the `.spherepatch` loader; in this case the calls are made in a post-APP function of a node in the scene graph, using parameters that are intelligently chosen based on the current distance from the eye to the closest point on the textured geometry, and are updated every frame.

Notice that even though the `.spherepatch` loader manages the *virtualLODOffset* and *numEffectiveLevels*, you can still modify or override its behavior with the clipfly GUI controls. This is accomplished using a special set of “limit” parameters that are provided as a convenience and stored on the `pfMPClipTexture`. The intended use is for applications such as clipfly to set the limits based on GUI input or other criteria:

```
mpcliptex->setLODOffsetLimit(lo, hi);  
mpcliptex->setEffectiveLevelsLimit(lo, hi);  
mpcliptex->setMinLODLimit(lo, hi);  
mpcliptex->setMinLODLimit(lo, hi);  
mpcliptex->setLODBiasLimit(Slo, Shi, Tlo, Thi, Rlo, Rhi);
```

Then the callback functions of intelligent loaders such as `.spherepatch` query the limits:

```
mpcliptex->getLODOffsetLimit(&lo, &hi);  
mpcliptex->getEffectiveLevelsLimit(&lo, &hi);  
mpcliptex->getMinLODLimit(&lo, &hi);  
mpcliptex->getMinLODLimit(&lo, &hi);  
mpcliptex->setLODBiasLimit(&Slo, &Shi, &Tlo, &Thi, &Rlo, &Rhi);
```

The loaders use the limits to modify the selection of the final parameters sent to `pfMPClipTexture`.

The limits are not enforced by `pfMPClipTexture`; they are provided merely to facilitate communication from the application to the function controlling the parameters. That function is free to ignore or only partially honor the limits if it wishes.

The limits may also be queried frame-accurately from the `pfMPClipTexture` in the CULL process, so they can also be used by scene loaders such as the `.ct` loader that use the per-tile method described in the next section.

Per-Tile Setting of Virtual Cliptexture Parameters

Many applications require accessing a wider range of the cliptexture's data than can be obtained by a single setting of *virtualLODOffset* and *numEffectiveLevels*. This can be accomplished by partitioning the database into "tiles" roughly according to distance from the eye or from the texture's clipcenter, and setting the parameters for each tile every frame in the pre-CULL func of the pfGroup or pfGeode representing that tile, by calling **pfClipTexture::applyVirtual()**, **pfTexture::applyMinLOD()**, **pfTexture::applyMaxLOD()**, and **pfTexture::applyLODBias()**.

Tiling Strategies

Choosing a database tiling strategy requires careful thought and tuning. The most conceptually straightforward method is to use a static 2d grid-like spatial partitioning. This method requires tuning the granularity of the partitioning for the particular database and capabilities of the machine: if a tile is too big and sufficiently close to the eye, there may be no possible combination of *virtualLODOffset* and *numEffectiveLevels* that allows access to both the necessary spatial range and texture LOD range without garbage in the distance or excess bluriness in the foreground; but if there are too many tiles, the overhead of changing the parameters for each tile can become excessive.

In general, assuming the maximum active area is 32Kx32K (as it is on InfiniteReality), each tile should be small enough so that it covers at most approximately 16K texels at the finest texture LOD that will be used when rendering it; this is so that when the clipcenter is close enough to the tile to require accessing that finest texture LOD, the 32Kx32K good area centered at approximately the clipcenter will be able to cover it with some slop left over to account for the inexact placement of the good area (see the IR cliptexture bugs doc). (Finer tiles such as 8Kx8K or even 4Kx4K can be used for improved stability under extreme magnification; see the IR cliptexture bugs doc).

This rule has two important consequences:

- If your cliptexture has insets (i.e. localized regions in which higher-res data is available) you can make the tiling coarser in the regions where only low-res data is available, and finer at the insets.
- If you use pfLODs to optimize your database, the coarse LODs of the pfLOD can (and should) be tiled more coarsely than the fine ones.

This is because the coarser LODs are used at far distances, and at those far distances the mipmapping hardware will only want to access correspondingly coarse texture levels anyway, so the 16Kx16K can be measured in terms of the texels of those coarse texture levels.

A more general tiling strategy that requires less empirical database tuning than the static tiling method is to make the tiles be concentric rings around the texture's clipcenter (in 2d) or around the eye point (in 3d), with sizes increasing in approximately powers of 2. However, since the clipcenter and view position changes, this means the tiles must move as well, which requires dynamically changing the topology of the scene graph and/or morphing the geometry so that the tiles always form those concentric rings around the current focus.

The .ct loader and pfASD's ClipRings both use this dynamic strategy. The .ct loader is interesting in that the morphing is done for the sole purpose of forming these concentric tiles for virtual-cliptexturing an otherwise trivial scene. It looks like simply a square textured by the cliptexture, but if you turn on scribed mode in *perfly* or *clipfly*, you can see the morphing rings that make up the square.

Doing Per-tile Updates

To do per-tile updates, use the following procedure:

1. On each tile (typically a pfGroup or pfGeode) put a pre-node CULL func:

```
tile->setTravFuncs(PFTRAV_CULL, tilePreCull, NULL);
```

2. Make sure the effect of the tile's pre-CULL func happens in the DRAW before the contents of the tile are rendered, and that the tile's contents do not co-mingle with other tiles (this is not guaranteed by default, for the benefit of CULL whose sole purpose is to return a CULL result without losing the advantages of uncontained CULL sorting):

```
tile->setTravMode(PFTRAV_CULL, PFTRAV_CULL_SORT,  
PFN_CULL_SORT_CONTAINED);
```

3. In the pre-node CULL func for the tile, set the parameters:

```
static int tilePreCull(pfTraverser *trav, void *)  
{  
    int virtualLODOffset, numEffectiveLevels;  
    float minLOD, maxLOD;  
    float biasS, biasT, biasR;  
  
    //Choose intelligent values for parameters.  
  
    cliptex->applyVirtualParams(virtualLODOffset,  
numEffectiveLevels);  
    cliptex->applyMinLOD(minLOD);  
    cliptex->applyMaxLOD(maxLOD);  
    cliptex->applyLODBias(biasS,biasT,biasR);  
}
```

The values given to the apply functions are not stored in the `pfClipTexture` or retained from frame to frame; when you call these functions, they override the corresponding values stored in the cliptexture.

It is not necessary to call all four of the **apply...()** functions; only use the ones you care about (e.g. most applications would not care about `LODBias`). However, if you ever call a given one of these functions, say **applyMinLOD()**, on a particular cliptexture for any tile, then you must call **applyMinLOD()** for every tile on that cliptexture during that frame and forever after; if you omit it the tile will not necessarily get the value stored on the `pfMPClipTexture` or `pfClipTexture`; rather, it will get whatever value happened to be most recently set when rendering that tile in the DRAW (which may be nondeterministic due to CULL sorting of the scene graph).

How to Choose Virtual Cliptexture Parameters

The `libpfutil` library provides a function called `pfuCalcVirtualClipTexParams`, which can be very useful in selecting the virtual cliptexture parameters, no matter whether you are updating per-frame or per-tile.

Essentially, you give to `pfuCalcVirtualClipTexParams` every piece of information you know about the cliptexture:

- The tile in question.
- The limits specified elsewhere, for example, by the clifly GUI.

pfuCalcSizeFinestMipLOD() returns the lower bounds on `minLODPixTex`, which is one of the input parameters to `pfuCalcVirtualClipTexParams`.

The function returns optimal values for `virtualLODOffset`, `numEffectiveLevels`, `minLOD`, `maxLOD` that you can:

- Set on the `pfMPClipTexture` in the APP process if your application is using the per-frame method.
- Apply to the `pfClipTexture` per-tile in the CULL process if using the per-tile method.

For more details; you may also want to read the commented source code to understand its constraints and heuristics, and how to modify `pfuCalcVirtualClipTexParams` to implement your own algorithm if it does not exactly suit your needs.

Custom Read Functions

Sometimes the read function supplied by IRIS Performer to download texture data from disk to mem region isn't good enough. The application may need to do additional operations at read time, such as uncompression, or may need a more sophisticated read function, such as an interruptible one for reading large tiles from slow storage devices. A read function may need to signal an applications secondary caching system; for example, reading from tape storage to disk.

IRIS Performer provides support for application supplied custom read functions. The read function is supplied at configuration time, and there is API in both the configuration utilities and the cliptexture and image cache configuration files for supplying a read function.

A read function is called by the image caches read queue. The read queue expects a read function with the following function signature:

```
int ExampleReadFunction(pfImageTile *it, int ntexels)
```

The image tile pointer provides information about the read request, such as the disk to read from, the dimensions and format of the texel data, and the destination tile in system memory to write to. The *ntexels* argument is an integer indicating the number of texels to read from disk. The read function returns another integer indicating the number of texels actually read. Two example read functions are supplied in

/usr/share/Performer/src/lib/libpfd/pfdLoadImage.c, **ReadNormal()** and **ReadDirect()**.

These functions are C versions of the C++ functions that IRIS Performer uses to read texture data. In IRIS Performer, the **ReadDirect()** function is called by the read queue; it tries to use direct i/o to get the highest possible disk read performance. If the read direct call fails, it calls **ReadNormal()**, which uses normal **fopen()**-style read.

When providing a read function at configuration time, You supply the function name, and optionally the name of a DSO library containing the function. If no dynamic shared library is supplied, The read function is searched for in the application's executable.

To set read custom read functions using the configuration utilities, simply fill in the *readFunc* field in the **pfuImgCacheConfig** or **pfuClipTexConfig** structure (the first structure has priority over the second if both are set). The field should contain a pointer to the customer read function. Be sure the function has the proper signature.

When supplying custom read functions in the configuration files, you simply provide an entry in one of two formats:

```
read_func ReadFunctionName  
read_func DSOLibraryName ReadFunctionName
```

For hints on when and how to use custom read functions, see the customizing read functions in “Custom Read Functions” on page 372.

Using Cliptextures

This section provides guidelines for using cliptextures, describing common cliptexture application techniques, ways to solve problems, and some hints and tips to make using cliptextures easier.

Cliptexture Insets

Cliptexture load control makes it possible to create cliptextures with incompletely filled levels. A cliptexture, being much larger than an ordinary texture, may not be used in a homogeneous way. Some areas of the cliptexture may be viewed in detail, others only at a distance. A good example of this usage pattern is flight simulation. The terrain around an airport will be seen from low altitude, terrain far from population centers may never be seen below 40,000 feet. It is also possible that high resolution data is simply not available for the entire cliptexture. Both of these cases make it valuable to create cliptextures with incompletely populated values.

Regions of filled in data are called insets. Insets can be any shape, and do not need to match tile boundaries (although this requires filling the rest of the tile with super sampled data). For an inset to work properly, all of the levels from the pyramid up to the finest level desired, must be available within the inset boundaries.

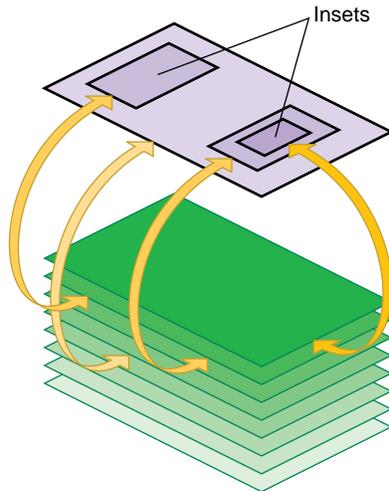


Figure 10-12 Cliptexture Insets

Insets are supported in cliptextures as a natural consequence of load control. As the clipped region moves from a region that has texel data to one that doesn't, DTR will blur the texture down to the highest level that can completely fill the clipped region.

Adding Insets to Cliptextured Data

In large cliptextures, it may not be practical or even desirable to completely fill each level with texel data. Cliptexture's load control, DTR, automatically adjusts the finest visible level based on what texels are available. If finer levels are not available, DTR automatically "blurs down" to the highest complete level in the clip region.

Applications may use insets if there are only limited areas where the viewer is close to the terrain. An example application would be a commercial flight simulator, where the inset high-resolution data would be around the airports where the aircraft takes-off and lands. The terrain over which the aircraft cruises can be lower resolution.

Insets and DTR

To create insets properly, you have to understand how DTR load control works. At the beginning of each frame, DTR examines a level's mem region to see if the tiles covering the tex region are all loaded. If the tiles are all available, DTR will make that level visible.

DTR does this examination starting with the coarsest clipped level. If the current level is complete, it marks that level as visible and repeats the process for the next finest level, until it gets to the top level or finds an incomplete level.

Building Insets

To create an inset, assume you have a cliptexture that is complete at a coarse level. You choose an area of the clipmap that you would like to have visible at some finer level. In order to make that area available, you have to provide texel data in that area for each level from the coarse complete level to the finer level you want to show.

When the clip region is completely enclosed by the finer level data, DTR checks all the levels from the pyramid level on up, and allows the finer level to be shown in that area. (The pyramid levels are always complete; see Figure 10-1.)

Because DTR works from the bottom up (coarser to finer levels), an inset area must have texel data available from the finest level all the way down to the pyramid level. If a level's clip region is missing or incomplete, DTR does not allow the image to sharpen up to that level; the inset gets blurry.

Inset Boundaries

When the clipcenter is set such that the clip region is completely enclosed by the insetted area, a properly constructed inset is sharp, using the finer resolution texel data. But what happens when the clip region only partially covers an inset? In that case, DTR does not sharpen up beyond the finest complete level, and the clip region gets blurry, *including the part of the clip region covered by the inset*. Remember, the clip region only sharpens to the finest level that is *complete* within the clip region.

This blurriness may not be a problem. If you know that the application moves far enough away from the terrain before the clip region crosses an inset border, MIPmapping uses the coarser texture levels before DTR forces the texture to use them. Sometimes, the application would like a static boundary between the inset and the surrounding coarser data, even when crossing an inset boundary close to the textured geometry.

Supersampled Data

Getting a static inset border requires creating a boundary of supersampled data around the inset. This means creating texel data for the insetted levels that is deliberately made as blurry as the surrounding base level. This border of blurry data must be at least as wide as the clip region to ensure a smooth transition.

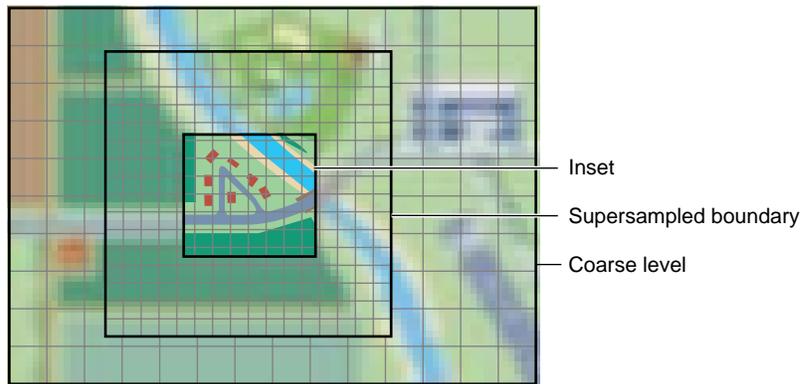


Figure 10-13 Supersampled Inset Boundary

How does this work? When the clip region crosses an inset border, it starts to cover the boundary region. Since the boundary region has the same levels filled in as the inset region, DTR still sees complete data up to the same finer level. The texel data of the border has been blurred, however, so it *looks* like the coarser base level. This allows a hard transition between the finer inset data and the surrounding coarse data. Since DTR still sees complete levels, as you move away from the inset, it doesn't suddenly blur.

Since the boundary data is at least as wide as the clip region, the inset boundary has moved out of the clip region before the clip region hits the far edge of the boundary region. At this point, DTR blurs down to the coarser base level, since the finer data is no longer incomplete, but there is no visual change, since the boundary texels were blurry already.

Note: Supersampled borders do not guarantee a seamless transition between insets and their surroundings, only that the inset region does not suddenly blur or sharpen as the clip region crosses the inset border. Seamless transitions only happen if the application is careful to get far enough from the clipmapped terrain to already be using the coarse levels before crossing the inset border.

Multiple Insets

Insets do not have to be any particular size or shape, although they are usually multiples of the tile size, and at least as big as the clip region so they can be viewed without a seam of blurriness. Typically, insets are designed so when the application is close enough to view the finer inset levels, the clip region is already completely enclosed by the inset region.

Keep in mind that insets are not the same size on each level, since texels from coarser levels cover more geometry. If an inset isn't a multiple of the tile size at a given level, the tile has to be partially inset data, and partially supersampled data, or all fine data, since DTR does not work with partial tiles.

Estimating Cliptexture Memory Usage

Because cliptextures are a voracious consumer of system and texture memory, it is important to accurately predict the system resources required to run a cliptexture application. It is better to customize your application than to rely on the cliptexture auto-resizing feature, since auto-resizing doesn't take into account multiple cliptextures or pftTextures in your application.

Cliptextures use both system memory (texel caching, read queue elements as well object overhead) and texture memory. The following estimation ignores the smaller contributors to system memory overhead and concentrates on image cache consumption of system memory for mem regions and tex regions in texture memory.

System Memory Estimation

The following values are required to estimate system memory requirements:

- Size of clipmap level 0
- Clip size (in texels)
- Tile size (in texels; assuming tile size is the same for all levels)
- Texel size in bytes
- Whether the tiles have high disk latency

Given these values, compute the estimate for system memory requirements using the following procedure:

1. Round up clip size to even multiple of tile size in each dimension.
2. Divide each dimension by tile size in that dimension.
3. Add 2 tiles to each dimension for a tile boundary of 1.

If there is high latency downloading, such as reading tiles Over the network, or decompressing tiles, add 4 tiles per dimension, giving a tile boundary of 2.

You now have the number of tiles in each dimension per clipped level.

4. Multiply each tile number in each dimension by the corresponding tile size in that dimension.

You now have the number of texels in each dimension.

5. Multiply the texel dimensions together.
6. Scale by the size of each texel.
7. Add in the fixed cost of image cache structs.

You now have the system memory cost in bytes for each clipped level.

8. Treat each level bigger than clip size as clipped. Add 4/3rds of the clip size scaled by the texel size for the pyramid levels.

This estimate is a bit too conservative, since the lowest clipped levels may exceed the entire level size with a border of 2 tiles. It is a function of tile size and clip size.

9. Scale the clipped level size by the number of clipped levels.

Example Estimating System Memory Requirements

The example uses the following values in its estimation:

- 2M top level
- 1K clip size
- 512 Tile Size (everything square)
- 1 byte texel size (LMV example)

Example 10-1 estimates system memory requirements using the preceding procedure.

Example 10-1 Estimating System Memory Requirements

1. No-op: 1K, 1K (for both s and t).
2. $1K/512 = 2$, 2 (for both s and t).
3. $2+4 = 6$, 6 (for both s and t; high latency on tile download)
4. $6 * 512 = 3K$, 3K (for both s and t)
5. $3K * 3K = 9M$
6. $9M * 1 = 9M$
7. $9M * 10 = 90M$ (for 2M -> 4K levels) + 2M (for 2K level) = 92M
8. $4/3 * 1K * 1K = 1.3M$
9. Total Size $92M + 1.3M = 93.3M$

Texture Memory Estimation

The following values are required to estimate texture memory requirements:

- Clip size (in texels).
- Whether the clipmap is virtual or non-virtual.
- Number of levels in use (if less than 16).

Given these values, you can compute the estimate for texture memory requirements using one of the following guidelines:

- If the clipmap is virtual, multiply the number of levels by the square of the clip size.
- If the clipmap is non-virtual:
 1. Multiply the number of levels bigger than the clip size by the square of the clip size.
 2. Add $4/3$ times the clip size squared.

There is, however, a further complication involved in accurately estimating texture memory requirements.

Texture Memory Usage: A Further Complication

InfiniteReality rendering boards come with either 16 or 64 megabytes of texture memory. Unfortunately, you can not just use the texture memory any way you want. The texture memory is divided into two equal banks. Each adjacent mipmap level clipmapped or not, must be placed in opposite banks. This ends up restricting the amount of texture memory available for clipmapping.

A further restriction is that texture formats can take up 16 bits or 32 bits of data per texel, but nothing in-between. This means an 888 RGB format takes up 32 bits per texel, just like an 8888 RGBA format.

To give you an example of this restriction, consider an example using RGB texel data, 8 bits per component, and a clip size of 2048 by 2048. The largest level is 8K by 8K. The system has an RM board with 64M of texture memory, so it would seem that there is plenty room, but the following calculation shows otherwise:

1. The cliptexture's non-virtual, so the total texture memory requirement is the clip size times the number of clipped levels plus $4/3$ of the pyramid:
2. 4K, 4K levels are clipped to 2K X 2K: RGB, 8 bits per channel 4 bytes (not 3!) per texel times 2K X 2K = 4M of texels per level;
3. 6M of texture memory per clipped level
4. So that's 32M of texture memory
5. 2K and below is the pyramid, so $4/3$ of 16M = $21\frac{1}{3}$ M
6. Total is $53\frac{1}{3}$ M of texture memory.

Unfortunately, the texture does not fit into texture memory because:

1. 64M of texture memory means two 32M banks.
2. Each level must be in the opposite 32M bank.
3. Consequently, 8K level becomes 16M in bank 0 (16M left).
4. At the 4K level, 16M goes into bank 1 (16M left).
5. At the 2K level, 16M goes into bank 0 (0M left).
6. At the 1K level, 8M goes into bank 1 (8M left).
7. At the 512 level, there is no room in bank 0!!

The best you could do is to have only 1 clipped level, as follows:

1. At the 4K level, 16M goes into bank 0 (16M left).
2. At the 2K level, 16M goes into bank 1 (16M left).
3. At the 1K level, 8M goes into bank 0 (8M left).
4. At the 512 level, 4M goes into bank 1 (12M left).
5. At the 256 level, 2M goes into bank 0 (6M left); and so on.

Probably a better solution would be to use the 5551 format RGBA texels, which only use 16 bits per texel, allowing more levels, as follows:

1. At the 32K level, 8M goes into bank 0 (24M left).
2. At the 16K level, 8M goes into bank 1 (24M left).
3. At the 8K level, 8M goes into bank 0 (16M left).
4. At the 4K level, 8M goes into bank 1 (16M left).
5. At the 2K level, 8M goes into bank 0 (8M left).
6. At the 1K level, 4M goes into bank 1 (12M left).
7. At the 512 level, 2M goes into bank 0 (6M left).
8. At the 256 level, 1M goes into bank 1 (11M left); and so on.

You can get a lot more mileage out of smaller texel formats than less levels. This becomes even more true for RMs with only 16M of texture memory.

Using Cliptextures in Multipipe Applications

IRIS Performer provides good support for multipipe cliptextures, allowing applications to ignore many of the differences between single pipe and multi-pipe operations. The primary issue in multi-pipe applications is knowing when to make master/slave cliptextures, what parameters should be shared, and when and how to create separate centers in different master and slave cliptextures.

When to Make Master/Slave Cliptexture Groups

When it's possible, it is desirable to make master/slave cliptexture groups in multipipe applications. Master/slave groups share the same mem regions and disk access bandwidth, reducing the load on the system. Masters and slave can also take advantage of sharegroups, automating some of the work of synchronizing slave cliptextures with their masters.

Master and slave cliptextures *don't* work when the different cliptextures represent different textures. Separate cliptextures must be created for each texture that has to be displayed. Another condition that prevents using master/slave cliptexture groups is when the center for the cliptexture in each pipe is completely independent. Master and slave cliptextures assume that the tex region for each cliptexture is always completely enclosed by the shared mem region. If that assumption is violated, the cliptexture data will be invalid for the parts of the tex region outside of the shared mem region, and the cliptextures will print error messages.

Slave Cliptextures with Offset Centers

There is no reason for the slave cliptextures to have the same centers as the master, as long as the tex regions always stay within the mem region. Sometimes it is desirable for an application to have views with slightly different viewpoints for each pipe. This can be done by turning off clipcenter sharing, and having the application set a slave's center directly. The application is responsible for keeping the tex region inside the master's mem region at all times. The position of the master's center determines the groups mem region, so the master's center can not be offset from the center of the mem region.

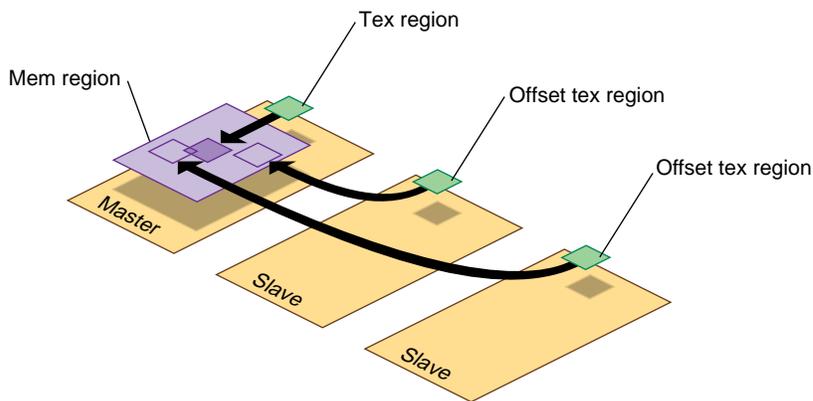


Figure 10-14 Offset Slave Tex Regions

Virtualizing Cliptextures

Virtual cliptextures are one of the most challenging features to use in an IRIS Performer application. Cliptextures themselves are challenging enough, since they tie together functionality in the scene graph, pfPipes and pfChannels. Virtual cliptextures add an additional level of complication, since they require that the application segment the terrain, estimate the texture LOD levels needed for each terrain segment based on the current eyepoint, and update the virtual cliptexture parameters appropriately.

Some tips to consider when working with virtual cliptextures:

- Get your application working with a non-virtual cliptexture first. It's hard to separate virtual cliptexture problems from basic cliptexture configuration problems (which are usually easier to fix).
- Start off with a single segment and as little complexity in the application as possible, then get that working. It makes debugging much simpler.
- When in doubt, print it out. For debugging purposes, a well placed set of **pfNotify()** statements can be really helpful. It's also useful to set up a canonical scene, where you know what parameters *should* be generated, then compare them against what the program does.
- Take maximum advantage of sample code and utilities. Try to re-use some of the example code provided by IRIS Performer. Using (or just reading) through the loaders, example programs, and utilities listed in this section "Cliptexture Sample Code" on page 373 can save you hours of work.

Customizing Load Control

Setting texload time, multiple cliptexture load control, normally, bandwidth from disk to system memory is optimized by image cache configuration. You can use the streams feature in image cache configuration files to maximize bandwidth by configuring the system with as more disks and disk controllers, and copying the texture data files over multiple disks. By using the streams feature in image cache configuration files, you can then parallelize the disk downloads over separate disks and disk controllers. You can also stripe disks to increase disk download bandwidth.

Texture memory bandwidth is more a matter of careful rationing of DRAW process time each frame. You will have to ration between sending geometry and texture data to the graphics pipeline. You can adjust the cliptexture's texload time to minimize idle time in the draw process. DTR computes texture download time using a cost table to estimate what the download updates will cost each frame. It's a good estimate, but not a perfect one. You may have to build in some time margin in the DRAW process to avoid dropping frames.

Download time setting can be as simple as finding the minimum time that still allows the cliptexture to completely sharpened when the clipcenter is stationary. If the texload time is too small, a cliptexture can get "stuck" and never sharpen beyond a given level.

Sophisticated users might consider adjusting the invalid border as well, which will change the effective clip size of the cliptexture. This could be used to allow a new level to be gradually loaded over a number of frames; trading off a finer visible level against a smaller effective clip region.

Custom Read Functions

Custom read functions allow the application to control what happens when texture data is downloaded from disk. Operations include: texture data decompression, texture data image processing, signaling an update of a disk cache from tape, etc. As described in the API section, replacing the read function is fairly easy to do in IRIS Performer.

One caveat: increasing the overhead of read functions can have undesirable consequences. The latency of read operations determines the minimum size of the image cache mem regions, since they need to lookahead to compensate for high latency reads. Low bandwidth read operations effect how fast the center can move before DTR must blur down to coarser levels.

One way around these problems is to implement a lookahead disk cache. Rather than have the read function decompress files, have it read files from a cache of files that have already been decompressed by an asynchronous process. The read function can signal the other process to decompress more files as it gets close to the edge of the cache.

Texture data image processing, since it is relatively fast compared to disk reads, usually doesn't require such elaborate measures. Changing the read function can be done in conjunction with modifying the image cache mem region data to ensure that all data read from disk is processed. A good example of this technique is the gridify feature, described in "Invalidating Cliptextures" on page 353.

Cliptexture Sample Code

The best way to learn to use cliptextures is to work from existing code. IRIS Performer has a number of demo programs, test programs, loader code, and utilities, with different levels of sophistication:

Test and Demo Programs

- */usr/share/Performer/src/pguide/libpr/C/icache.c* - a simple libpr-style program that uses an image cache and the texture transform matrix to scroll texture across a polygon.
- */usr/share/Performer/src/pguide/libpr/C/icache_mwin.c* - This program is a multiwindow version of **icache**; it uses master and slave image caches. Note that the tex regions of the slaves image caches are offset from the master.
- */usr/share/Performer/src/pguide/libpr/C/cliptex.c* - a simple libpr-style program that uses a cliptexture to display a bird's eye view of data. On a system that supports cliptexturing, it moves the clipcenter, allowing the user to see the rectangle of texture resolution move as the center translates between opposite diagonals.
- */usr/share/Performer/src/pguide/libpr/C/cliptex_mwin.c* - This is a multiwindow version of **cliptex**. It uses master and slave cliptextures.
- */usr/share/Performer/src/pguide/libpf/C/cliptex.c* - This is a libpf implementation using cliptextures. Rather than use clipcenter nodes, it uses a simple centering mechanism based on the x and y coordinates of the channel's viewpoint.
- */usr/share/Performer/src/pguide/libpf/C/virtcliptex.c* - This is the virtual cliptexture version of the **cliptex** program. It will take any size cliptexture and virtualize it. It divides a flat terrain in the x,y plane into a rectangular grid, attaching geodes with callbacks to each grid square. The callback calculates the virtual cliptexture parameters and applies them.

IRIS Performer Cliptexture Applications

- */usr/share/Performer/src/app/sample/C/perfly.c* - This sample application supports cliptextured scene graphs. It assumes that the loaders will do the basic configuration, but it does the post loading cliptexture configuration, creating pfMPClipTextures and attaching them to pipes. It assumes that clipcenter nodes are in the scenegraph, and that they will do the centering work. Pressing g will toggle the gridify feature.
- */usr/share/Performer/src/app/sample/C/clipfly.c* - This is the cliptexture version of the **perfly** sample application. It contains extra interface sliders and buttons that allow you to control many more cliptexture parameters.

Loaders that Support Cliptextures

- */usr/share/Performer/src/lib/libpfdb/libpfim/pfim.c* - This is the IRIS Performer example loader. It contains simple tokens to create clipcenter nodes and cliptextures. It is a good starting point for cliptexture configuration in the loader.
- */usr/share/Performer/src/lib/libpfdb/libpfct/pfct.C* - This is a more sophisticated cliptexture sample loader. It automatically creates some simple cliptextured geometry, and supports virtual cliptextures, providing the geometry segmentation and scene graph callbacks.
- */usr/share/Performer/src/lib/libpfdb/libpfvct/pfvct.C* - This is a very simple pseudo-loader that will adjust a cliptextures parameters so it can be used as a virtual cliptexture, even if its dimensions are smaller than 32K by 32K.
- */usr/share/Performer/src/lib/libpfspherepatch/pfspherepatch.C* - this is a cliptexture loader designed to apply a cliptexture to a sphere. It is a good example of a specific cliptexture application.

Cliptexture Utility Code

- */usr/share/Performer/src/lib/libpfutil/gridify.C* - the gridify functionality illustrates techniques for dynamically modifying cliptexture data, and illustrates how to replace the cliptexture's read function.
- */usr/share/Performer/src/lib/libpfutil/trav.c* - the function `pfuFindClipTextures` illustrates how to traverse the scenegraph to find cliptextures.
- */usr/share/Performer/src/lib/libpfutil/pfuClipCenterNode.C* - this code defines the clipcenter node, and contains example code for creating customized clipcenters by subclassing.
- */usr/share/Performer/src/lib/libpfutil/clipcenter.c* - the `pfuProcessClipCenters()` and `pfuProcessClipCentersWithChannel()` functions illustrate how to use clipcenters in an application.
- */usr/share/Performer/src/lib/libpfutil/cliptexture.c* - the `pfuAddMPClipTextureToPipes()` and `pfuAddMPClipTexturesToPipes()` functions illustrate how to work with cliptextures and pipes.

“Windows”

This chapter describes how to create, configure, manipulate, and communicate with a window in Performer.

Windows

Rendering to the graphics hardware requires a window. A window is an allocated area of the screen with associated framebuffer resources. The X window system manages the use of shared resources amongst the different windows. Windows can be requested directly from an X window server. With a bit of interfacing, both IRIS GL and OpenGL graphics contexts can render into X windows.

This chapter describes how to create, configure, manipulate, and communicate with a window using `pfWindow` in IRIS Performer. The extended `libpf` object `pfPipeWindow`, based on `pfWindow`, is also mentioned in this chapter as the two objects share much functionality. Likewise, for good understanding of windowing issues, the next chapter, Chapter 12, “`pfPipeWindows` and `pfPipeVideoChannels`,” should also be read.

pfWindows for both OpenGL and IRIS GL

An X window with an OpenGL graphics context is called an OpenGL/X window. An X window with an IRIS GL graphics context is called a mixed model IRIS GL (GLX) window. IRIS GL supports a third option: pure IRIS GL windows. Pure IRIS GL windows are convenient and flexible for rendering purposes but can not be used as X windows in X applications. If, for example, you want to put your rendering window inside a larger Motif® window, you will need an X window. `Libpr` provides utilities to shield you from the differences between the different types of windows and guide you in your dealings with the window system. Applications that use the IRIS Performer window utilities can be completely portable between IRIS GL and OpenGL and still have the option of using pure IRIS GL windows if desired when running in IRIS GL. You’ll be able to use your windows in X applications, or direct your rendering to a pre-created window. The *libpr* windowing support centers around the `pfWindow`. The *libpf* windowing support is based on `pfWindow` and uses a `pfPipeWindow`.

pfWindows are structures for managing any of the different kinds of windows and associated pfState. pfWindows provide an efficient windowing interface between your application and the window system. pfWindows shield you from the functional and performance differences between the different graphics libraries and the different window system interfaces and allow you to configure, manipulate, and query IRIS GL, IRIS GL mixed model (GLX), and OpenGL/X windows through a GL and window system independent interface. pfWindows also keep track of your graphics state: they include a pfState which is automatically initialized when you open a window, and switched for you when you change windows.

IRIS Performer automatically configures and initializes your window so that it will be ready to start rendering efficiently. In the simplest case, pfWindows make creating a graphics application that can run on any Silicon Graphics machine with IRIS GL or OpenGL a snap. pfWindows do not limit your ability to configure any part or all of your windowing environment yourself; you can use the *libpr* pfWindows to manage your GL windows even if you create and configure the actual windows yourself.

Creating a pfWindow

A pfWindow structure is created with **pfNewWin()**. It can then be immediately opened with **pfOpenWin()**. Example 11-1 shows the most basic pfWindow operations in *libpr* program: to open and clear a pfWindow and swap front and back color buffers.

Example 11-1 Opening a pfWindow

```
int main (void)
{
    pfWindow *win;
    /* Initialize Performer */
    pfInit();
    pfInitState(NULL);

    /* Create and open a Window */
    win = pfNewWin(NULL);
    pfWinName(win, "Hello from IRIS Performer");
    pfOpenWin();

    /* Rendering loop */
    while (1)
    {
        /* Clear to black and max depth */
```

```

        pfClear(PFCL_COLOR | PFCL_DEPTH, NULL);
        ...
        pfSwapWinBuffers(win);
    }
}

```

The pfWindow in Example 11-1 will have the following configuration:

Window system interface

OpenGL windows will be an X window using the OpenGL/X interface.
IRIS GL windows will be pure IRIS GL.

Screen: The pfWindow will open a window on the screen specified by the DISPLAY environment variable, or else on screen 0.

Position and size:

The position and size will be undefined and the window will come up as a rubber-bend for the user to place and stretch.

Framebuffer configuration:

The window will be doublebuffered RGBA with depth and stencil buffers allocated. The size of these buffers will depend on the available resources of the current graphics hardware platform. GLX and OpenGL/X windows will also have multisample buffers allocated if they are available on current hardware platform.

Libpr state: A pfState will be created and initialized with all modes disabled and no attributes set.

Graphics state: The pfWindow will be in RGBA color mode with subpixel vertex positioning, depth testing and viewport clipping enabled. The Viewing projection will be a two-dimensional one-one orthographic mapping from eye coordinates to window coordinates with distances to near and far clipping planes -1 and 1, respectively. The model matrix will be the current matrix and will be initialized to the identity matrix.

Typically, pfWindows go through a bit more initialization than that of Example 11-1. The type of pfWindow type, set with **pfWinType0** is a bitmask that selects the window system interface and the type of rendering window. The default window type is a normal graphics rendering window and is pure IRIS GL under IRIS GL operation and X under OpenGL. operation. Table 11-1 lists the possible selectors that can be OR-ed together for specification of the window type.

Table 11-1 pfWinType() Tokens

PFWIN_TYPE_ Bitmask Token	Description
X	Window will be an X window, as opposed to a pure IRIS GL window. This only has effect under IRIS GL operation.
STATS	Window will have framebuffer resources to accommodate hardware statistics modes. This type cannot be combined with PFWIN_TYPE_OVERLAY or PFWIN_TYPE_NOPORT.
OVERLAY	Window will have only overlay planes for rendering. This type cannot be combined with PFWIN_TYPE_STATS or PFWIN_TYPE_NOPORT.
NOPORT	Window will have a graphics context but no physical window or graphics or framebuffer rendering resources and will not be placed on the screen. This token can not be used in combination with any other type token.
PBUFFER	The pfWindow drawable will be created as a pbuffer and will not be visible.
UNMANAGED	Other than select upon open, no unrequested window management operations are done on automatically on the pfWindow.

The selection of screen can be done explicitly with **pfWinScreen()**, or implicitly by opening a connection to the window system using **pfOpenScreen()** with the desired screen as the default screen. A window system connection can communicate with any screen on the system; the default screen only determines the screen for windows that do not have a screen explicitly set for them. Only one window system connection should be opened for a process. See “Communicating with the Window System” later in this section for details on efficient interaction with the window system.

The position and/or size, is set with **pfWinOriginSize()**. If the x and y components of the origin are (-1), the window will open with position undefined for the user to place. If the x or y components of the size are (-1), the window will open with both position and size undefined (the default) for the user to place and stretch. The X window manager may override negative origins and place the window at (0,0). If the window is already opened when **pfWinOriginSize()** is called, the window will be reconfigured to the specified origin and size upon the next **pfSelectWin()**. Similarly, **pfWinFullScreen()** will cause a window to open as full screen or to become full screen upon the next call to **pfSelectWin()**. A full screen window will have its border automatically removed so that the drawing area truly gets the full rendering surface. The routines for querying the

position and size work a bit differently than the pattern established by the rest of *libpr* get and set pairs of routines. This is because a user may change the origin or size independently of the program and under certain conditions, querying the true current X window size and origin can be expensive. **pfGetWinOrigin()** and **pfGetWinSize()** will always be fast and will return the last explicitly set origin and size, such as by **pfOpenWin()**, **pfWinOriginSize()**, or **pfWinFullScreen()**. If the window origin or size has been changed, but not through a pfWindow routine, the values returned by **pfGetWinOrigin()** and **pfGetWinSize()** may not be correct. **pfGetWinCurOriginSize()** will return an accurate size and origin relative to the pfWindow parent. For pure IRIS GL windows, this will also be reasonably fast; however, for X windows, it will be expensive and should not be done in real-time situations. The parent of an IRIS GL window is always the screen, but not so with X windows. **pfGetWinCurScreenOriginSize()** will return the size and the screen-relative origin of the pfWindow. If the pfWindow is an X window, this command will be quite expensive and is not recommended except for rare use or initialization purposes.

pfPipeWindows, discussed in Chapter 12, “pfPipeWindows and pfPipeVideoChannels,” take advantage of the multiprocessed *libpf* environment to always be able to return an accurate window size and origin relative to the window parent. However, even for pfPipeWindows, getting a screen-relative origin can be an expensive operation.

Hint: Users are strongly encouraged to write programs that are window-relative and do not depend on knowing the current exact location of a window relative to its parent or screen.

Configuring the Framebuffer of a pfWindow

IRIS Performer provides a default framebuffer configurations for the current graphics hardware platform for the standard window types: normal rendering, statistics (stats), and overlay. You may want to define your own framebuffer configuration, such as single-buffered, stereo, etc. You can use utilities in *libpr* to help you with this task, or create your own framebuffer configuration structure with X utilities, or even create the window yourself and apply it to the pfWindow. **pfOpenWin()** will respect any specified framebuffer configuration. Additionally, **pfOpenWin()** uses any window or graphics context that is assigned to it and only creates what is undefined.

pfWinFBConfigAttrs() can be used to specify an array of framebuffer attribute tokens listed in Table 11-2. The tokens are exactly like the OpenGL/X tokens and the same attribute list can be used for all window types: pure IRIS GL, mixed model IRIS GL, and OpenGL/X windows. Note that if an attribute array is specified, the tokens modify configuration with no attributes set, not the default IRIS Performer framebuffer configuration.

Table 11-2 pfWinFBConfigAttrs() Tokens

PFFB_Token	Value	Description
BUFFER_SIZE	integer > 0	The size of the color index buffer
LEVEL	integer > 0	The color plane level: normal color planes have level = 0 overlay color planes have level > 0 underlay color planes have level < 0 There may be only one or no levels for overlay and underlay color planes on some graphics hardware configurations.
RGBA	Boolean: true if present	Use RGBA color planes (instead of color index)
DOUBLEBUFFER	Boolean: true if present	Use double-buffered color buffers
STEREO	Boolean: true if present	Allocate left and right stereo color buffers (allocates back left and back right if DOUBLEBUFFER is specified).
AUX_BUFFER	integer > 0	Number of additional color buffers to allocate
RED_SIZE GREEN_SIZE BLUE_SIZE ALPHA_SIZE	integer > 0	Minimum number of bits color for components R, G, and B will all be the same and be the maximum specified. Alpha may be different.
DEPTH_SIZE	integer > 0	Number of bits in the depth buffer
STENCIL	integer > 0	Number of bits allocated for stencil. One is used by pfDecal rendering and three or four are used by the hardware fill statistics in pfStats.

Table 11-2 (continued) pfWinFBConfigAttrs() Tokens

PFFB_Token	Value	Description
ACCUM_RED_SIZE ACCUM_GREEN_SIZE ACCUM_BLUE_SIZE ACCUM_ALPHA_SIZE	integer > 0	Number of bits per RGBA component for the accumulation color buffer.
USE_GL	Boolean: true if present	Accepted for compatibility with X routines. Has no effect.

If you desire more control over the exact framebuffer configuration of your pfWindow, you have several options. For pure IRIS GL windows you can make GL framebuffer configuration calls, such as **RGBsize()**, **zbsize()**, and **mssize()**, directly. You can tell IRIS Performer to not do any window configuration by setting an empty attribute array. For X windows you can provide the appropriate framebuffer description for the current GL operation to the pfWindow using **pfWinFBConfig()**. X uses *visuals* to describe available framebuffer configurations. XVisualInfo pointer with **XGetVisualInfo()** will return a list of all visuals on the system and you can search through them to find the appropriate configuration. OpenGL/X also uses GLXFBConfigSGIX to describe framebuffer configurations. You can select either the visual or the GLXFBConfigSGIX for your window and set it on the pfWindow with **pfWinFBConfig()**. **pfGetWinFBConfig()** will always return the corresponding X visual.

libpr also offers utilities for creating framebuffer configurations (**pfFBConfig**) independently of a pfWindow. **pfChooseFBConfig()** takes an attribute array of tokens from Table 11-2 and will return a **pfFBConfig** structure that can be used with your pfWindows, or with X Windows created outside of *libpr*, such as with Motif. You may get back a framebuffer configuration that is better than the one you requested. IRIS Performer will give you back the maximum framebuffer configuration that meets your request that will not add any serious performance degradations. There are specific machine dependent instances where when possible, for performance reasons, we do limit the framebuffer configuration. See the **pfChooseWinFBConfig()** reference page for the specific details. The *libpfutil* utility **pfuChooseFBConfig()** in `/usr/share/Performer/src/lib/libpfutil/xwin.c` provides a limiting framebuffer configuration chooser, complete with source code.

You can use **pfQuerySys()** to query particular framebuffer resources in the current hardware configuration and then use **pfQueryWin()** to query your resulting framebuffer configuration.

There is a special utility for supporting mixed model IRIS GL (GLX) windows. GLX windows use a special attribute array returned by **GLXgetConfig()** and expected by **GLXlink()** for creating a framebuffer configuration and graphics window. You can set and get this special GL-dependent attribute array with **pfWinFBConfigData()** and **pfGetWinFBConfigData()**, respectively. This configuration array is useful for hooking up GLX windows with X windows from other toolkits or with Motif. Under OpenGL operation, **pfWinFBConfigData()** just expects a configuration attribute array appropriate for **glXChooseVisual()** or **pfChooseWinFBConfig()**.

pfWindows and GL Windows

■ Advanced

libpr allows you direct access to the GL and X window handles, or to create your own windows and set them on the *pfWindow*.

You can create your own windows (and/or in the case of OpenGL/X, graphics contexts) and set them on the *pfWindow*. You can then call **pfOpenWin()** to make sure everything is hooked up correctly, apply any specified origin and size, and to initialize your IRIS Performer state. Under pure IRIS GL operation, a window and a graphics context are the same thing. A pure IRIS GL window is created with the **winopen()** command and can be assigned to the *pfWindow* with **pfWinWSDrawable()**, or **pfWinGLCxt()**.

pfOpenWin() will automatically call **pfInitGfx()** and will automatically create a new *pfState* for your window. If you have your own window management and do not call **pfOpenWin()** then you should definitely call **pfInitGfx()** to initialize the window's graphics state for IRIS Performer rendering and you will also need to call **pfNewState()** to create a *pfState* for IRIS Performer's state management.

For X windows, IRIS Performer maintains two windows and a graphics context. The top level X window is the one that placed on the screen and is the one that you should use in your application for selecting X events. This top level window is very lightweight and has minimal resources allocated to it. IRIS Performer then maintains a separate X window that is a child of the parent X window and is the one that is attached to the graphics context. This allows you to select different framebuffer resources for the same drawing area by just selecting a different graphics window and graphics context pair for the parent X window. *pfWindows* directly support this functionality and this is discussed in the next section, "Manipulating a *pfWindow*". Finally, with OpenGL, you may choose to draw to a different X Drawable than a window. X windows are created with the X function **XCreateWindow()**. Mixed model IRIS GL windows have an X window serve as both the graphics drawable and the GL context. OpenGL graphics contexts are created

with **glXCreateContext()**. The parent X Window can be set with **pfWinWSWindow()**, the graphics window or X Drawable is set with **pfWinWSDrawable()**, and can be an X window, pbuffer, or pixmap. The graphics context is set with **pfWinGLCxt()**. For compatibility between GLs, IRIS Performer defines the following GL and Window System independent types defined in Table 11-3. If you create your own window but want to use **pfQueryWin()** you must also provide the framebuffer configuration information with **pfWinFBConfig()** and **pfWinFBConfigData()** for OpenGL and GLX respectively. **pfQueryWin()** uses the internally stored visual, and in the case of GLX, the attribute array given to the GLX call **GLXlink()**.

Table 11-3 Window System Types

pfWS Type	X Type	pfWindow Set/Get Routine
pfWSWindow	X Window	pfWinWSWindow() pfGetWinWSWindow()
pfWSDrawable	Drawable (window, pbuffer, pixmap)	pfWinWSDrawable() pfGetWinWSDrawable()
pfGLContext	IRIS GL: int OpenGL: GLXContext	pfWinGLCxt() pfGetWinGLCxt()
pfFBConfig	XVisualInfo* or GLXFBConfigSGIX*	pfWinFBConfig() pfGetWinFBConfig()
pfWSCconnection	Display*	pfGetCurWSCconnection()

Manipulating a pfWindow

Windows are opened with **pfOpenWin()** and closed with **pfCloseWin()**. When a window is closed, its graphics context is deleted. If you have multiple windows, you select the window to draw to with **pfSelectWin()**. Multiple windows can be made more efficient using share groups configured with **pfWinShare()** to share hardware resources. Multiple windows can be made to have swapbuffers execute simultaneously through window swap groups created with **pfAttachWinSwapGroup()**. There are also some additional modes on pfWindows to control their behavior under various operations. This section goes through the basics of these important features.

There are some modes you can set that can effect the general look and behavior of your window and alternate configuration windows. These boolean modes can be individually set and changed at any time with **pfWinMode()** and the tokens in Table 11-4.

Table 11-4 pfWinMode() Tokens

PFWIN_ Token	Description
NOBORDER	Window will be without normal window system border
HAS_OVERLAY	Overlay alternate configuration window will be managed by the pfWindow. pfOpenWin() will automatically create an overlay window if one has not already been set. pfWinIndex(win, PFWIN_OVERLAY_WIN) will also automatically create and open an overlay window if one has not already been set. This mode only has effect for X windows.
HAS_STATS	Statistics alternate configuration window will be managed by the pfWindow. pfOpenWin() will automatically create a statistics window if one has not already been set. pfWinIndex(win, PFWIN_OVERLAY_WIN) will also automatically create and open a statistics window if one has not already been set and if the current window cannot support statistics. This mode only has effect for X windows.
AUTO_RESIZE	The graphics window and active alternate configuration windows are automatically resized to match the parent pfWinWSWindow() . This mode is enabled by default and only has effect for X windows.
ORIGIN_LL	The origin of the pfWindow, for placement purposes, will be the lower-left corner. X uses the upper left corner as the origin and pure IRIS GL uses the lower-level. This mode is enabled by default.
EXIT	The application will receive a DeleteWindow message upon selection of the "Exit" from the window system menu on the window border. This mode only has effect for X windows.

Alternate Framebuffer Configuration Windows

IRIS Performer supports multiple framebuffer configurations for the same drawing area in a GL independent fashion with alternate configuration windows. An IRIS Performer alternate configuration window has the same window parent (**pfWinWSWindow()**) but may have a different drawable and graphics context. There are standard alternate configuration windows for overlay and statistics windows that can be automatically created upon demand. For pure IRIS GL, alternate configuration windows must have their graphics context be the same as the base window. The rest of this section assumes the use of X windows in either GLX or OpenGL/X.

An alternate configuration window is created as a full pfWindow and is an alternate configuration window by virtue of being given to a base window in a pfList of alternate configuration windows, or being directly assigned as one of the standard alternate configuration windows with either of **pfWinOverlayWin()** or **pfWinStatsWin()**. A pfWindow may be an alternate configuration window of only one base window at a time; alternate configuration windows may not be instanced between base windows. The sharing of window attributes between alternate configuration windows, such as the parent X window and GL objects (for OpenGL windows), must be set with **pfWinShare()** on the base window and applied to the alternate configuration windows with **pfAttachWin()**. You select the desired alternate configuration window to draw into with **pfWinIndex()** and provide an index into your alternate configuration window list or one of the standard indices (PFWIN_GFX_WIN, PFWIN_OVERLAY_WIN, or PFWIN_STATS_WIN). PFWIN_GFX_WIN is the default window index and selects the base window. If the alternate configuration window has not been opened, it will be opened automatically upon being selected for rendering. Example 11-2 demonstrates creating a pfWindow using the default overlay window. The graphics drawable and graphics context of an alternate configuration window of a pfWindow can be closed with **pfCloseWinGL()**. This can be called on the base window, in which case the active alternate configuration window's GL window and context will be closed, or it can be called on the alternate configuration window pfWindow directly. The main parent window will remain on the screen and a new alternate configuration window can be applied to it or **pfOpenWin()** can be called to create a new graphics window and context.

Window Share Groups

Multiple windows on a screen will require duplicate processing and resources unless they are set up as share groups. A `pfWindow` is attached to the group of another with `pfAttachWin(groupWin, attachee)`. The attributes to be shared are set with `pfWinShare()` on any of the windows in the group. The full list of attributes are in the reference page for `pfWindow` (and similarly for `pfPipeWindow`) but most notably are `PFWIN_SHARE_GL_CXT` for using the same graphics context across multiple windows, `PFWIN_SHARE_STATE` for sharing full state information, and `PFWIN_SHARE_GL_OBJS` for sharing display lists and textures across windows. These specific share parameters are only supported by OpenGL/X operation. In particular, sharing GL objects is important if a display list (such as for fonts) are to be created for one context and used in multiple contexts. When default alternate configuration windows are automatically created (overlay and stats) they are configured to share GL objects with the base window. A *libpf* `pfPipeWindow` example of window share groups is in `/usr/share/Performer/src/pguide/libpf/C/multiwin.c`.

Synchronization of Swapbuffers for Multiple Windows

OpenGL `pfWindows` in window swap groups will have simultaneous hardware execution of swapbuffers. There is a similar mechanism for `pfPipeWindows` activated through `pfChannel` share groups sharing `PFCHAN_SWAPBUFFERS_HW` that supports both OpenGL and IRIS GL and is discussed in Chapter 2, "Setting Up the Display Environment."

A window swap group is created by attaching windows with `pfAttachWinSwapGroup(groupWin, attachee)`. There is no global list maintained for the swap group and their status so you cannot get back a list of windows in the group. However, `pfWinInSwapGroup()` will return 1 if the specified window as been synchronzied to a swap group and 0 otherwise. This synchronization configuration will actually take place upon a call to `pfSelectWin()` for the window. Windows of separate screens can be attached but this also requires a BNC cable (of any Ohms) to be attached to the swap ready connectors of the graphics pipelines. Detach from swap groups is not supported. GLX barriers are used for multipipeline synchronization. If necessary, you can have a `pfWindow` explicitly join a specific barrier group with `pfWinSwapBarrier()`. When windows of multiple screens are attached, the video vertical retrace of those screens should also be synchronzied with `genlock(7)`.

Communicating with the Window System

You can communicate with a local or remote window server by means of a window system connection, a `pfWConnection` (in X, also known as a Display connection). You can use your `pfWConnection` for selecting X events for your window, as is demonstrated in Example 11-4.

Libpr offers several utilities for creating a connection to a window server. A given connection can communicate with any screen managed by that window server so usually a process only needs one connection. A process should not share the connection of another process, so you will need a connection per process. Typically, there is exactly one window server on a machine but that is not required. *Libpr* maintains a `pfWConnection` for the current process. By default, this connection obeys the setting of the `DISPLAY` environment variable which can point to a window server on a local or a remote machine. The current connection can be requested with `pfGetCurWConnection()`, and can be set with `pfSelectWConnection()`. It is recommended that whenever possible, this connection be used to limit the total number of open connections. `pfOpenScreen()` is a convenient mechanism for opening a connection with a specified default screen. `pfOpenWConnection()` allows you to specify the exact name specifying the desired target for the connection. Both `pfOpenScreen()` and `pfOpenWConnection()` allow you to specify if you would like the new connection to automatically be made the current `libpr pfWConnection`; this is recommended.

More pfWindow Examples

Example 11-2 demonstrates the creation of a window with a default overlay window.

Example 11-2 Using the Default Overlay Window

```
int main (void)
{
    pfWindow *win, *over;
    /* Initialize Performer */
    pfInit();
    pfInitState(NULL);

    /* Initialize the window. */
    win = pfNewWin(NULL);
    pfWinOriginSize(win, 100, 100, 500, 500);
    pfWinName(win, "Iris Performer");
    pfWinType(win, PFWIN_TYPE_X);
}
```

```
    pfWinMode(win, PFWIN_HAS_OVERLAY, 1);
    pfOpenWin(win);
    /* First select and draw into the overlay window */
    pfWinIndex(win, PFWIN_OVERLAY_WIN);
    /* Select causes the index to be applied */
    pfSelectWin(win);
    ...
    /* Then select the main gfx window */
    pfWinIndex(win, PFWIN_GFX_WIN);
    pfSelectWin(win);
    ...
}
```

Example 11-3 demonstrates creating a custom overlay window and is taken from the sample program `/usr/share/Performer/src/pguide/libpr/C/winfbconfig.c`.

Example 11-3 Creating a Custom Overlay Window

```
static int OverlayAttrs[] = {
    PFFB_LEVEL, 1, /* Level 1 indicates overlay visual */
    PFFB_BUFFER_SIZE, 8,
    None,
};

int main (void)
{
    pfWindow *win, *over;
    /* Initialize Performer */
    pfInit();
    pfInitState(NULL);

    /* Initialize the window. */
    win = pfNewWin(NULL);
    pfWinOriginSize(win, 100, 100, 500, 500);
    pfWinName(win, "Iris Performer");
    pfWinType(win, PFWIN_TYPE_X);
    pfWinMode(win, PFWIN_HAS_OVERLAY, 1);

    over = pfNewWin(NULL);
    pfWinName(over, "Iris Performer Overlay");
    pfWinType(over, PFWIN_TYPE_X | PFWIN_TYPE_OVERLAY);
    /* See if we can get the desired overlay visual */
    if (!(pfChooseWinFBConfig(over, OverlayAttrs)))
        pfNotify(PFNFY_NOTICE, PFNFY_PRINT,
            "pfChooseWinFBConfig failed for OVERLAY win");
}
```

```

    pfOpenWin(win);
    /* First select and draw into the overlay window */
    pfWinIndex(win, PFWIN_OVERLAY_WIN);
    /* Select causes the index to be applied */
    pfSelectWin(win);
    ...
    /* Then select the main gfx window */
    pfWinIndex(win, PFWIN_GFX_WIN);
    pfSelectWin(win);
    ...
}

```

Example 11-4 demonstrates the selection of X input events on a pfWindow. This example is taken from `/usr/share/Performer/src/pguide/libpr/C/hlcube.c`. See the `/usr/share/Performer/src/pguide/libpf/C/complex.c` sample program for a detailed example of using either GL or forked X input on pfWindows.

Example 11-4 pfWindows and X Input

```

    pfWSConnection Dsp;

void main (void)
{
    pfWindow *win;
    pfWSWindow xwin;

    /* Initialize Performer */
    pfInit();
    pfInitState(NULL);

    /* Initialize the window. */
    win = pfNewWin(NULL);
    pfWinOriginSize(win, 100, 100, 500, 500);
    pfWinName(win, "Iris Performer");
    pfWinType(win, PFWIN_TYPE_X);
    pfOpenWin(win);
    ...
    /* set up X input event handling on pfWindow */
    Dsp = pfGetCurWSConnection();
    xwin = pfGetWinWSWindow(win);
    XSelectInput(Dsp, xwin, KeyPressMask );
    XMapWindow(Dsp, xwin);
    XSync(Dsp, FALSE);
    ...
    do_events(win);
}

```

```
    }
    static void
    do_events(pfWindow *win)
    {
        while (1) {
            while (XPending(dsp))
            {
                XEvent event;
                XNextEvent(Dsp, &event);
                switch (event.type)
                {
                    case KeyPress:
                        ....
                }
            }
        }
    }
}
```

“pfPipeWindows and pfPipeVideoChannels”

This chapter describes advanced topics in setting the display.

pfPipeWindows and pfPipeVideoChannels

This chapter describes the additional windowing and video-channel based functionality provided by `pfPipeWindows` and `pfPipeVideoChannels`. These *libpf* objects, based on their *libpr* counterparts, `pfWindows` and `pfVideoChannels`, provide automatic configuration, multiprocessing, and extended functionality by being hooked together with `pfChannels`.

Using `pfPipeWindows`

IRIS Performer can automatically create and open a full screen window with a default configuration for your `pfPipe`. At the other extreme, you can create and configure your own windows and set them on a `pfPipe`. Your window may be OpenGL/X, pure IRIS GL, IRIS GLX (also known as *mixed model*). For all window types, there is a single interface for creating, configuring, and managing the windows. In all cases, the `pfPipeWindow` is the mechanism by which a `pfPipe` knows about and keeps track of the windows to which it is to render, the size of the render area, and the framebuffer configuration. `pfPipes` and `pfChannels` need this information for proper viewport and frustum management and for using rendering features like antialiasing, transparency for fade LOD, and layers for decal geometry that are all affected by framebuffer configuration.

In the simplest case, IRIS Performer automatically creates a `pfPipeWindow` for the application and automatically open a full screen window upon the first call to `pfFrame()`. This trivial case is demonstrated in Example 12-1.

Creating, Configuring and Opening `pfPipeWindow`

In most cases, there are some window parameters, such as size and origin, that you will want to set. You may also have custom graphics state that you need to set to fully initialize your rendering window. This section describes the basics for setting up windows through the `pfPipeWindow` mechanism.

A pfPipeWindow can be created for a pfPipe using **pfNewPWin(pipe)**. If you create a pfPipeWindow, then you are responsible for explicitly opening it. The call to **pfOpenPWin(pwin)** from the application process will cause the next call to **pfFrame()** to trigger the opening of the pfPipeWindow in the draw process. A pfPipeWindow created in the application will be a rubber-band window of undefined size for the user to stretch out. This is in contrast to the full screen window that IRIS Performer creates on your behalf in the fully automatic case. To easily get a full screen window, you can use the **pfPWinFullScreen()** function. **pfPWinOriginSize()** can be used to set a fixed position and size for the window. The code in Example 12-1, placed in the application process, will create and open a window in the lower-left corner of the screen of size 500 pixels on each side.

Example 12-1 Creating a pfPipeWindow

```
main()
{
    pfPipe *pipe;
    pfPipeWindow *pwin;
    pfInit();
    ...
    pfConfig();
    /* Create pfPipeWindow for pfPipe 0 */
    pipe = pfGetPipe(0);
    pwin = pfNewPWin(pipe);
    /* Set the origin and size of the pfPipeWindow */
    pfPWinOriginSize(pwin, 0, 0, 500, 500);
    /* Tell IRIS Performer that the pfPipeWindow is ready to
     * be opened
     */
    pfOpenPWin(pwin);
    /* trigger the opening of the pfPipeWindow
     * in the draw process
     */
    pfFrame();
    ...
    while(!SimDone())
    { ... }
}
```

The pfPipeWindow is always physically opened in the draw process when processing the application frame that requested the window to be opened. When both the cull and draw processes are running as separate processes, there might be a 2 frame delay (2 additional calls to **pfFrame()**) for the window do actually be opened. Additionally, if the draw is running as a separate process, the window won't be opened right after pfFrame but some time in that following frame. If the pfPhase is such that the application process is allowed to spin ahead while the draw process does expensive initialization (anything but PFPHASE_FREE_RUN), the application process may execute many **pfFrame()** calls before the window is physically opened in the draw process. If in the application process you need to check on a result from opening the window, such as framebuffer configuration, you will want to do something that is in effect equivalent to the following:

```
while (!pfIsPWinOpen(pwin)) pfFrame();
```

pfPipeWindows are actually built upon *libpr* pfWindows, but have added support for handling the multiprocessed environment of *libpf* applications and fit into the *libpf* display hierarchy of pfPipes, pfPipeWindows, and pfChannels. Additionally, pfPipeWindows support the multiprocessing environment of *libpf* by having a separate copy of each pfPipeWindow in each pipeline process. All of the “windowness” of pfPipeWindows really comes from the fact that there is a pfWindow internal to the pfPipeWindow. Many of the basic support routines, such **pfPWinFullScreen()** and **pfWinFullScreen()**, have very similar functionality for pfWindows and pfPipeWindows. However, there are situations where pfPipeWindows are able to provide the same functionality in a much more efficient manner. Management of dynamic window origin and size is one case where pfPipeWindows have a real advantage over pfWindows. pfPipeWindows are able to take advantage of the multiprocessed *libpf* environment to always be able to return an accurate window size and origin relative to the window parent. A process separate from the rendering process is notified by the window system of changes in the pfPipeWindow's size in an efficient manner without impacting the window system or the rendering process. This can be forced off for the real-time static displays of a deployed visual simulation system by making the pfPipeWindow of type PFPWIN_TYPE_NOXEVENTS which will prevent IRIS Performer from tracking the window. Further details regarding basic window creation and configuration are discussed with pfWindows in Chapter 11, “Windows.”

Note: pfPWin*() routines expect a pfPipeWindow and the pfWin*() routines a pfWindow(). These routines are not interchangeable; pfWindow routines cannot accept pfPipeWindows and visa versa. The PFPWIN_* tokens can be used with the pfPipeWindow routines.

Windows have some intrinsic type attributes that must be set before the window is opened. The selection of the screen of a window is determined by the pfPipe that it is opened on, or set for both the pfWindow and its pfPipe with the call **pfPWinScreen()**, or else by the value of the DISPLAY variable when the window is finally opened. The window system configuration of the window must also be set before the window is opened. Windows under OpenGL operation will always be X windows. However, under IRIS GL operation, a pfPipeWindow will by default be a pure IRIS GL window. To render IRIS GL into an X window, the X window type must be specified with the command, **pfPWinType(pwin, PFPWIN_TYPE_X)**. An open window must be closed for its type to be changed. The window type argument is actually a bitmask and the type of a pfPipeWindow can include the attributes listed in Table 12-1.

Table 12-1 pfPWinType Tokens

PFPWIN_TYPE_* Bitmask Token	Type Attributes
X	Rendering will be done to an X window. Ignored by OpenGL as all OpenGL rendering is done to X windows.
STATS	The window's normal drawing configuration will support graphics statistics. This affects framebuffer configuration and fill statistics.
SHARE	The pfPipeWindow will automatically be attached to the first pfPipeWindow of the parent pipe with pfAttachPWin()
PBUFFER	The window drawable is a pbuffer; not visible on the screen.
NOXEVENTS	Window size and position tracking will not be done.
UNMANAGED	No automatic window management operations other than select for rendering will happen. Window will not be auto-sized, or tracked. Swapbuffers will not automatically be done.

pfPipeWindows have a target default framebuffer configuration. The ability to meet this target will depend on the current graphics hardware configuration, as well as their type. The following parameters are part of the target default configuration and are listed in their order of priority. If the goal framebuffer configuration cannot be created on the current graphics hardware configuration, lower priority parameters will be downgraded as specified.

- double buffered,
- RGB mode with eight bits per color component (four if eight cannot be supported),

- z-buffer with depth of 23 or 24 bits, as available
- one bit stencil buffer (windows type PFWIN_TYPE_STATS will still require 4 bits of stencil),
- multisample buffer of eight, four, or zero samples as available.
- four bit stencil buffer if still available after the above is satisfied.

pfPipeWindows have IRIS Performer *libpr* rendering state automatically initialized when they are opened. Additionally the following graphics state is automatically initialized when a window is opened, or upon any call to **pfInitGfx()** for an open window:

- in pure IRIS GL windows, the framebuffer configuration is restored to default; however, if multisample buffers already exist, the default multisampled configuration is used,
- RGB mode is enabled,
- z-buffer is enabled and a z range is set,
- viewport clipping is enabled,
- subpixel vertex accuracy is enabled,
- the viewing matrix is initialized to a two-dimensional one-to-one mapping from eye coordinates to window coordinates.,
- the model matrix is initialized to the identity matrix and made the current GL matrix,
- backface removal is enabled,
- smooth shading is enabled,
- if the current graphics hardware platform supports multisampling, multisampled antialiasing will be enabled with **pfAntialias(PFAA_ON)**,
- a default modulating texture environment is created,
- a default lighting model is created.

Custom framebuffer configuration for a pfPipeWindow can be specified with **pfPWinFBConfigAttrs()**, **pfPWinFBConfig()**, and **pfChoosePWinFBConfig()**. These routines have identical functionality as each of the corresponding pfWindow routines. However, the function **pfChoosePWinFBConfig()** has the constraint that it be called in the draw process because it creates and stores internal data from the window server that must be kept local to the process in which it is called. Table 12-2 lists the different pfPipeWindow routines and describes multiprocessing constraints.

The flexibility in changing the framebuffer configuration of a pfPipeWindow is GL dependent. IRIS GL supports reconfiguration of the framebuffer. However, in GLX or OpenGL/X windows, it is considerably trickier. The main window can remain in place but structures under it must be switched or replaced. If multiple framebuffer configurations are likely to be desired, multiple graphics contexts can be created for the window using pfWindows. pfPipeWindows and pfWindows both allow you to have a list of alternate pfWindows that render to exactly the same screen area but may have different framebuffer configuration. You then select the current configuration for a pfPipeWindow with **pfPWinIndex()**. There are two kinds of common alternate configuration windows that can be created automatically for you: overlay windows created in the overlay planes and windows to support hardware fill statistics (discussed in Chapter 18, “Statistics”). You can use **pfPWinMode()** to indicate that you would like these windows created for you automatically. Special tokens to **pfPWinIndex()** are used to select these common special alternate configuration windows—PFWIN_GFX_WIN, PFWIN_OVERLAY_WIN and PFWIN_STATS_WIN—where PFWIN_GFX_WIN selects the normal default drawing window. Note that only a pfWindow, never a pfPipeWindow, can be an alternate configuration window. The source code in Example 12-2 is taken from */usr/share/Performer/src/pguide/libpf/C/pipewin.c* and demonstrates the automatic creation and selection of overlay and statistics windows for a pfPipeWindow. This also shows usage of pfChannels and interaction between pfPipeWindows and pfChannels discussed in the section “Creating and Configuring a pfChannel” in Chapter 2.

Example 12-2 pfPipeWindow With Alternate Configuration Windows for Statistics

```
main()
{
    pfPipe *pipe;
    pfPipeWindow *pwin;
    pfInit();
    ....
    pfConfig();

    /* Create pfPipeWindow for pfPipe 0 */
```

```

pipe = pfGetPipe(0);
pwin = pfNewPWin(pipe);
/* request automatic default overlay and stats windows */
pfPWinMode(pwin, PFWIN_HAS_OVERLAY, PF_ON);
pfPWinMode(pwin, PFWIN_HAS_STATS, PF_ON);
/* Open the main graphics window */
pfOpenPWin(pwin);
pfFrame();

while(!SimDone())
{
    ...
    if (Shared->winSel == PFWIN_STATS_WIN)
    {
        /* select statistics window and enable fill stats */
        pfPWinIndex(Shared->pw, PFWIN_STATS_WIN);
        pfFStatsClass(fstats,
            PFSTATSHW_ENGFPIPE_FILL, PFSTATS_ON);
        pfEnableStatsHw(PFSTATSHW_ENGFPIPE_FILL);
    }
    else
    {
        /* we are not doing statistics so turn them off */
        pfFStatsClass(fstats,
            PFSTATSHW_ENGFPIPE_FILL, PFSTATS_OFF);
        pfDisableStatsHw(PFSTATSHW_ENGFPIPE_FILL);
        pfPWinIndex(Shared->pw, Shared->winSel);
    }
    ...
}

/* Channel draw process drawing function */
void DrawFunc(void pfChannel *chan)
{
    pfPipeWindow *pwin;
    pwin = pfGetChanPWin(chan);
    if (pfGetPWinIndex(pwin) == PFWIN_OVERLAY_WIN)
    {
        /* Draw overlay image */
        DrawOverlay();
        /* Put back the normal drawing window */
        pfPWinIndex(pwin, PFWIN_GFX_WIN);
        /* Indicate that we will now draw to the window */
        pfSelectPWin(pwin);
    }
}

```

```
        /* call the main IRIS Performer drawing function */
        pfDraw();
    }
```

Notice that in Example 12-2, although the pfPipeWindow is doublebuffered, the front and back color buffers are never explicitly swapped. For pfPipeWindows, this operation is done automatically after all channels on the parent pfPipe have completed their drawing for the given frame. The color buffers of a pfPipeWindow may be swapped explicitly with pfSwapWinBuffers. This call may be placed in a user-swap function call back placed on the pfPipe with **pfPipeSwapFunc()** to replace the pfPipe normal swap behavior. The swap callback will be called in the draw process at the end of the frame after all pfChannels in all pfWindows have been drawn for the pfPipe. The function is called for all of the pfPipeWindows on the pfPipe. This is additionally useful for doing end-of-frame rendering or readbacks from the framebuffer.

You may need to set additional window and graphics state to complete the initialization of your pfPipeWindow. Calling **pfOpenPWin()** from the application process does not give you the opportunity to do this. However, with **pfPWinConfigFunc()**, you can supply a window configuration callback function that will enable you to open and initialize your pfPipeWindow in the draw process. A call to **pfConfigPWin()** will trigger one call of the window configuration callback in the draw process upon the next call to **pfFrame()**. **pfConfigPWin()** can be called at any time to trigger the calling of the current window configuration function in the draw process. Example 12-3 demonstrates initializing a pfPipeWindow from a draw process window configuration callback. It creates a global light to serve as the Sun in the window configuration callback. (see the */usr/share/Performer/src/pguide/libpf/C/complex.c* example).

Example 12-3 Custom Initialization of pfPipeWindow State

```
main()
{
    pfPipe *pipe;
    pfPipeWindow *pwin;
    pfInit();
    ....
    pfConfig();

    /* Create pfPipeWindow for pfPipe 0 */
    pipe = pfGetPipe(0);
    pwin = pfNewPWin(pipe);
    /* Set the configuration function for the pfPipeWindow */
    pfPWinConfigFunc(pwin, OpenPipeWindow);
    /* Indicate that OpenPipeWindow should be called in the
```

```

        * draw process.
        */
        pfConfigPWin(pwin);

        /* trigger OpenPipeWindow to be called in the draw process */
        pfFrame();
        while(!SimDone())
        { ... }
    }

    /* Initialize graphics state in the draw process */
    void
    OpenPipeWindow(pfPipeWindow *pw)
    {
        /* Set some configuration stuff */
        pfPWinOriginSize(pw, 0, 0, 500, 500);
        /* Open the window - will give us initialized libpr and
        graphics state
        */
        pfOpenPWin(pw);

        /* create a global light in the "south-west" (QIII) */
        Sun = pfNewLight(NULL);
        pfLightPos(Sun, -0.3f, -0.3f, 1.0f, 0.0f);
    }

```

In Example 12-3 the functions **pfPWinOriginSize()** and **pfOpenPWin()** are now called in the draw process, as opposed to the application process as in Example 12-1. In general, configuring or editing any *libpf* object must be done in the application process. **pfPipeWindows** must be created in the application process. However, **pfPipeWindows** may be configured, edited, opened and closed in the **pfPWinConfigFunc()** configuration callback which will be called in the draw process. Window operations are best done in a configuration callback, though they can also be done in the drawing callback for a **pfChannel** on the window. Any function which aspires to directly affect the graphics context must be called in the drawing process. Table 12-2 shows which processes (application or draw via a configuration function) that **pfPipeWindow** calls can be made from and further detail about these functions can be found in the discussion of **pfWindows** in Chapter 11, "Windows."

Table 12-2 Processes From Which to Call Main pfPipeWindow Functions

pfPipeWindow Function	Application Process	Draw process
pfNewPWin()	Yes.	No.
pfPWinMode()	Yes,	Yes.
pfPWinIndex()	Yes,	Yes.
pfPWinConfigFunc()	Yes.	No.
pfOpenPWin() pfClosePWin() pfClosePWinGL()	Yes.	Yes.
pfPWinOriginSize() pfPWinFullScreen()	Yes.	Yes.
pfGetPWinCurOriginSize() pfGetPWinCurScreenOriginSize()	X — Yes. IRIS GL — No.	Yes.
pfPWinFBConfigAttrs()	Yes.	Yes.
pfChoosePWinFBConfig()	No.	Yes.
pfPWinFBConfig()	Yes, but the pfFBConfig* must be valid for access in the draw process.	Yes.
pfPWinType() pfPWinScreen() pfPWinShare(), pfAttachWin()	Yes (before opened).	Yes (before opened).
pfPWinWSWindow() pfPWinWSDrawable()	X — Yes. IRIS GL — ID must be valid in the draw process.	Yes.
pfPWinGLCxt()	Yes, but the context must be created in the draw process.	Yes.
pfQueryWin() pfMQueryWin()	No.	Yes.
pfAddPWinPVChan()	Yes.	Yes.
pfAttachPWinSwapGroup	Yes.	Yes.

IRIS Performer provides GL independent framebuffer configuration utilities. In most cases, **pfPWinFBConfigAttrs(pwin, attrs)** can be used to select a framebuffer configuration for your pfPipeWindow based on the array of attribute tokens, *attrs*. If *attrs* is NULL, the default framebuffer configuration will be selected. If *attrs* is not NULL, the rules for default values follow the rules for configuring windows in OpenGL and X which are different from values in the IRIS Performer default window configuration. Such window framebuffer configuration should be done in the draw process in a window configuration callback function before the call to **pfOpenPWin()**. Window framebuffer configuration for pfPipeWindows is identical to that of pfWindows and is discussed in more detail in Chapter 11, “Windows,” but the following is a simple example of the specification of framebuffer configuration taken from the sample source code example program `/usr/share/Performer/src/pguide/libpf/C/pipewin.c`.

Example 12-4 Configuration of a pfPipeWindow Framebuffer

```
static int FBAttrs[] = {
    PFFB_RGBA,
    PFFB_DOUBLEBUFFER,
    PFFB_DEPTH_SIZE, 24,
    PFFB_RED_SIZE, 8,
    PFFB_SAMPLES, 8,
    PFFB_STENCIL_SIZE, 1,
    NULL,
};

main()
{
    pfPipe *pipe;
    pfPipeWindow *pwin;
    pfInit();
    ....
    pfConfig();

    /* Create pfPipeWindow for pfPipe 0 */
    pipe = pfGetPipe(0);
    pwin = pfNewPWin(pipe);
    /* Set the framebuffer configuration */
    pfPWinFBConfigAttrs(Shared->pw, FBAttrs);
    /* Indicate that the window is ready to open */
    pfOpenPWin(pwin);
    /* trigger the opening of the window in the draw */
    pfFrame();
    ...
}
```

If you want to do all of your own window creation and management you can do so and just give IRIS Performer the handles to your windows with the **pfPWinWSDrawable()** function; you may also provide a parent X window with the **pfPWinWSWindow()** function. **pfOpenPWin()** will make use of any windows that have already been provided. More details regarding the creation and configuration of pfPipeWindows and pfWindows are discussed in Chapter 11, “Windows.”

pfPipeWindows in Action

pfPipeWindows allow for a reasonable amount of flexibility in the running application. pfPipeWindows can be re-ordered on their parent pfPipe to control the order that they are drawn in with the command **pfMovePWin(pipe, index, pwin)**. pfPipeWindows can be dynamically opened and closed in the application or draw processes with **pfOpenPWin()** and **pfClosePWin()**. Additionally, **pfConfigPWin()** can be re-issued at any time from the application process to call the current window configuration function to dynamically open, close, and reconfigure pfPipeWindows.

The following example is taken from the distributed source code example file */usr/share/Performer/src/pguide/libpf/C/pipewin.c* and demonstrates the dynamic closing of a window from the application process in the simulation loop and the reuse of **pfConfigPWin()** to reopen the window.

Example 12-5 Opening and Closing a pfPipeWindow

```
main()
{
    ...
    /* main simulation loop */
    while (!Shared->exitFlag)
    {
        /* wait until next frame boundary */
        pfSync();
        pfFrame();
        /* Set view parameters for next frame */
        UpdateView();
        pfChanView(chan, Shared->view.xyz, Shared->view.hpr);

        /* Close pfPipeWindow */
        if (Shared->closeWin == 1)
        {
            pfClosePWin(Shared->pw);
            ct = pfGetTime();
        }
    }
}
```

```

        Shared->closeWin = 2;
    }
    /* then wait two seconds and reconfig window */
    else if ((Shared->closeWin == 2) &&
            (pfGetTime() - ct > 2.0f))
    {
        pfConfigPWin(Shared->pw);
        Shared->closeWin = 3;
        pfNotify(PFNFY_NOTICE, PFNFY_PRINT, "OPEN");
    }
    ...
}

```

Motif

You may want your windows to reside within a larger Motif interface and window hierarchy. IRIS Performer supports this and allows you to run the Motif main loop in a separate process so that you can maintain control of your simulation loop. The Motif interface is created in its own process and Motif event handlers and callbacks will be executed in that process. The Motif callbacks set flags in shared memory to communicate with the main application. Part of this communication is the sharing of X windows between IRIS Performer and Motif. The example program */usr/share/Performer/src/pguide/libpf/C/motif.c* demonstrates the basic elements of this integrated IRIS Performer-Motif hook-up.

Multiple pfPipeWindows and Multiple pfPipes

The use of multiple windows on a single graphics pipe can add overhead. The sharing of the graphics context between windows consumes almost all of this overhead. To simply share a single graphics context across windows of two pfPipe objects, include `PFPWIN_TYPE_SHARE` in the `pfPWinType()` call. The sharing of pfPipeWindows and attributes can be completely controlled by setting up the sharing manually to create pfPipeWindow share groups with `pfPWinAttach(groupPWin, attachee)` and `pfPWinShare()` as is done with pfWindows, discussed in Chapter 11, "Windows." pfPipeWindows can have pfWindows in their share group if a pfPipeWindow is the main group window.

Multiple windows, particularly those on separate graphics pipelines, that are intended to produce results that can be seen as a single image, such as projected side by side on a large screen or to video outputs used for a stereo display, must have their video vertical retraces synchronized with `genlock(7)` and their doublebuffering synchronized. This is

necessary for both image quality and performance reasons as the last window to finish operation can hold up all of the rendering processes. Window double buffering synchronization can be done through pfChannel share groups with the PFCHAN_SWAPBUFFERS_HW token, as discussed in Chapter 2, “Setting Up the Display Environment,” or explicitly by attaching the windows to form window swap groups with **pfAttachPWinSwapGroup(groupPWin, attachee)** as discussed in Chapter 11, “Windows.” pfPipeWindows can have pfWindows in their swap groups if a pfPipeWindow is the main group window. The sample program */usr/share/Performer/src/pguide/libpf/C/multipipe.c* demonstrates multipipe synchronization.

Controlling Video Displays

You use pfPipeVideoChannel to direct the output of pfChannels to specified video displays, as shown in Figure 12-1. IRIS Performer uses the XSGIvc(3), which is a Silicon Graphics extension of the X library, for video channel management.

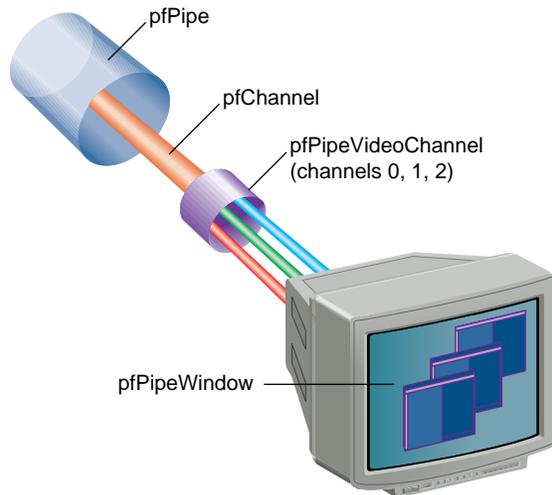


Figure 12-1 Directing Video Output

pfPipeVideoChannels are based on pfVideoChannels; however, pfPipeVideoChannels are maintained by libpf and are used by libpf to render the output of pfChannels within a pfPipeWindow. The pfVideoChannel API is duplicated for pfPipeVideoChannels. **pfPVChan*()** methods operate on a pfPipeVideoChannel and **pfVChan*()** methods operate on a pfVideoChannel.

There are several sample programs to help understand the use of pfVideoChannels and pfPipeVideoChannels. The *libpr* program */usr/share/Performer/src/pguide/libpr/C/queryvchan.c* shows how to query video channel attributes through IRIS Performer and how to query additional attributes directly through the XSGIvc interface. */usr/share/Performer/src/pguide/libpr/C/vchan.c* shows basic video channel creation. On an InfiniteReality, this example does resizing and translation of the video channel output area. The *libpf* program */usr/share/Performer/src/pguide/libpf/C/pvchan.c* shows basic pfPipeVideoChannel creation and hookup.

Creating a pfPipeVideoChannel

You create a pfPipeVideoChannel from a pfPipe using **pfNewPVChan()** and providing the parent pfPipe. The pfPipeVideoChannel is then attached to a pfPipeWindow with **pfAddPWinPVChan()** which will return an index into the pfPipeWindow's video channel list. Additionally, if the pfPipeVideoChannel has not already been assigned a hardware video channel with **pfPVChanId()**, the next active video channel will be assigned.

```
pfPipe *p = pfGetPipe(0);
pfPipeVideoChannel *pvc = pfNewPVChan(p);
pfPVChanId(pvc, 0);
pvcIndex = pfPWinAddPVChan(pwin, pvc);
```

To find out if a pfPipeVideoChannel with its current video channel assignment is active for displaying output, call **pfIsPVChanActive()**, which will return 0 if the video channel assignment is not fully defined or if the channel is not active and will return 1 otherwise. The assignment of a hardware video channel is not complete until the screen of the pfPipe is known and so might not be done immediately if the pfPipe screen has not been set with **pfPipeScreen()** or if the pfPipeWindow is not open. Even if you have explicitly assigned a hardware video channel Id, it is only meaningful relative to a known screen. The hardware video channel assignment can be changed at any time with **pfPVChanId()**. It is an error to have multiple pfPipeWindows and pfPipeVideoChannels attempt to manage the same hardware video channel. The index returned by **pfAddPWinPVChan()** is then used for a pfChannel to reference this

pfPipeVideoChannel. pfPipeWindows always have an initial pfPipeVideoChannel already attached whose default video channel will be the first active video channel on the screen of the pfPipe. So, only add pfPipeVideoChannels if you actually need additional video channels.

Multiple pfPipeVideoChannels in a pfPipeWindow

The only video channels a pfPipeVideoChannel can manage are those of the screen of the pfPipe. Use **pfGetNumScreenPVChans()** to find out how many active video channels are on a given screen.

To add additional pfPipeVideoChannels to a single pfPipeWindow, use **pfPWinAddPVChan()**. The routine returns an index number associated with the pfPipeWindow, or -1 if an error occurs. If the pfPipeVideoChannel does not already have an assigned hardware video channel, the next active video channel relative to the video channels already attached to the pfPipeWindow will be assigned.

There are list routines to manage the list of pfPipeVideoChannels on a pfPipeWindow. Use **pfGetPWinNumPVChans()** to find out how many pfPipeVideoChannels are being managed by the pfPipeWindow. **pfPWinRemovePVChan()** and **pfPWinRemovePVChanIndex()** disassociate a pfPipeVideoChannel from a pfPipeWindow, using either the pfPipeWindow object or an index number to specify the pfPipeWindow.

There are additional utilities to find pfPipeVideoChannels on pfPipeWindows. You can obtain the index value of a pfPipeVideoChannel for a pfPipeWindow using **pfGetPWinPVChanIndex()**, which returns the index of a pfPipeVideoChannel, or -1 if the pfPipeVideoChannel is not registered with the pfPipeWindow. Use **pfGetPWinPVChanId()** to find a pfPipeVideoChannel on a pfPipeWindow with the specified hardware Id. NULL will be returned if no such pfPipeVideoChannel exists on the specified pfPipeWindow.

Configuring a pfPipeVideoChannel

pfPipeVideoChannels are bound to their hardware video channels in a lazy fashion as needed by configuration requests. Basic queries of a video channel do not require any explicit binding. Changing a video channel's properties does require explicit binding. pfPipeWindows manage this process. However, explicit binding and unbinding might be necessary if changes are made to video channels directly through the XSGIvc API and not through the pfPipeVideoChannel API. This is quite reasonable since pfPipeVideoChannels do not duplicate all of XSGIvc. A pfPipeVideoChannel is bound to its hardware video channel with **pfBindPVChan()**. All of the pfPipeVideoChannels associated with a pfPipeWindow can be bound in one step with **pfBindPWinPVChans()** and unbound with **pfUnbindPWinPVChans()**. You can get the XSGIvc handle from a pfPipeVideoChannel to do your own configuration or extended queries with **pfGetPVChanInfo()**.

Use pfPipeVideoChannels to Control Frame Rate

There are two mechanisms by which pfPipeVideoChannels can help you maintain constant frame rate in your application. Dynamic Video Resolution (DVR) addresses reducing load caused by filling to many pixels. Pan/Zoom video scan-out to sample different parts of the frame buffer, under resize, to be selected asynchronously to a draw process. Both of these mechanisms make use of editing the size and or origin of the output area of a pfPipeVideoChannel, supported by InfiniteReality graphics platforms. Use **pfPVChanOutputSize()** and **pfPVChanOutputAreaScale()** will change the output area size of the bound video channel. **pfPVChanOutputOrigin()** will change the origin of the output area. The pfPipeVideoChannel(3) references more routines to manage video channel origin and size.

On InfiniteReality graphics platforms, you can use pfPipeVideoChannels to dynamically adjust the size of the output area of the video channel. The output area is then automatically zoomed up to full video channel size by the InfiniteReality hardware using bilinear filtering. This operation has no added performance cost or latency. This feature can be used to allow pfChannels to reduce their viewport size to the reduced video channel output area. Reducing the number of pixels drawn reduces the fill load for the pfPipe and can be used as a load management technique for maintaining constant frame rates. pfPipeVideoChannels support manual resizing, allowing you to implement your own load management, or will automatically resize the output area and the pfChannel viewports. You can enable and select a resizing mode with **pfPVChanDVRMode()** and providing PFPVC_DVR_MANUAL or PFPVC_DVR_AUTO. The default value is PFPVC_DVR_OFF. For more information, see "Maintaining Frame Rate Using Dynamic Video Resolution" on page 128.

pfPipeVideoChannels also support asynchronous editing of their size and origin. This can be used in an asynchronous process, or in an application process that is reliably running at frame rate, to edit the origin and size of the video channel. These changes will affect the following video field if the **pfPVChanMode()** for PFVCHAN_AUTO_APPLY is set to 1 (default is 0) and the PFVCHAN_SYNC mode is set to PFVCHAN_SYNC_FIELD (default is PFVCHAN_SYNC_FRAME which selects apply upon swapbuffers).

Real-time changes to pfPipeVideoChannel origin or size should be done between **pfSync()** and **pfFrame()** to affect the next draw frame or video field.

“Managing Nongraphic System Tasks”

This chapter describes clocks, memory allocation, synchronous I/O, error handling and notification, and search paths.

Managing Nongraphic System Tasks

This chapter describes objects that manage nongraphic tasks, including

- Queues
- Clocks
- Memory allocation
- Synchronous I/O
- Error handling and notification
- Search paths

Handling Queues

A pfQueue object is a queue of elements, which are all the same type and size; the default size is the size of a void pointer. A pfQueue object actually consists of three interrelated queues, as shown in Figure 13-1.

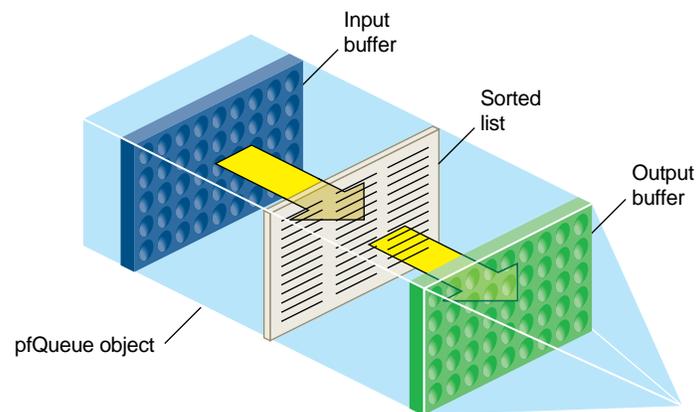


Figure 13-1 pfQueue Object

- Input buffer—where processes dump values to be added to the pfQueue object.
- Output buffer—values at one end of the queue that processes may remove from the pfQueue object.
- Sorted list—sorted values that processes may not remove from the pfQueue object.

Note: In non-sorting mode, there is only the Input buffer; values in the output buffer and the Sorted list are transferred into the input buffer.

Values in the Input buffer are not sorted and are not part of the Sorted list. Values in the Sorted list and the Output buffer are sorted (when the pfQueue object is in sort mode) according to a user-defined sorting function. Sorted values of highest priority are automatically moved from the Sorted list to the Output buffer whenever the pfQueue object is sorted. Priority is defined by the sorting function, for example, if a pfQueue object contains pointers to tiles of texture, the sorting function might sort according to the proximity of the viewer and the tile: the closer the tile is to the viewer, the higher its priority, the more likely the pointer to the tile will be in the Output buffer. Processes do not have access to values in the Sorted list; only to those values in the Output buffer.

Multiprocessing

Because there are separate input and output buffers, multiple processes can add or retrieve elements, but only one process can actually insert elements into the Input buffer and one process retrieve elements from the Output buffer at one time. The process adding elements to the Input buffer can be different from the process removing elements from the Output buffer.

Queue Contents

The contents of the pfQueue object can be any fixed-size object, for example, pfQueues often contain pointers to Performer objects. You might use a pfQueue object, for example, to organize tiles of texture according to the direction the viewer is looking and the proximity of the viewer to the tiles. Because you declare the size and type of objects in the pfQueue in the constructor, you cannot change the type or size of its elements after its creation.

Adding or Retrieving Elements

You can insert elements into the Input buffer or remove them from the Output buffer using the following methods, respectively:

- `pfQueue::insert()`
- `pfQueue::remove()`

These methods can be used by multiple processes asynchronously without collision.

Warning: Do not insert NULL elements into the queue.

The `pfQueue` object is resized dynamically when the number of elements inserted into the queue exceeds its declared size; the size is doubled automatically. Doubling the size prevents repeated, incremental, costly resizing of the queue.

Tip: Doubling the size of the queue can cause excessive memory allocation. It is important therefore to accurately declare the size of the queue.

You can set the size of the queue in the constructor of the `pfQueue` object or afterwards by using `pfQueue::setArrayLen()`. `pfQueue::getNum()` returns the number of elements in the queue.

Retrieving Elements From the Queue

It is possible for you to

1. Create a thread to retrieve elements from the Output buffer.
2. Use the `pfQueue::remove()` method to retrieve the element.
3. Delete the thread.

It is much easier, however, to use the `pfQueue::addServiceProc()` method to perform all of those tasks. This method

- Creates a thread.
- Returns the thread ID.
- Invokes the developer-supplied function in the argument of the function.
- Deletes the thread.

The developer-supplied function must take, as its argument, an element from the Output buffer and process it. For example, if the queue contains pointers to tiles of texture, the function might download a tile from disk to the image cache.

Related Methods

pfQueue provides a variety of other methods, described in Table 13-1, that return information about the threads created to process the elements in the Output buffer of the pfQueue object.

Table 13-1 Thread Information

Method1	Description
getServiceProcPID()	Returns the ID of the created thread.
pfGetGlobalQueueServiceProcPID()	Returns the ID of the nth thread.
getNumServiceProcs()	Returns the number of currently active threads.
pfGetNumGlobalQueueServiceProcs()	Returns the number of processes that have been sproc'd by all pfQueue's.
pfGetGlobalQueueServiceProcQueue()	Returns the pfQueue associated with a particular thread.
exitServiceProc()	Terminates a specific thread.
exitAllServiceProcs()	Terminates all pfQueue object threads.

pfQueue Modes

pfQueue objects can run in one of two modes:

- non-sorting
- sorting

Either the elements in the queue are sorted according to some criteria specified by a developer-supplied sorting function, or not.

The sorting function is null and the sorting mode is non-sorting by default.

Non-Sorting Mode

In non-sorting mode, the Sorting list and the Output buffer are empty; all pfQueue elements are in the Input buffer. Processes append new input objects to the front of the queue while (potentially) other processes read and remove pfQueue objects from the other end of the queue.

A process can potentially read and remove all of the elements in a non-sorted queue. Access to the elements is not random, however; it is sequential and ordered according to FIFO.

Sorting the pfQueue

Multiple processes can add to the Input buffer asynchronously. The objects remain unsorted and separate from the Sorted list and Output buffer until the sorting function is triggered. At that time,

1. The objects in the Input buffer are flushed into the Sorted list.
2. The objects in the Sorting list and the Output buffer are resorted together.

To sort the elements in a pfQueue, you:

1. Specify a developer-supplied sorting function using `pfQueue::setSortFunc()`.
2. Enable sorting by passing a non-NULL argument to `pfQueue::setSortMode()`.
3. Specify the maximum and minimum number of values for the input and output of the sorting function using `pfQueue::setInputRange()` and `pfQueue::setOutputRange()`.

Tip: You must specify the sorting function before enabling sorting, otherwise sorting remains disabled and pfQueue returns a warning.

The sorting function runs in a separate thread parallel to the function specified in the argument of pfQueue. You can even specify that the sorting function run on a CPU different from the one processing the pfQueue object, as described in “Running the Sort Process on a Different CPU” on page 422.

In sorting mode, only those elements in the Output buffer are available to processes. Access to the elements in the Output buffer is not random, but sequential and in a FIFO order.

Sorting Function

The sorting function sorts, according to its own criteria, the elements in the Sorting list and the Output buffer. To sort the queue, you must

- Implement your own function to sort the `pfQueue` object.
- Identify the function in your application using `pfQueue::setSortFunc()`.
- Make the function return a value of type that matches that of `pfQueueSortFuncType`.
- Make the function handle an input data structure of type `pfQueueSortFuncData()`, defined as follows:

```
typedef struct {
    pfList *sortList; //list of elements to sort
    volatile int *inSize; //number of elements on input queue
    volatile int *outSize; //number of elements on output queue
    int inHi; // maximum number of elements at the input
    int inLo; // minimum number of elements at the input
    int outHi; // maximum number of elements at the output
    int outLo; // minimum number of elements at the output
} pfQueueSortFuncData;
```

The actual data in the `pfQueue` object is maintained in a `pfList`, which the `pfQueueSortFuncData` struct points to.

Input and Output Ranges

The range values work as triggers to start the sorting function, which sleeps otherwise. For example, when the number of unprocessed inputs is greater than `inHi`, `pfQueue` calls the sorting function to sort the `pfQueue` object.

You can set the minimum and maximum number of input and output elements entered before the sort is triggered using the following methods:

- `pfQueue::setInputRange()`
- `pfQueue::setOutputRange()`

Table 13-2 shows the default range values:

Table 13-2 Default Input and Output Ranges

Range	Minimum	Maximum
Input	0	3
Output	2	5

The range values have no effect in non-sorting mode.

Triggering the Sort

The sorting function sleeps until one of the following conditions occurs:

- The number of elements in the Input buffer exceeds the input maximum range value.
- The number of elements in the Output buffer drops below the output minimum range value.
- `pfQueue::notifySortProc()` is called.

By increasing the maximum number of values allowed in the Input buffer, or reducing the minimum number of values allowed in the Output buffer, the sorting function is potentially called fewer times.

Table 13-2 shows that, using default range values, the queue is sorted when three or more elements are added to the Input buffer or when two or less values remain in the Output buffer.

The `pfQueue::notifySortProc()` is provided for those times when the queue should be sorted without regard to the number of elements in the Input or Output buffers. For example, if an element in the queue changes, it might be necessary to resort the queue. If, for example, the elements are sorted alphabetically, the sort function should be explicitly called when one of the elements is renamed.

Running the Sort Process on a Different CPU

You can run the sorting process on a different CPU from the one processing the `pfQueue` by:

- Using `getSortProcPID()` to get the process ID of the sorting function and assigning the process to run on a specified CPU with IRIS Performer or IRIX utilities.
- Using the `pfuProcessManager` provided in *libpfutil*. See the `pfuInitDefaultProcessManager(3)` reference page for more information.

High-Resolution Clocks

IRIS Performer provides access to a high-resolution clock that reports elapsed time in seconds to support for timing operations. To start a clock, call `pfInitClock()` with the initial time in seconds—usually 0.0—as the parameter. Subsequent calls to `pfInitClock()` reset the time to whatever value you specify. To read the time, call `pfGetTime()`. This function returns a double-precision floating point number representing the seconds elapsed from initialization added to the latest reset value.

The resolution of the clock depends on your system type and configuration. In most cases, the resolved time interval is under a microsecond, and so is much less than the time required to process the `pfGetTime()` call itself. Onyx, Crimson™, Indigo²™, Indigo®, and Indy™ systems all provide submicrosecond resolution. Newer systems, including Onyx2, OCTANE, and O2 have even higher resolution clocks and use the `CYCLE_COUNTER` functionality through `syssgi(2)`. On a machine that uses a fast hardware counter, the first invocation of `pfInitClock()` forks off a process that periodically wakes up and checks the counter for wrapping. This additional process can be suppressed using `pfClockMode()`.

If IRIS Performer cannot find a fast hardware counter to use, it defaults to the time-of-day clock, which typically has a resolution between one and ten milliseconds. This clock resolution can be improved by using fast timers. See the `ftimer(1)` reference page for more information on fast timers.

By default, processes forked after the first call to `pfInitClock()` share the same clock and will all see the results of any subsequent `pfInitClock()`. All such processes receive the same time.

Unrelated processes can share the same clock by calling **pfClockName()** with a clock name before calling **pfInitClock()**. This provides a way to name and reference a clock. By default, unrelated processes don't share clocks.

Video Refresh Counter (VClock)

The video refresh counter (VClock) is a counter that increments once for every vertical retrace interval. There is one VClock per system. In systems where multiple graphics pipelines are present, but not genlocked (synchronized, see the `setmon(3)` reference page), screen 0 is used as the source for the counter. A process can be blocked until a certain count, or the count modulo some value (usually desired number of video fields per frame) is reached.

Table 13-3 lists and describes the `pfVClock` routines.

Table 13-3 pfVClock Routines

Function	Action
<code>pfInitVClock</code>	Initialize the clock to a value.
<code>pfGetVClock</code>	Get the current count.
<code>pfVClockSync</code>	Block the calling process until a count is reached.

When using **pfVClockSync()**, the calling routine is blocked until the current count modulo *rate* is *offset*. The VClock functions can be used to synchronize several channels or pipelines.

Memory Allocation

You can use IRIS Performer memory-allocation functions to allocate memory from the heap, from shared memory, and from data pools.

Table 13-4 lists and describes the IRIS Performer shared memory routines.

Table 13-4 Memory Allocation Routines

Function	Action
<code>pfInitArenas</code>	Create arenas for shared memory and semaphores.
<code>pfSharedArenaSize</code>	Specify the size of a shared memory arena.
<code>pfGetSharedArena</code>	Get the shared memory arena pointer.
<code>pfGetSemaArena</code>	Get the shared semaphore/lock arena pointer.
<code>pfMalloc</code>	Allocate from an arena or the heap.
<code>pfFree</code>	Release memory allocated with <code>pfMalloc()</code> .

Allocating Memory With `pfMalloc()`

`pfMalloc()` can allocate memory either from the heap or from a shared memory arena. Multiple processes can access memory allocated from a shared memory arena, whereas memory allocated from the heap is visible only to the allocating process. Pass a shared-memory arena pointer to `pfMalloc()` to allocate memory from the given arena. `pfGetSharedArena()` returns the pointer for the arena allocated by `pfInitArenas()`, or NULL if the given memory was allocated from the heap. Alternately, an application can create its own shared memory arena; see the `acreate(3P)` reference page for information on how to create an arena.

To allocate memory from the heap, pass NULL to `pfMalloc()` instead of an arena pointer.

Under normal conditions `pfMalloc()` never returns NULL. If the allocation fails, `pfMalloc()` generates a `pfNotify()` of level `PFNFY_FATAL`, so unless the application has set a `pfNotifyHandler()`, the application will exit.

Memory allocated with `pfMalloc()` must be freed with `pfFree()`, not with the standard C library's `free()` function. Using `free()` with data allocated by `pfMalloc()` will have devastating results.

Memory allocated with **pfMalloc()** has a reference count (see “**pfDelete()** and Reference Counting” in Chapter 1 for information on reference counting). For example, if you use **pfMalloc()** to create attribute and index arrays, which you then attach to **pfGeoSets** using **pfGSetAttr()**, IRIS Performer automatically tracks the reference counts for the arrays, letting you delete the arrays much more easily than if you create them without **pfMalloc()**. All the reference-counting routines (including **pfDelete()**) work with data allocated using **pfMalloc()**. Note, however, that **pfFree()** doesn’t check the reference count before freeing memory; use **pfFree()** only when you’re sure the data you’re freeing isn’t referenced.

pfGetSize() returns the size in bytes of any data allocated by **pfMalloc()**. Since the size of such data is known, **pfCopy()** also works on allocated data.

Although **pfMalloc()**-allocated data behaves in many ways like a **pfObject** (see “Nodes” in Chapter 3), such data doesn’t contain a user data pointer. This omission avoids requiring an extra word to be allocated with every piece of **pfMalloc()** data.

Note: All *libpr* objects are allocated using **pfMalloc()**, so you can use **pfGetArena()**, **pfGetSize()**, and **pfFree()** on all such objects. However, it’s recommended that you use **pfDelete()** instead of **pfFree()** for *libpr* objects, in order to maintain reference-count checking.

Shared Arenas

pfInitArenas() creates two arenas, one for the allocation of shared memory with **pfMalloc()** and one for the allocation of semaphores and locks with **usnewlock()** and **usnewsema()**. The arenas are visible to all processes forked after **pfInitArenas()** is called.

Applications using *libpf* don’t need to explicitly call **pfInitArenas()**, since it’s invoked by **pfInit()**.

The shared memory arena can be allocated by memory-mapping either swap space (*/dev/zero*, the default) or an actual disk file (in the directory specified by the environment variable **PFTMPDIR**). The latter requires sufficient disk space for as much of the shared memory arena as will be used, and disk files are somewhat slower than swap space in allocating memory.

By default, IRIS Performer creates a large shared memory arena of 256 MB. Though this approach makes large numbers appear when you run *ps(1)*, it doesn't consume any substantial resources, since swap or file system space isn't actually allocated until accessed (that is, until **pfMalloc()** is called).

Because IRIS Performer cannot increase the size of the arena after initialization, an application requiring a larger shared memory arena should call **pfSharedArenaSize()** to specify the maximum amount of memory to be used. Arena sizes as large as 1.7 GB are usually acceptable; but you may need to set the virtual-memory-use and memory-use limits, using the shell *limit* command or **setrlimit()**, to allow your application to use that much memory. To use arenas larger than 4G, you must use 64-bit operation.

If you are having difficulties in creating a large arena, it could be due to fragmentation of the address space from too many DSOs. You can reduce the number of DSOs you are using by compiling some of them statically. You can also change the default address of the DSOs by running *rqs(1)* with a custom *so_locations* file.

Allocating Locks and Semaphores

An application requiring lockable pieces of memory should consider using *pfDataPools*, described below. Alternatively, when a lock or semaphore is required in an application that has called **pfInitArenas()**, you can call **pfGetSemaArena()** to get an arena pointer, and you can allocate locks or semaphores using **usnewlock()** and **usnewsema()**.

Datapools

Datapools, or *pfDataPools*, are also a form of shared memory, but they work differently from **pfMalloc()**. Datapools allow unrelated processes to share memory and lock out access to eliminate data contention. They also provide a way for one process to access memory allocated by another process.

Any process can create a datapool by calling **pfCreateDPool()** with a name and byte size for the pool. If an unrelated process needs access to the datapool, it must first put the datapool in its address space by calling **pfAttachDPool()** with the name of the datapool. The datapool must reside at the same virtual address in all processes. If the default choice of an address causes a conflict in an attaching process **pfAttachDPool()** will fail. To avoid this **pfDPoolAttachAddr()** can be called before **pfCreateDPool()** to specify a different address for the datapool.

Any attached process can allocate memory from the datapool by calling **pfDPoolAlloc()**. Each block of memory allocated from a datapool is assigned an ID so that other processes can retrieve the address using **pfDPoolFind()**.

Once you've allocated memory from a datapool, you can lock the memory chunk (not the entire `pfDataPool`) by calling **pfDPoolLock()** before accessing the memory. This locking mechanism works only if all processes wishing to access the datapool memory use **pfDPoolLock()** and **pfDPoolUnlock()**. After a piece of memory has been locked using **pfDPoolLock()**, any subsequent **pfDPoolLock()** call on the same piece of memory will block until the next time a **pfDPoolUnlock()** is called for that memory.

`pfDataPools` are `pfObjects`, so call **pfDelete()** to delete them. Calling **pfReleaseDPool()** unlinks the file used for the datapool—it doesn't immediately free up the memory that was used or prevent further allocations from the datapool; it just prevents processes from attaching to it. The memory is freed when the last process referring to the datapool **pfDelete()**s it.

CycleBuffers

A multiprocessed environment often requires that data be duplicated so that each process can work on its own copy of the data without adversely colliding with other processes. `pfCycleBuffer` is a memory structure which supports this programming paradigm. A `pfCycleBuffer` consists of one or more `pfCycleMemories` which are equally-sized memory blocks. The number of `pfCycleMemories` per `pfCycleBuffer` is global and is set once with **pfCBufferConfig()**, and is typically equal to the number of processes accessing the data.

Note: `pfFlux` replaces the functionality of `pfCycleBuffer`.

Each process has a global index, set with **pfCurCBufferIndex()**, which indexes a `pfCycleBuffer`'s array of `pfCycleMemories`. When each process has a different index (and its own address space), mutual exclusion is ensured if the process limits its `pfCycleMemory` access to the currently indexed one.

The “cycle” term of pfCycleBuffer refers to its suitability for pipelined multiprocessing environments where processes are arranged in stages like an assembly line and data propagates down one stage of the pipeline each frame. In this situation, the array of pfCycleMemories can be visualized as a circular list. Each stage in the pipeline accesses a different pfCycleMemory and at frame boundaries the global index in each process is advanced to the next pfCycleMemory in the chain. In this way, data changes made in the head of the pipeline are propagated through the pipeline stages by “cycling” the pfCycleMemories.

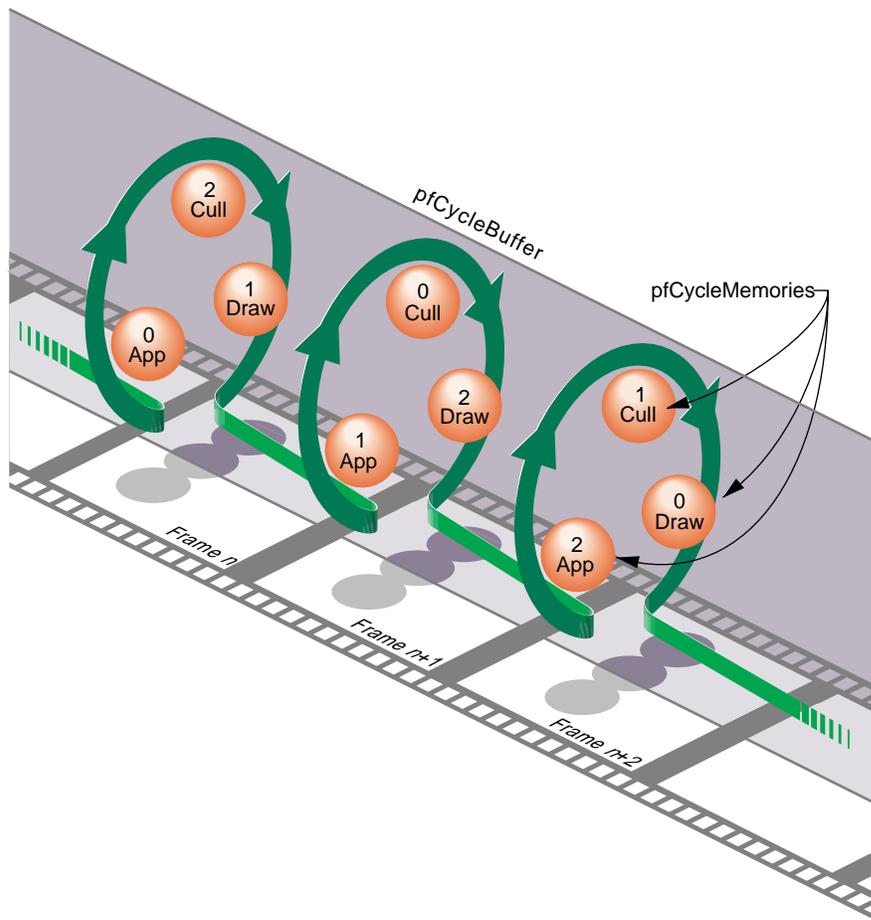


Figure 13-2 pfCycleBuffer and pfCycleMemory Overview

Cycling the memory buffers works if each current `pfCycleMemory` is completely updated each frame. If this is not the case, buffer cycling will eventually access a “stale” `pfCycleMemory` whose contents were valid some number of frames ago but are invalid now. `pfCycleBuffers` manage this by frame-stamping a `pfCycleMemory` whenever `pfCBufferChanged()` is called. The global frame count is advanced with `pfCBufferFrame()` which also copies most recent `pfCycleMemories` into “stale” `pfCycleMemories` thereby automatically keeping all `pfCycleBuffers` current.

A `pfCycleBuffer` consisting of `pfCycleMemories` of `nbytes` size is allocated from memory arena with `pfNewCBuffer(nbytes, arena)`. To initialize all the `pfCycleMemories` of a `pfCycleBuffer` to the same data call `pfInitCBuffer()`. `pfCycleMemory` is derived from `pfMemory` so you can use inherited routines like `pfCopy`, `pfGetSize`, and `pfGetArena()` on `pfCycleMemories`.

While `pfCycleBuffers` may be used for application data, their primary use is as `pfGeoSet` attribute arrays, e.g., coordinates or colors. `pfGeoSets` accept `pfCycleBuffers` (or `pfCycleMemory`) references as attribute references and automatically select the proper `pfCycleMemory` when drawing or intersecting with the `pfGeoSet`.

Note: *libpf* applications need not call `pfCBufferConfig()` or `pfCBufferFrame()` since the *libpf* routines `pfConfig()` and `pfFrame()` call these respectively.

Asynchronous I/O

A nonblocking file interface is provided to allow real-time programs access to disk files without affecting program timing. The system calls `pfOpenFile()`, `pfCloseFile()`, `pfReadFile()`, and `pfWriteFile()` work in an identical fashion to their IRIX counterparts `open()`, `close()`, `read()`, and `write()`.

When `pfOpenFile()` or `pfCreateFile()` is called, a new process is created using `sproc()`, which manages access to the file. Subsequent calls to `pfReadFile()`, `pfWriteFile()`, and `pfSeekFile()` place commands in a queue for the file manager to execute and return immediately. To determine the status of a file operation, call `pfGetFileStatus()`.

Error-Handling and Notification

IRIS Performer provides a general method for handling errors both within IRIS Performer and in the application. Applications can control error-handling by installing their own error-handling functions. You can also control the level of importance of an error.

Table 13-5 lists and describes the functions for setting notification levels.

Table 13-5 pfNotify Functions

Function	Action
pfNotifyHandler	Install user error-handling function.
pfNotifyLevel	Set the error-notification level.
pfNotify	Generate a notification.

pfNotify() allows an application to signal an error or print a message that can be selectively suppressed. **pfNotifyLevel()** sets the notification level to one of the values listed in Table 13-6.

Table 13-6 Error Notification Levels

Token	Meaning
PFNFY_ALWAYS	Always print regardless of notify level
PFNFY_FATAL	Fatal error
PFNFY_WARN	Serious warning
PFNFY_NOTICE	Warning
PFNFY_INFO	Information and floating point exceptions
PFNFY_DEBUG	Debug information
PFNFY_FP_DEBUG	Floating point debug information

The environment variable **PFNFYLEVEL** can be set to override the value specified in **pfNotifyLevel()**. Once the notification level is set via **PFNFYLEVEL** it can not be changed by an application.

Once the notify level is set, only those messages with a priority greater than or equal to the current level are printed or handed off to the user function. Fatal errors cause the program to exit unless the application has installed a handler with **pfNotifyHandler()**.

Setting the notification level to PFNFY_FP_DEBUG has the additional effect of trapping floating point exceptions such as overflows or operations on invalid floating point numbers. It may be a good idea to use a notification level of PFNFY_FP_DEBUG while testing your application, so that you will be informed of all floating-point exceptions that occur.

File Search Paths

IRIS Performer provides a mechanism to allow referencing a file via a set of path names. Applications can create a search list of path names in two ways: the PFPATH environment variable and **pfFilePath()**. (Note that the PFPATH environment variable controls *file search paths* and has nothing to do with the pfPath data structure.)

Table 13-7 describes the routines for working with pfFilePaths.

Table 13-7 pfFilePath Routines

Routine	Action
pfFilePath	Create a search path.
pfFindFile	Search for the file using the search path.
pfGetFilePath	Supply current search path.

Pass a search path to **pfFilePath()** in the form of a colon-separated list of path names. Calling **pfFilePath()** a second time replaces the current path list rather than appending to it.

The environment variable PFPATH is also a colon-separated list of path names, similar to the PATH variable. **pfFindFile()** searches the paths in PFPATH first, then those given in the most recent **pfFilePath()** call; it returns the complete pathname for the file if the file is found. IRIS Performer applications should use **pfFindFile()** (either directly or through routines such as **pfdLoadFile()**) to look for input data files.

pfGetFilePath() returns the last search path specified by a **pfFilePath()** call. It doesn't return the path specified by the PFPATH environment variable—if you want to find out that value, call **getenv(3c)**.

“Dynamic Data”

This chapter describes how to connect pfFlux, pfFCS, and pfEngine nodes, which together can be used for animating geometries.

Dynamic Data

Making your data dynamic allows your scenes to change. Geometries can change location, orientation, color, texture, or change into different things altogether.

pfEngines compute the changes. pfFluxs are the containers for the output of those engines.

This chapter explains how to create dynamic structures that can generate and manipulate their own dynamic data using pfFlux, pfEngine, and pfFCS.

pfFlux

pfFlux is a container for dynamic data that enables multiprocessed generation and use of data in the scene graph. A pfFlux internally consists of multiple buffers of data, each of which is associated with a frame number. The numbering allows multiple processes to each have a copy of the data containing the frame they are working on. Multiple reader processes can share a copy of the current results, or be using the frame of results that is appropriate for that process.

Creating and Deleting a pfFlux

pfFlux::pfFlux() creates and returns a handle to a pfFlux. Each pfFlux buffer is a pfFluxMemory. When you create a pfFlux, you specify the number of buffers it contains as well as the size of each buffer. The pfFlux buffers will automatically be allocated from the same arena as the parent pfFlux. If for the number of buffers you specify `PFFLUX_DEFAULT_NUM_BUFFERS`, the flux will be created with a default number of buffers automatically for the current multi-process configuration of your application, as set by pfMultiprocess. You can globally redefine this default number of buffers for successive creation of pfFluxes using **pfFlux::setDefaultNumBuffers()**. If you change the default number of buffers, the effect takes place only for pfFluxs created after the change.

Note: IRIS Performer sets the default number of `pfFlux` buffers when `pfConfig()` is called according to the number and type of processes requested with `pfMultiprocess()`. Generally, the number of buffers is equal to one more than the number of running processes that typically might generate `pfFlux` data or use `pfFluxed` results. `DBASE` and `LPOINT` processes are not included in the count but `ISECT` and `COMPUTE` processes and additional graphic pipes creating additional `DRAW` and possibly `CULL` processes do add to the default number of `pfFlux` buffers.

You can return the number of buffers in a `pfFlux` and the number of bytes in the buffers using the `getDefaultNumBuffers()` and `getDataSize()` methods, respectively.

To delete a `pfFlux`, as with all `pfObjects`, use `pfDelete()`.

Initializing the Buffers

Generally, `pfFlux` buffers do not require initialization because they are fully recomputed for every frame. One case where you would want to initialize them is when the data in the buffers is static. For example, if you have a `pfFlux` of coordinates where most do not change, rather than continuously updating this static data, it is far more efficient to initialize the buffers. You cannot depend on the order in which you get `pfFlux` buffers at run-time and coordinates in the buffer can not assume results from the previous frame. If an element in the buffer is ever to be dynamic, it should always be recomputed.

IRIS Performer provides two ways of initializing or setting the data held in the `pfFlux` buffers:

- `pfFlux::initData()` to provide a template
- `pfFlux::callDataFunc()` to provide a callback function

You can immediately initialize all buffers `pfFlux` by calling the `initData()` method and providing a template data buffer that will be directly copied into the `pfFlux` buffers.

In the argument of `pfFlux::callDataFunc()`, you pass a pointer to data, and a pointer to a callback function that operates on the buffers in a `pfFlux`. This function will be immediately called on each buffer of the `pfFlux`.

An initialization callback can also be provided when the `pfFlux` is created

```
pfFlux *flux = new pfFlux(initFunc, PFFLUX_DEFAULT_NUM_BUFFERS);
```

and the function will be called for each flux buffer. If the pfFlux is not created with enough buffers and a new pfFluxMemory buffer must be created at runtime, the callback function will be called. For better and reliable performance, you generally want to ensure that you have given yourself enough buffers up front.

pfFlux Buffers

A pfFlux buffer is of type pfFluxMemory. Each buffer consists of a:

- Header
- Data portion

The header portion consists of:

- Pointer to the data portion of the pfFluxMemory.
- Frame number set automatically or explicitly by **pfFlux::setFrame()**.
- Set of flags, including read and write.

The data portion of a pfFluxMemory contains one frame of information. The **getFluxMemory()** method returns a pointer to the data portion of a pfFluxMemory

To return the parent pfFlux containing the buffer, use **pfFlux::getFlux()**, which returns NULL if the specified data is not part of a pfFlux. This is useful to find out, for example, if an attribute buffer of a pfGeoSet is a pfFlux.

At a given moment, a pfFlux buffer is either readable or writable, but never both. When a buffer is writable, its data can be changed. When a buffer is readable, its data should not be changed because there might be other processes reading that same buffer that would then be immediately affected by any changes. For performance reasons, a buffer marked readable is not locked.

Reading pfFlux Buffers

To get the current results for reading from a pfFlux, you can use the **getCurData()** method with code similar to the following C example:

```
pfVec3 *cur_verts;  
  
cur_verts = (pfVec3*)pfGetFluxCurData(flux);
```

In this example, **getCurData()**:

- Finds a readable buffer in the **pfFlux**, *flux*, whose frame number is the closest to the current flux frame number, but not greater than the current flux frame number.
- Returns a pointer, *cur_verts*, to that buffer.

If you have an old copy of a data buffer from a previous call to **getCurData()** and now just want to update to a new version and no longer have a pointer to the parent flux, you can use **pfFlux::getWritableData()** and provide your data pointer. For performance reasons, it is better to save your **pfFlux** pointer and not depend on this convenience.

When **getCurData()** is called, it is expected to hold previous results of computation. This computation might be done explicitly by your code in another process, or might be done automatically if the **pfFlux** is the destination of a **pfEngine**. Additionally, the **pfEngine** computation might be triggered immediately if the **pfFlux** is a **pfEngine** destination and if the **pfFlux** mode **PFFLUX_ON_DEMAND** mode is set by the **setMode()** method and if the client **pfEngine** sources are dirty. **pfEngine** details are discussed more later in this chapter.

Writing to **pfFlux** Buffers

When you want to write data to a **pfFlux** buffer, you use the **getWritableData()** method with code similar to the following C++ example:

```
pfVec3 *verts;
int i, num_verts;

verts = (pfVec3*)flux->getWritableData();

/* Set all verts to 1.0, 2.0, 3.0 */
num_verts = flux->getDataSize() / sizeof(pfVec3);
for (i = 0; i < num_verts; i++)
    verts[i].set(1.0f, 2.0f, 3.0f);

flux->writeComplete();
```

When **pfGetFluxWritableData()** is called, pfFlux searches for the buffer whose frame number is equal to the pfFlux frame number. There are three possible results:

- If there is a match and the buffer is writable, **getWritableData()** returns a pointer to that buffer.
- If there is a match but the buffer is readable, **getWritableData()** causes one of the following actions to occur, according to whether the PFLUX_WRITE_ONCE mode specified in **pfFluxMode()** is set to:
 - PF_ON, **pfGetFluxWritableData()** returns NULL if there is already a readable buffer with a frame number that matches the current flux frame number.
 - PF_OFF, **pfGetFluxWritableData()** returns a pointer to the readable data buffer.
- If there is no match, an unused buffer is made writable and its frame buffer number is set to that of the current pfFlux frame number.

If **pfGetFluxWritableData()** is called again for the same frame and the PFLUX_WRITE_ONCE mode is PF_ON (off by default), information is not copied again into the same buffer; instead, NULL is returned. In this way, the mode can prevent modified data from being clobbered by a second call to **pfGetFluxWritableData()** and the NULL return value can be used to avoid needlessly recomputing unused data.

pfFluxWriteComplete() should be called when computation for a writable pfFlux buffer is complete. This method changes the specified buffer from writable to readable.

Coordinating pfFlux and Connected pfEngines

pfFluxes maintain pointers to:

- pfEngines, called source engines, whose destinations are this pfFlux.
- A list of pfEngines, called client engines, that use this pfFlux as a source.

To return a handle to these engines, use **pfGetFluxSrcEngine()** and **pfGetFluxClientEngine()**, respectively.

To return the number of connected source and client pfEngines, use **pfGetFluxNumSrcEngines()** and **pfGetFluxNumClientEngines()**, respectively.

pfFluxWriteComplete() method triggers client pfEngine evaluation according to whether the PFFLUX_PUSH mode specified in **pfFluxMode()** is set to:

- PF_ON, **pfEngineEvaluate()** is performed on its client pfEngines to push the results through a chain of computation.
- PF_OFF, **pfEngineSrcChanged()** is performed on its clients to tell those pfEngines that they have dirty sources.

Triggering pfFlux Evaluation

pfFlux evaluation is really a convenient one-step combined evaluation of a source pfEngine combined with getting and completing a writable buffer of data. Triggering the evaluation of pfFlux may trigger the evaluation of the pfFlux's source pfEngines, particularly if the PFFLUX_ON_DEMAND mode is set to PF_ON.

To explicitly trigger a pfFlux, the **evaluate** method can be used with a mask that is provided and passed through evaluation chains to potentially limit which pfFluxes in a chain are evaluated. For a pfFlux to be evaluated, both of the following conditions must be satisfied:

- The bits in the current mask must match any of the bits in the evaluation mask associated with a pfFlux.
- **pfFluxEvaluate()** or **pfFluxEvaluateEye()** is called.

The mask is a bitmask that you use to trigger the evaluation of the source pfEngines of a pfFlux. **pfFluxMask()** and **pfGetFluxMask()** set and get, respectively, the evaluation mask of a pfFlux. The default mask is PFFLUX_BASIC_MASK. Masks enable selective evaluation of pfFlux source pfEngines.

pfFluxEvaluate() triggers an evaluation of pfFlux source pfEngines if any of the bits in the current mask match any of the bits in the evaluation mask of the pfFlux.

pfFluxEvaluateEye() is the same **pfFluxEvaluate()** but also makes it easy to pass the current eye point through a chain of computation. This is a particularly common case in scene graphs and one very common use is morphing level of detail based on distance from the current eyepoint.

Calling **pfFluxEvaluate()** or **pfFluxEvaluateEye()** is the equivalent of calling **pfEngineEvaluate()** on the source engines followed by calling **pfFluxWriteComplete()** on the pfFlux.

For more information about pfEngine, see “pfEngine” on page 446.

Synchronized Flux Evaluation

There are times when you want to ensure that the dynamic data for a given frame in a number of pfFluxes becomes readable at precisely the same time. Particularly when computations are so complicated that they must be completed over multiple frames, you might want the computations of vertices for the different pfGeoSets for a given frame to be made usable at the same time. Consider the following example:

You are using pfASD and you need shapes comprised of multiple pfGeoSets to move together in response to morphing terrain.

One pfGeoSet might encapsulate the texture of a roof, another a wall, another a window, and another a door. Since a pfGeoSet can only encompass one texture, each of these parts of a house must remain separate pfGeoSets whose data must be encapsulated in separate pfFluxes. If, for rendering, the roof of one frame was used with the wall of another, it might appear that the house is breaking apart.

IRIS Performer uses sync flux groups to ensure that the same frame of data is being used from all fluxes in a group.

Synchronizing pfFluxes with Flux Sync Groups

You can make one or more pfFluxes belong to a flux sync group using the pfFlux **setSyncGroup()** method and providing the integer identifier of the desired group. To get the flux sync group identifier of a pfFlux, use the **getSyncGroup()** method.

Note: IRIS Performer doesn't maintain a list of pfFluxes in a flux group, instead an internal field in pfFlux identifies the flux sync group it belongs to. For this reason, there is now way to get a list from IRIS Performer of all of the fluxes in a sync group.

For convenience, a flux sync group can be identified by a string name, set with **pfFlux::getSyncGroupName()**. The unsigned integer identifier can be gotten from the string name using **pfFlux::getNamedSyncGroup()**. **pfFlux::getNamedSyncGroup** will also automatically generate a new sync group identifier for a new name. The identifier of the first flux sync group you create is automatically one.

Note: Once you name a sync group, the name cannot be changed.

pfFlux::getNumNamedSyncGroups() returns the number of named sync groups.

Enabling a Flux Sync Group

To enable group synchronization of the `pfFlux`s in the flux sync group, enable the sync group using `pfFlux::enableSyncGroup()`. You can disable group synchronization using `pfFlux::disableSyncGroup()`.

`pfFlux::getEnableSyncGroup()` returns whether or not a sync group is enabled.

Initially, all `pfFlux`s are all part of flux sync group zero, which can never be enabled.

Evaluating a Synchronized Flux Group

After all of the `pfFlux`s in an enabled flux sync group are calculated, you must call `pfFlux::syncGroupReady()` to specify that the fluxes are ready to be read.

When `pfFrame` is called, `pfFlux::syncComplete()` is called on flux sync groups, which

- Marks the writable buffers with the current flux frame number.
- Makes their writable buffers readable.

Fluxed Geosets

Most often you use dynamic data to change the attributes, location, or the orientation of geometries. Morphing geometries, for example, is a matter of repositioning the vertices of a geometry.

You can, however, use dynamic data to change the higher level description of geometries. You might, for example, create a geometry editor that adds or subtracts triangles to and from geometries.

Note: While IRIS Performer is set up to flux any object derived from `pfMemory`, only `pfGeode` and `pfGeoSet` are currently modified to accept fluxed and unfluxed forms without any special `pfFlux` method.

To dynamically change a `pfGeoSet`, you must operate on the data held in the `pfFlux` buffers, usually when the buffers are initialized.

Example of a Fluxed pfGeoSet

Example 14-1 shows how to turn the data portion of a pfFluxMemory into a fluxed pfGeoSet using pfFluxedGSetInit().

Example 14-1 Fluxed pfGeoSet

```
int make_fluxed_gset(pfFluxMemory *fmem)
{
    pfGeoSet *gset;
    pfVec3 *coords;

    if (fmem == NULL)
        return pfFluxedGSetInit(fmem);

    pfFluxedGSetInit(fmem);

    gset = (pfGeoSet*)fmem->getData();

    gset->setPrimType(PFGS_TRIS);

    ... // finish initializing pfGeoSet

    return 0;
}

main()
{
    pfFlux *fluxed_gset;
    pfGeoSet *gset;

    pfInit();
    pfMultiprocess(PFMP_DEFAULT);
    pfConfig();

    fluxed_gset = new pfFlux(make_fluxed_gset,
        PFFLUX_DEFAULT_NUM_BUFFERS);
    gset = (pfGeoSet*)fluxed_gset->getCurData();

    ...
}
```

Fluxed Coordinate Systems

A pfFCS is similar to a pfDCS node in that both nodes contain dynamic data. In addition to pfDCS functionality, however, a pfFCS uses a pfFlux to hold its matrix. This fluxed matrix can then be computed by a pfEngine and potentially asynchronously. This is the structure shown in Figure 14-1.

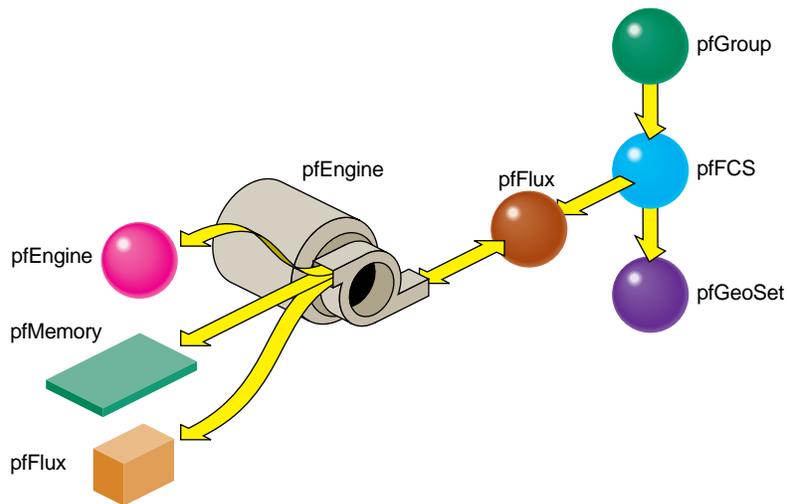


Figure 14-1 pfEngine Drives a pfFlux Node Animated a pfFCS Node

In this figure, the pfEngine performs calculations on the data input from multiple sources, including a pfMemory, a container for static data, a pfFlux, and an additional source pfEngine. The main pfEngine sends its resulting matrix to a pfFlux. The pfFlux is attached to the pfFCS with the pfFCS `setFlux()` method. This flux then:

- Can trigger the pfEngine to directly recompute its data if in `PFFLUX_ON_DEMAND` mode when the pfFCS calls `getCurData()` on the flux
- Will use frame accurate results with other fluxes if a member of a flux sync group
- Contains the matrix for the pfFCS node to produce a transformed coordinate system for the current frame for children of the node in the scene graph.

Since a pfFCS node is of type pfGroup, you can connect many nodes to it. This functionality is valuable if many geometries need to share the a transformation, such as the moving limbs of a walking character whose overall location is changing every frame.

For an example of a pfEngine, pfFlux, pfFCS example, see *fcs_engine.C* in *sample/pguide/libpf/C++*.

Replacing pfCycleBuffer With pfFlux

Prior to version 2.2 of IRIS Performer, the customary way of manipulating dynamic data was to use a pfCycleBuffer. Morphing was accomplished using pfCycleBuffer and pfMorph. While pfCycleBuffer and pfMorph are still supported for compatibility, they are obsoleted by pfEngine and pfFlux.

Note: If your applications do not contain pfCycleBuffer or pfMorph, skip to the next section. This section explains how to replace pfCycleBuffer and pfMorph with pfFlux and pfEngine.

pfFlux Differences

pfFlux is similar to, but far more powerful than, pfCycleBuffer:

- Where pfCycleBuffer is unaware of the nodes driving it, pfFlux is aware of its parent nodes. When attached to a pfEngine, for example, a pfFlux can trigger a pfEngine to recompute it's output.
- pfFlux provides a mechanism for updating data in processes that are completely asynchronous to the main APP, CULL, DRAW pipeline stages.

Converting to pfFlux

To convert from pfCycleBuffer to pfFlux, use code similar to the following:

```
/* Replace pfCyclebuffer creation with pfFlux: */
pfFlux *flux = pfFlux(size, PFFLUX_DEFAULT_NUM_BUFFERS);

/* replace getting of read-only data
 * pfCBufGetCurData() for read becomes:
 */
curData = flux->getCurData();

/* replace getting of data to edit.*/

/* get writable buffer BEFORE editing data */
data = flux->getWritableData();

/* ... edit data */

/* declare data edited after editing for the frame is done.
 * Replace pfCBufferChanged(pfCycleBuffer *cbuf) becomes:
 */
flux->WriteComplete();
```

pfEngine

A pfEngine performs calculations. The source can either be static data, such as a pfMemory, or dynamic data, such as a pfFlux. The destination of a pfEngine is fed into a pfFlux, as shown in Figure 14-1.

Creating and Deleting Engines

The constructor for pfEngine requires that you specify the computation type of pfEngine you are creating. IRIS Performer provides many types of engines, each performing a different calculation on the input data. Table 14-1 describes the engine types:

Table 14-1 pfEngine Types

Engine	Description
PFENG_SUM	Sums the input array of floats into a destination array of floats.
PFENG_MORPH	Morphs between the input data
PFENG_BLEND	Is a light-weight version of PFENG_MORPH.
PFENG_TRANSFORM	Translates a set of data with a matrix operation.
PFENG_ALIGN	Generates a translation matrix from the input data.
PFENG_MATRIX	Generates a matrix of type rotation, translation, scale, non-uniform scaling, or combine, using pre or post multiplication.
PFENG_ANIMATE	Same as PFENG_MATRIX except that the sources are arrays of animation frames.
PFENG_BBOX	Computes the bounding box of the input array of data.
PFENG_TIME	Takes a time, in seconds, and makes it into a frame number that is useful in driving the frame source of PFENG_MORPH, PFENG_BLEND, and PFENG_ANIMATE.
PFENG_STROBE	Switches iteration sets of floats, called <i>items</i> , between an on and off based on time.
PFENG_USER_FUNCTION	User-defined function.

pfEngine::getFunction() returns the pfEngine type. These engine types are described in further detail in “Setting Engine Types and Modes” on page 448.

To delete a pfEngine, as with all pfObjects, use **pfDelete()**.

Setting Engine Types and Modes

Table 14-1 lists the different types of IRIS Performer-supplied pfEngines. Many of the pfEngines have different modes of operation. For example, PFENG_ANIMATE offers the following modes:

- PFENG_ANIMATE_ROT
- PFENG_ANIMATE_TRANS
- PFENG_ANIMATE_SCALE_UNIFORM
- PFENG_ANIMATE_SCALE_XYZ
- PFENG_ANIMATE_BASE_MATRIX

All of these modes specify what the engine changes. PFENG_ANIMATE_ROT, for example, specifies that the engine rotates a geometry, PFENG_ANIMATE_TRANS translates a geometry, and PFENG_ANIMATE_SCALE_UNIFORM scales a geometry.

pfEngine::setMode() sets the mode value; **pfEngine::getMode()** returns the mode value.

The following sections describe the engine types and their mode values, if any.

PFENG_SUM Engines

PFENG_SUM adds arrays of floats to form a destination array of floats. One use for PFENG_SUM is aligning geometries to height, such as buildings, to a pfASD terrain.

Since PFENG_SUM can have as few as one source it can be used to simply copy data from one location to another.

PFENG_MORPH Engines

Morphing is the smooth transition from one appearance to another. The effect is achieved through the reorientation of the vertices in pfGeoSets. Morphing can refer to geometries and their attributes. For example, you could “morph” the following:

- Color to simulate a flickering fire.
- Texture coordinates to simulate rippling ocean waves.
- Coordinates to make a 3D model of a face smile or frown.

PFENG_MORPH sets the destination of the pfEngine to a weighted sum of its sources. To specify the weighting, you use either:

- PFENG_MORPH_WEIGHTS
- PFENG_MORPH_FRAME

PFENG_MORPH_WEIGHTS contains an array of floats, or weighting values. PFENG_MORPH_SRC(n) is also an array; there is one element for each pfEngine source. To create the morph weighting, element 0 of PFENG_MORPH_WEIGHTS is multiplied by PFENG_MORPH_SRC(0); element 1 is multiplied by PFENG_MORPH_SRC(1), and so on.

PFENG_MORPH_FRAME contains a single float. This float specifies the weighting between two pfEngine sources, PFENG_MORPH_SRC(n). The integer portion of the float specifies the first of the two consecutive sources, and the decimal portion of the float specifies the weighting between those sources. For example, a PFENG_MORPH_FRAME of 3.8 would mean $\text{PFENG_MORPH_SRC}(3) * 0.2 + \text{PFENG_MORPH_SRC}(4) * 0.8$.

For an example of a morph engine, see *morph_engine.C* in *sample/pguide/libpf/C++*.

PFENG_BLEND Engines

PFENG_BLEND is a light-weight version of PFENG_MORPH. PFENG_BLEND sets the pfEngine destination to a weighted sum of elements of the pfEngine sources.

To specify the weighting, you use either:

- PFENG_BLEND_WEIGHTS
- PFENG_BLEND_FRAME

These weighting mechanisms work identically to those in “PFENG_MORPH Engines,” with the following exception: the source, PFENG_BLEND_SRC(n), should contain iteration elements. Each element is a set of floats, called *items*. The number of elements in each set is called a *stride*. So, the iteration items for pfEngine source 0 begin at *items* number $0 * \textit{stride}$; for source 1, at *items* number $1 * \textit{stride}$, and so on.

PFENG_BLEND_WEIGHTS contains an array of floats, one for each of the pfEngine sources, PFENG_BLEND_SRC(n).

PFENG_BLEND_WEIGHTS(0) is multiplied by the items starting at PFENG_BLEND_SRC(0*stride); PFENG_BLEND_WEIGHTS(1) is multiplied by the items starting at PFENG_BLEND_SRC(1*stride) and so on.

PFENG_BLEND_FRAME contains a single float. This float specifies the weighting between two consecutive PFENG_BLEND_SRC(n) sources. The integer portion of the float specifies the first of the two consecutive sources, and the decimal portion of the float specifies the weighting between those sources. For example, a PFENG_BLEND_FRAME of 3.8 would mean $PFENG_BLEND_SRC(3) * 0.2 + PFENG_BLEND_SRC(4) * 0.8$.

For an example of a blend engine, see *blend_engine.C* in *sample/pguide/libpf/C++*.

PFENG_TRANSFORM Engines

PFENG_TRANSFORM transforms the PFENG_TRANSFORM_SRC(n) array of floats by the matrix contained in PFENG_TRANSFORM_MATRIX.

PFENG_ALIGN Engines

PFENG_ALIGN generates an alignment matrix based on the sources. One use for PFENG_ALIGN is to align moving objects, such as vehicles, to a pfASD.

PFENG_ALIGN_POSITION determines the translational portion of the matrix. If PFENG_ALIGN_POSITION is NULL, the translational portion of the matrix is set to all zeros.

PFENG_ALIGN_NORMAL and PFENG_ALIGN_AZIMUTH determine the rotation portion of the matrix. If either are NULL, the rotation portion of the matrix is set to all zeros.

PFENG_MATRIX Engines

PFENG_MATRIX generates a matrix based on its sources. Applied to vertex coordinates of pfGeoSets, these routines provide the same mathematical effect as using pfDCSs in a scene graph. However, these pfEngines will use the host to compute the vertices and thus eliminate the need for matrices to be evaluated in the graphics pipeline. This trade-off might produce a faster rendering frame rate if there are sufficient host CPU resources for the computation involved.

The following tokens specify the kind of action performed by the PFENG_MATRIX engine:

PFENG_MATRIX_ROT rotates a geometry according to heading, pitch, and roll values; the equivalent is **pfDCS::setRot()**.

PFENG_MATRIX_TRANS transforms a geometry; the equivalent is **pfDCS::setTrans()**.

PFENG_MATRIX_SCALE_UNIFORM uniformly scales a geometry; the equivalent is **pfDCS::setScale()**.

PFENG_MATRIX_SCALE_XYZ non-uniformly scales a geometry; the equivalent is **pfDCS::setScale(x, y, z)**.

PFENG_MATRIX_BASE_MATRIX contains a pfMatrix that is either pre or post multiplied against the matrix generated by the other sources, depending on the PFENG_MATRIX_MODE mode set by the **setMode()** method; PF_OFF specifies pre-multiplication, PF_ON specifies post-multiplication.

Any or all of the sources can be NULL, in which case they have no effect on the resulting matrix.

PFENG_ANIMATE Engines

PFENG_ANIMATE animates a matrix based on its sources. This engine type is similar to PFENG_MATRIX, but instead of using single values for rotation, translation, and scaling, PFENG_ANIMATE uses arrays of values.

To specify the weighting, you use either:

- PFENG_ANIMATE_WEIGHTS
- PFENG_ANIMATE_FRAME

PFENG_ANIMATE_WEIGHTS contains a float for each of the values in the rotation, translation, and scale sources. PFENG_ANIMATE_SRC(n) is also an array; there is one element for each pfEngine source.

To create an animation, element zero of PFENG_ANIMATE_WEIGHTS is multiplied by PFENG_ANIMATE_SRC(0); element one is multiplied by PFENG_ANIMATE_SRC(1), and so on.

PFENG_ANIMATE_FRAME contains a single float. This float specifies the weighting between two of the values in the rotation, translation, and scale sources. The integer portion of the float specifies the first of the two consecutive values, and the fractional portion of the float specifies the weighting between those values. For example, a PFENG_ANIMATE_FRAME of 3.8 would mean $PFENG_ANIMATE_SRC(3) * 0.2 + PFENG_ANIMATE_SRC(4) * 0.8$.

The following tokens specify the kind of action performed by the PFENG_ANIMATE engine.

PFENG_ANIMATE_ROT rotates a geometry according to heading, pitch, and roll values; the equivalent is **pfDCS::setRot()**.

PFENG_ANIMATE_TRANS transforms a geometry; the equivalent is **pfDCS::setTrans()**.

PFENG_ANIMATE_SCALE_UNIFORM uniformly scales a geometry; the equivalent is **pfDCS::setScale()**.

PFENG_ANIMATE_SCALE_XYZ non-uniformly scales a geometry; the equivalent is **pfDCS::setScale(x, y, z)**.

PFENG_ANIMATE_BASE_MATRIX contains a pfMatrix that is either pre- or post-multiplied against the matrix generated by the other sources depending on the PFENG_MATRIX_MODE mode set by the pfEngine method, **setMode()**.

Any or all of the sources can be NULL, in which case they have no effect on the resulting matrix.

For an example of an animate engine, see *fcs_animate.C* in *sample/pguide/libpf/C++*.

For more information about animation, see “Animating a Geometry” on page 456.

PFENG_BBOX Engines

PFENG_BBOX generates a bounding box that contains the coordinates of the pfEngine source, PFENG_BBOX_SRC.

PFENG_TIME Engines

PFENG_TIME takes a time in seconds and converts it to a frame number, which can drive the sources of the following engine types: PFENG_MORPH, PFENG_BLEND, and PFENG_ANIMATE.

PFENG_TIME_TIME is the source time in seconds. This is usually connected to the pfFlux returned from **pfFlux::getFrame()**.

PFENG_TIME_SCALE contains four floats that are used to modify the incoming time:

- PFENG_TIME_SCALE[0] is an initial offset.
- PFENG_TIME_SCALE[1] is a scale factor.
- PFENG_TIME_SCALE[2] is a range.
- PFENG_TIME_SCALE[3] is a final offset.

The PFENG_TIME_MODE mode, set with **pfEngineMode()**, determines how the destination number moves between its start and end point. The two mode values include:

- PFENG_TIME_CYCLE makes the destination number go from start to end then restarts again at the beginning.
- PFENG_TIME_SWING makes the destination number go back and forth between the start and end.

Note: This mode is related to the interval mode of a pfSequence.

If the PFENG_TIME_TRUNC mode is set to PF_ON, the result is truncated.

PFENG_STROBE Engines

PFENG_STROBE switches iteration sets of floats, called *items*, between ON and OFF based on time. One use of PFENG_STROBE is light point animations.

PFENG_STROBE_TIME is the source time in seconds. This data is usually connected to the pfFlux returned from **pfFlux::getFrame()**.

PFENG_STROBE_TIMING contains iterations sets of three floats:

- PFENG_STROBE_TIMING[n*stride + 0] is the ON duration.
- PFENG_STROBE_TIMING[n*stride + 1] is the OFF duration.
- PFENG_STROBE_TIMING[n*stride + 2] is an offset.

PFENG_STROBE_ON contains iteration sets of floats, called *items*.

PFENG_STROBE_OFF contains iteration sets of floats, called *items*. If PFENG_STROBE_OFF is NULL, all off states are 0.0.

For an example of animation using a strobe engine, see *strobe_engine.C* in *sample/pguide/libpf/C++*.

PFENG_USER_FUNCTION Engines

When a pfEngine is of type PFENG_USER_FUNCTION, you specify the function of the pfEngine using **pfEngine::setUserFunction()**. **pfEngine::getUserFunction()** returns the pfEngine type.

For an example of animation using a user-defined engine, see *user_engine.C* in *sample/pguide/libpf/C++*.

Setting Engine Sources and Destinations

pfEngine sources can be any number of objects, including pfFluxs, pfMemory's, and pfEngines. The sources provide the input data for the pfEngine. pfEngine destinations are pfFluxs, which contain the pfEngine output.

pfEngine::setSrc() and **pfEngine::setDst()** set the pfEngine sources and destination, respectively. **pfEngine::getSrc()** and **pfEngine::getDst()** return the pfEngine sources and destination, respectively. **pfEngine::getNumSrcs()** returns the number of sources. A pfEngine can only have one destination.

Setting Engine Masks

pfEngine masks are bit masks that provide a means of selectively triggering pfEngines. Only those pfEngines that have masks that match the evaluation mask can be triggered, as shown in the evaluation method:

```
pfEngine::evaluate(int mask)
```

pfEngine::setMask() and **pfEngine::getMask()** set and return pfEngine masks, respectively.

Setting Engine Iterations

You can make pfEngines repeat their calculations, called *iterations*, when operating on an array of data instead of on a single piece of data. You also specify the unit of data, called an *item*, for example, a vector would have three *items* per unit. For example, if you want to add two arrays of 100 pfVec3s each, you set *iteration* to 100 and *item* to 3.

pfEngine::setIterations() and **pfEngine::getIterations()** set and get iterations, respectively.

Setting Engine Ranges

There are times when you might like to reduce computation needs by not evaluating engines, for example, when the eye point is far from the geometry being animated by a pfEngine.

You establish the location of an animated geometry, and an area located around the geometry using **pfEngine::setEvaluationRange()**. Only when the eye position is within that area can the pfEngine be evaluated.

The range functionality is only enabled when the PFENG_RANGE mode, created by **pfEngine::setMode()**, is set to PF_ON; the default is PF_OFF.

Evaluating pfEngines

To evaluate a pfEngine, you use one of the forms of **pfEngine::evaluate()** or **pfFlux::evaluate()**.

For more information about **pfFlux::evaluate()**, see “Triggering pfFlux Evaluation” on page 440.

The two forms of **evaluate()** are:

```
void pfEngine::evaluate(int mask);  
void pfEngine::evaluate(int mask, pfVec3 eye_pos);
```

For more information about *mask*, see “Setting Engine Masks” on page 455.

The second form of the method specifies the location of the viewer. The engine is only evaluated if the location of the viewer, *eye_pos*, is within the range of the pfEngine, set by **pfEngine::setEvaluationRange()**. For more information about the range of a pfEngine, see “Setting Engine Ranges” on page 455.

Note: The eye position has no effect on evaluation of the pfEngine if the PFENG_RANGE_CHECK mode is PF_OFF, the default.

Animating a Geometry

To animate a geometry using a combination of pfFlux, pfFCS, and pfEngines nodes, use the following guidelines:

1. Initialize and populate the pfFluxes.
2. Connect pfMemory or pfFluxes as the sources of a pfEngine.
3. Connect a pfFlux to the output destination of the pfEngine.
4. Connect the pfFlux containing the output of the pfEngine to the scene graph in one of three ways:
 - connect it as an attribute of a pfGeoSet using **setAttr()**
 - connect it as the bounding box of a pfGeoSet using **setBound()** where the mode argument is set to PFBOUND_FLUX
 - connect it directly to a pfFCS using **setFlux()**
5. Set up any needed flux sync groups for synchronizing transformations.

This scenario is the simplest set up; it is represented graphically in Figure 14-1. More complicated scenarios include chaining pfEngines together or running multiple geometries off of one pfFCS node.

The following code sample provides an implementation of the animation procedure:

Example 14-2 Connecting Engines and Fluxes

```
// create the nodes
pfFlux *myData1 = new pfFlux(100 * sizeof(pfVec3));
pfFlux *myData2 = new pfFlux(100 * sizeof(pfVec3));
pfEngine *myEngine = new pfEngine(PFENG_SUM);
pfFlux *engineOutput = new pfFlux(100 * sizeof(pfVec3));
pfFCS myFCS = new pfFCS();
pfGeode myGeode = new pfGeode();

// initialize and populate the flux nodes
myData1->init();
myData2->init();

// attach the pfFlux nodes as the source of the pfEngine
myEngine->setSrc(0, myData1, 0, 3);
myEngine->setSrc(1, myData2, 0, 3);

// attach a pfFlux to the output of the pfEngine
myEngine->setDst(engineOutput, 0, 3);
myEngine->iterations(100, 3);

// connect the pfFlux output node to the scenegraph
myFCS->setFlux(engineOutput);
// attach child geometry to be tranformed by the FCS
myFCS->addChild(myGeode);

...
// compute the data in the source pfFluxes to the engine
float *current = (float *)myData1->getWritableData();
... // compute data
myData1->writeComplete();
```


“Active Surface Definition”

This chapter describes the Active Surface Definition (ASD): a library that handles real-time surface meshing and morphing.

Active Surface Definition

Active Surface Definition (ASD) is a powerful real-time surface meshing and morphing library. It enables you to roam surfaces that are too large to hold in system memory very quickly. The surfaces, called meshes, are represented by triangles from more than one LODs.

ASD is a library that handles real-time surface meshing and morphing in a multiprocessing and multichannel environment. pfASD is an IRIS Performer scene graph node that allows you to place ASD information in a scene graph.

This chapter describes how to create and use ASD.

Overview

In the past, IRIS Performer applications have dealt with large surfaces in two ways:

- Level of detail (LOD), where the whole surface is one LOD.
- Patches, where the surface is broken into geometrical subunits, each of which can be at a different LOD level.

Each of these approaches has its disadvantages:

- When the entire surface is one LOD, with large surfaces, memory limitations often require such a high LOD that the resolution is poor.
- Patches can only morph between adjacent LODs, which is insufficient in large surfaces. The result is visible borders between LODs.

Active Surface Definition (ASD) is designed to solve these problems. ASD is a powerful real-time surface meshing and morphing library characterized by the following features:

1. Transitions between different levels of detail (LOD) appear smooth and void of spatial or temporal artifacts. Vertex position, normal, color, and texture coordinates can be morphed.
2. LODs can be generated using simple adaptations of well-known, non-uniform-tessellation surface subdivision algorithms.
3. ASD is real-time; in multiprocessor mode, it can sustain 60HZ operation while displaying complex surfaces.
4. Nearly-coplanar objects, such as road surfaces, are accurately represented in the non-uniform tessellation of each LOD using local textures.
5. Objects, such as buildings, may be modeled and rendered using alternate algorithms, yet remain attached to the surface.
6. Triangles substantially outside the viewing frustum are culled from rendering.
7. The evaluation function that specifies the morphing factor for each geometry is specified at run-time, which allows traversal to be optimized for different applications and data sets.
8. Huge surfaces, such as one-meter data of the entire United State, are supported using run-time paging from disk memory.

The pfASD approach uses a modeling surface that is a single, connected surface rather than a collection of patches.

An ASD surface contains several hierarchical level of detail (LOD) meshes where one level encapsulates a coarser LOD than the next. When rendering an ASD surface, an evaluation function selects polygons from the appropriate LODs and constructs a valid meshing to best approximate the real surface on the screen.

Unlike existing LOD schemes, pfASD selects triangles from many different LODs and combines them into a final surface. This feature lets a fly-through over a surface use polygons from higher LODs for drawing nearby portions of the surface in combination with polygons from low LODs that represent distant portions of the surface.

To review an ASD application, see *perf/test/simpleASD/simpleASD.C*.

Using ASD

Modern computer graphics systems render objects represented by faceted surfaces comprised of triangles. While rendering performance is increasing steadily, it remains necessary to limit the number of triangles that are rendered if a real-time rendering rate of 60 frames per second or greater is to be maintained.

Triangles may be omitted with no loss of image quality if they represent objects that are not in the field of view (view frustum culling) or if they represent objects whose visibility is occluded by other, nearer objects.

The number of rendered triangles can also be dramatically reduced with little or no loss of image quality if multiple representations of each object are maintained, and the representation used has as little detail as is necessary for displaying a good-quality image. This technique and a body of others related to it are collectively referred to as level of detail (LOD) reduction, and the multiple object representations are known as LODs.

LOD Reduction

LOD reduction is not a new idea, having been practiced in the field of real-time image generation for at least two decades. Early implementations eliminated the sudden, visible transition from one level of detail to another by alpha blending two models over a period of several frame times. More recently the fade transition has been replaced by a geometric morph solution, which eliminates the need to temporarily render additional triangles, and interacts more nicely with depth buffer hidden surface elimination.

When the object being rendered is very large, there is no single level of detail that is optimal for the entire object. Instead, it is desirable to render the object with a smooth variation of level of detail, allowing nearer portions to be represented accurately, and farther portions to be represented efficiently.

The need for spatially varying level of detail is particularly acute when rendering terrain, which may range from several feet to hundreds of miles from the viewpoint. Early attempts to support multiple LOD terrain modeled the surface as separate tiles, each of which was rendered at a single level of detail. This approach results in physical discontinuities between neighboring tiles rendered with different levels of detail, which are visible as obvious "walls."

Triangulated Irregular Networks

Triangulated irregular networks (TINs) can approximate a surface with fewer polygons than other uniformly-grided representations. However, TIN models are hard to create dynamically at interactive rates. Regular data, on the other hand, allows easier construction of LODs at interactive rates. We propose a new terrain framework, Active Surface Definition (ASD), that combines the advantages of both regular and irregular networks. The terrain database is pre-computed and stored in a hierarchical structure of efficient, irregular triangulations. LOD reduction is performed on the data structure at real-time frame rates, varying levels of detail both spatially and temporally.

Hierarchical Structure

Active Surface Definition defines a hierarchical structure that organizes all the LODs of a terrain. At run-time ASD traverses the structure, selecting triangles from different LODs to render the portion of the terrain that is within the culling frustum. Triangles are rendered either at pre-stored locations, when they are in a particular fully-morphed portion of a LOD range, or at computed morphed locations, when they are in the morphing transition portions of the LOD range, as shown in Figure 15-1.

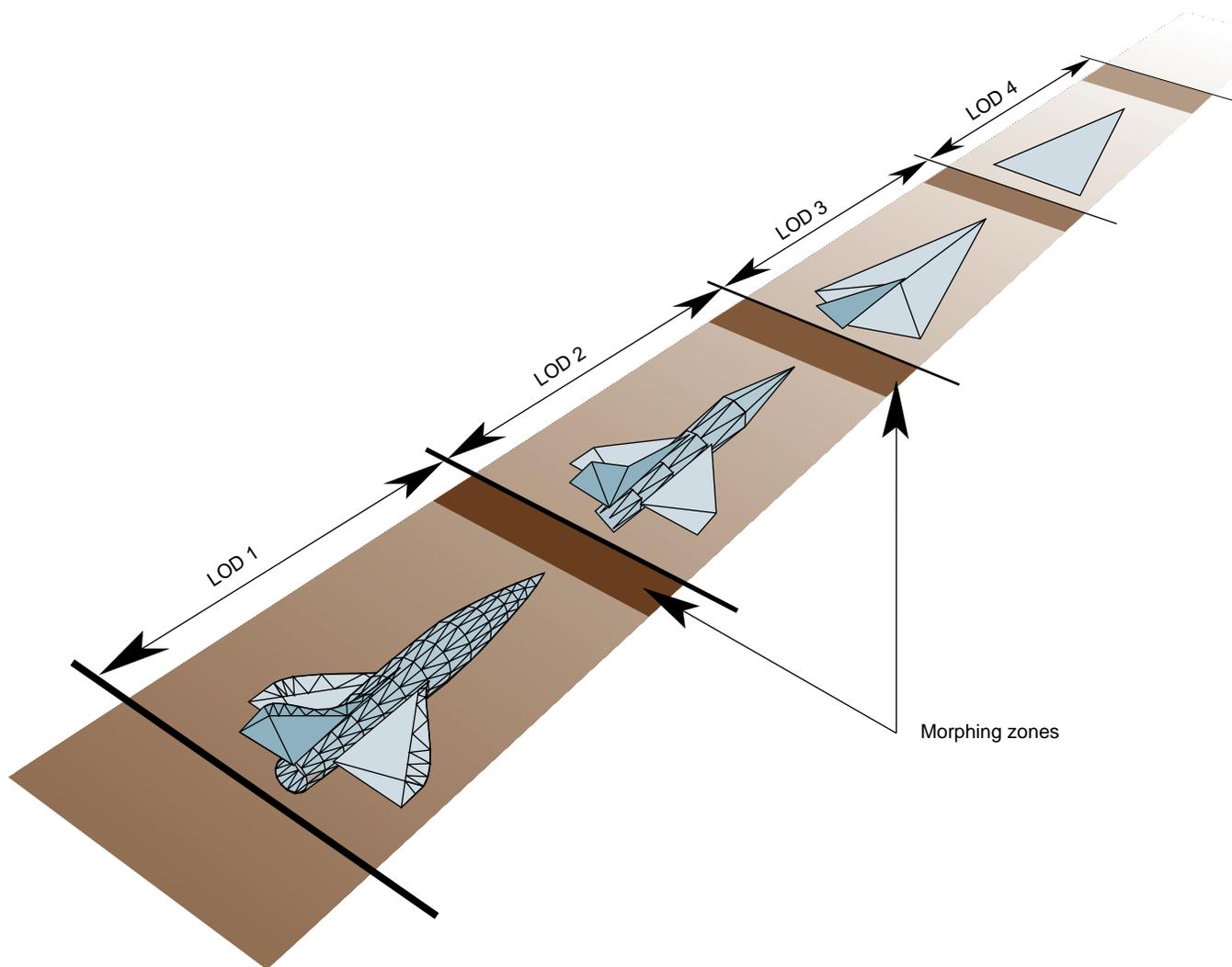


Figure 15-1 Morphing Range Between LODs

Figure 15-1 shows the complete object represented by an LOD. ASD is often used for very large terrains, like a map of the United States, so the entire terrain cannot fit into a single LOD range. In that case, parts of the large terrain would be represented by different LODs, as shown in Figure 15-2.

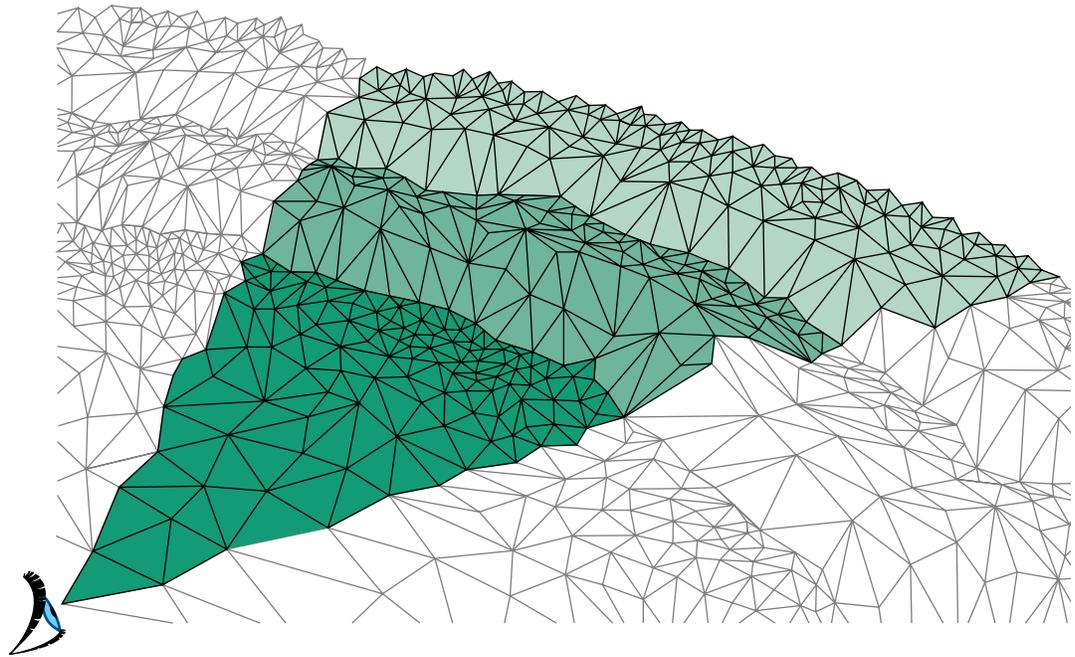


Figure 15-2 Large Geometry

In Figure 15-2, different parts of the terrain are displayed at different levels of resolution.

ASD Solution Flow Chart

To visualize large terrains using ASD, you use the following steps, which are portrayed in Figure 15-3:

1. Collect raw, elevation data.
2. Use a modeler to create ASD structures from the raw elevation data. There are various triangle tessellation algorithms that can be used to model the terrain into TINs. Adaptive tessellation and accurate representation and minimum visual distraction between LODs are potentially all supported by pfASD structures.
3. Place the ASD structures into a scene graph by attaching them to pfASD nodes.

4. Design an evaluation function that shows when a particular triangle on a particular LOD level in ASD structure should be selected.
5. IRIS Performer traverses and evaluates pfASD structures at run-time to create an active mesh that is used for rendering.

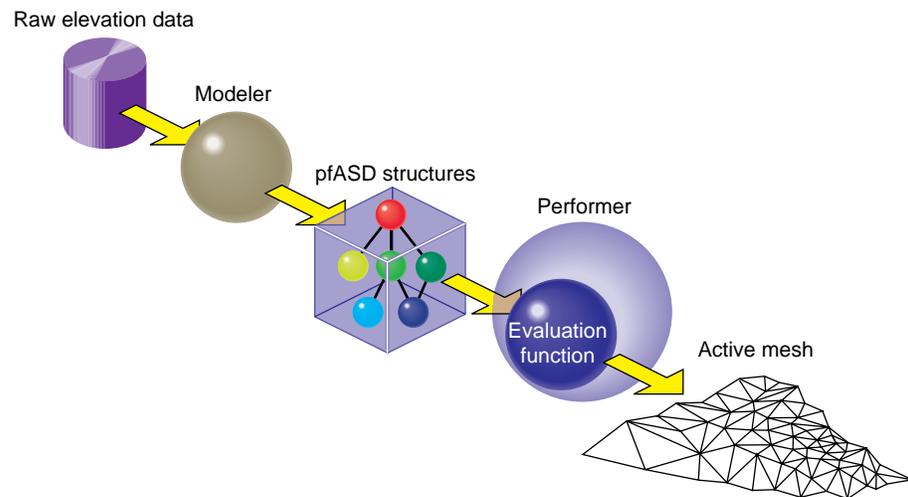


Figure 15-3 ASD Information Flow

A Very Simple ASD

To demonstrate the ASD concept, we shall now build a very simple ASD surface. The surface has two representations, which corresponds to two levels of detail (LOD). The coarser level, LOD 0, has only a single triangle: T0. The finer level, LOD 1, has four triangles: T1, T2, T3, T4, as shown in Figure 15-4.

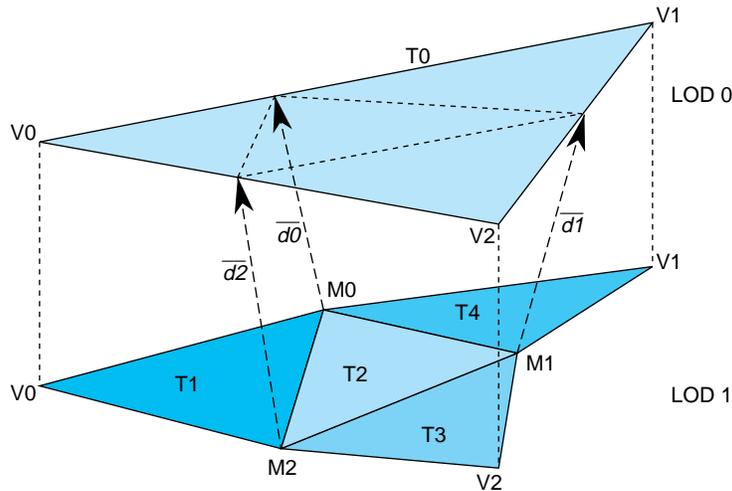


Figure 15-4 A Very Simple pfASD

pfASD requires that we specify a morphing relationship for the vertices in the two levels of detail. This relationship guides ASD to choose triangles from the appropriate LODs and place vertices in the correct positions.

Morphing Vector

Each triangle in LOD 0 can have up to four replacement triangles in a higher LOD. pfASD imposes the limitation that the replacement of T0 must include the vertices V0, V1, V2, and may include three more vertices. In our case, the replacement of T0 includes the vertices V0, V1, V2, M0, M1, M2. We express the morph behavior between two levels by describing the morph behavior of the triangle vertices.

Since V0, V1, and V2 remain unchanged, we need only specify the morphing behavior, or the morphing vector, M0, M1, and M2. The morphing vector of a vertex is a vector connecting the vertex to an edge of the lower resolution triangle. We specify morphing vectors d_0 , d_1 , and d_2 for the vertices M0, M1, and M2, respectively. The triangles in LOD1 can now morph smoothly by morphing the vertex M0, M1, and M2 along their morphing vectors d_0 , d_1 , and d_2 .

We call the edge position (M1+d1) unmorphed, and the M1 position fully morphed. The unmorphed position is the *reference position* of a vertex because it is a reference to show how a vertex should be coplanar with the triangle in the lower LOD when we replace the lower LOD triangle with a higher LOD triangles, while providing the least amount of visual distraction. The fully-morphed position is the *final position* of a vertex; that position should be chosen from the original raw data by various triangulation algorithms. It is recommended that the reference position be defined after the final position is chosen to most accurately design the adaptive tessellation of a terrain. pfASD handles the morphing of other attributes, such as normals, colors, and texture coordinates as well.

This completes the construction of a very simple pfASD. When flying over this model—say from V0 towards M1—pfASD shall morph M0 and M2 first, and continue to morph M1 as we get closer to the edge [V1,V2]. In other words, pfASD will morph closer triangles into their higher LOD first.

A Very Complex ASD

To view a complex ASD, run *perfly* with the *yosemite* data supplied in the images. Observe that the entire, visible terrain is represented by more than one LOD.

ASD Elements

pfASDs create active meshes to accurately and efficiently render terrains. A mesh is a surface tessellated into triangles, as shown in Figure 15-2. Each frame contains an active mesh. ASD reduces visual discontinuities between meshes by morphing geometry.

pfASD is defined by the following elements:

- Vertices
- Triangles
- Evaluation function

Vertices

The triangles of all LODs share a single pool of vertices: those vertices that define the triangles of the highest LOD. A few vertices exist in all the LODs. These vertices define the triangles in LOD0, and are typically chosen as corners of the terrain or other significant features. Each of the remaining vertices exists in a contiguous set of LODs, including the highest LOD. In order to facilitate the gradual introduction of a vertex into the terrain, the actual position of each vertex is supplemented by a reference position. If i is the lowest LOD that includes a vertex, then that vertex is located at its actual position in LODs i through $(n-1)$, and is morphed between its reference position and its actual position during the morphing zone of LOD i that is adjacent to LOD $(i-1)$ range.

Note: ASD could be extended to support multiple reference positions per vertex, allowing vertices to morph between multiple LODs. This extension may be supplied in the near future depending on demands.

A vertex is represented by its final position ($pfVec3$) and a morphing vector ($pfVec3$), which represents the difference between the final position and the reference position. The current position of a vertex is computed as:

$$V_{vertex} = V_0 + mV_d$$

V_0 is the final position of a vertex, m is the current morphing weight, and V_d is the morphing vector. Notice that the reference position of a vertex is always chosen to lie on an edge of a triangle from the lower LOD, though not necessarily at the centers of these edges. This is to ensure that the replacement of the lower LOD by the higher LOD happens when they are at coplanar positions, which eliminates sudden popping artifacts.

Attributes are represented by final position as well, as shown in Figure 15-5.

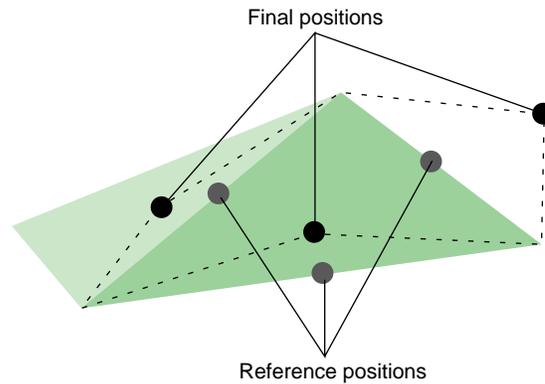


Figure 15-5 Reference Positions

Normals, colors, and texture coordinates can all be linearly interpolated, as specified.

A vertex always morphs along the morphing vector, v_d . When $m = 1$, the vertex is at a no-morph position, which means it most likely is not part of the active mesh, because it is on an edge of the parent triangle.

Triangles

A triangle exists in only one particular LOD. If the triangle is too coarse to accurately represent the current terrain, the triangle is removed from the active mesh. The position of a triangle is determined by the positions of its vertices, which may be morphed along the morphing vector.

In the pfASD structure, each triangle node, called an pfASDFace, can have up to four children. A sequence of frames may render the meshes shown in Figure 15-6.

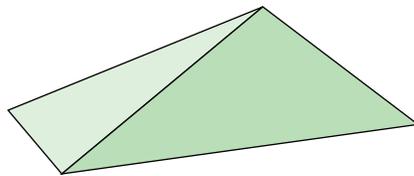


Figure 15-6 Triangulated Image

As the distance between a vertex, P, and a viewer changes through the morphing range, the side of the triangle associated with P is replaced by two edges from the next LOD. Figure 15-7 shows how the next LOD triangles replace the current LOD triangles.

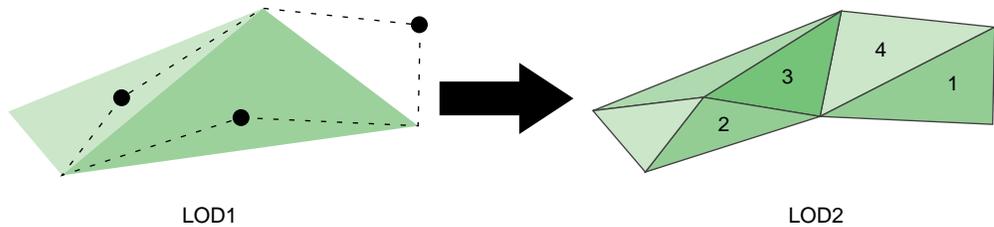


Figure 15-7 LOD1 Replaced by LOD2

Figure 15-7 shows the shapes of the triangles in two adjacent LODs.

Notice that only one side of the triangle on the left is changed; in this case, the original triangle is now replaced by two triangles. The triangle that was on the right is now completely gone; in its place are four triangles, as labeled. One triangle can be replaced by up to four child triangles, depending on whether one, two, or three sides of the triangles are replaced by two lines.

Sides shared by two triangles are evaluated only once. Morphing the shared side of one triangle necessarily morphs it to the same position in the neighboring triangle.

Evaluation Function

The evaluation function determines the morph weight of every vertex. This function returns a floating point value between 0.0 and 1.0 where 1.0 means the vertex is not morphed and therefore not active. Since it is not active, it is not in the current mesh; its geometry is represented by coarser LOD triangles. 0.0 means that the triangle is completely morphed. In this case, the vertices are in their final positions in the active mesh. Any number between 0.0 and 1.0 signifies a morphed position. IRIS Performer constructs a smooth mesh based on the results from the evaluation function.

You can customize an evaluation function so that it applies to your application. For example, instead of distance, your evaluation function might be based on altitude.

For more information about the evaluation function, see “Default Evaluation Function” on page 483.

Data Structures

Raw geometry data is converted into a tree-like, hierarchical structure of data, as shown in Figure 15-8.

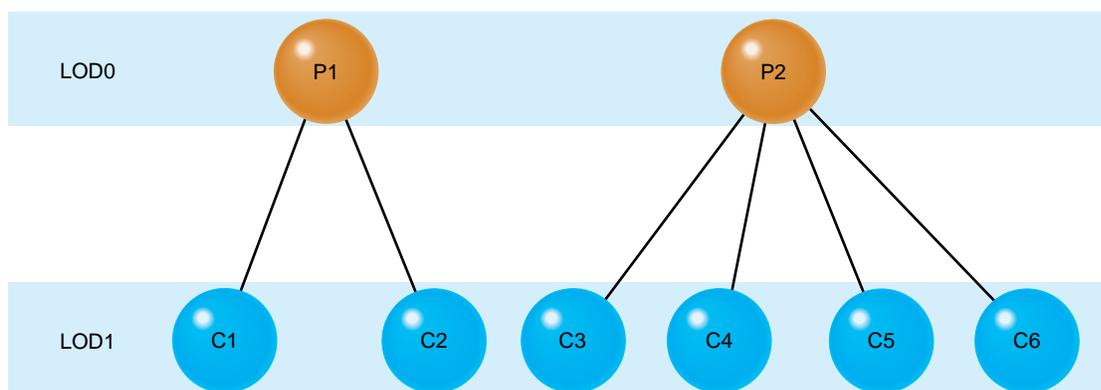


Figure 15-8 Data Structures

In Figure 15-8, each horizontal layer of triangles is equivalent to a single LOD mesh. The nodes in the tree structure represent triangles in LOD layers of the terrain. Each triangle contains three end vertices and up to three reference vertices. These vertices are indices into the vertex and attribute arrays.

A vertex may be shared by multiple triangles within a single LOD and by many more triangles throughout the data structure. A single position pair suffices for all the triangles that share a vertex, but each triangle may specify its own vertex attribute pairs. This is the reason that the vertex and attribute arrays are represented separately.

In Figure 15-8, the nodes in the top, root level represent the two LOD0 triangles shown in Figure 15-6. The six triangles from LOD1, labeled C1 through C6, correspond to nodes from the second level in the tree.

IRIS Performer uses three data structures to encapsulate the triangle mesh information:

- Triangle—encapsulates information about the sides, vertices, attributes, reference points, parent, and children of a triangle.
- Attributes—encapsulates information about the attributes of each vertex, including the normal, color, and texture coordinates.
- Vertex—encapsulates information about a morphing vector and the coordinates of its final position.

Figure 15-9 shows the data structures, their fields, and their relationships.

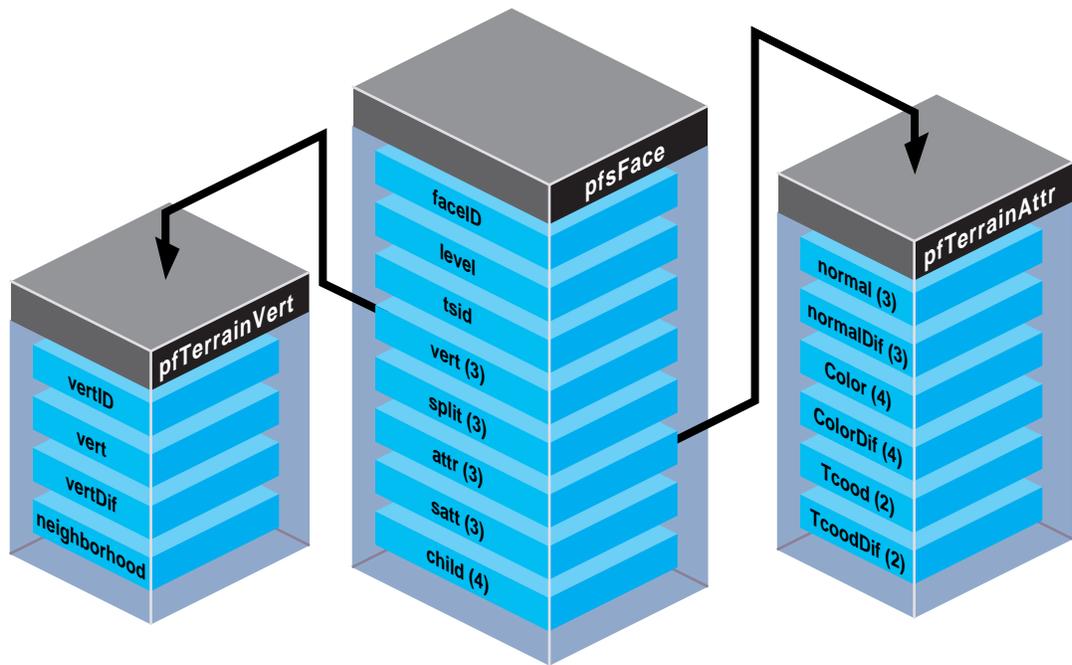


Figure 15-9 ASD Data Structures

The following sections describe these data structures in detail.

Triangle Data Structure

The Triangle data structure in PFASD contains information about the triangles in the triangle mesh.

```
typedef struct pfASDFace
{
    int level;
    int tsid;
    int vert[3];
    int attr[3]
    int refvert[3];
    int refattr[3];
    int child[4];
    int refvert[3];
    ushort gstateid;
    ushort mask;
} pfASDFace;
```

Table 15-1 describes the fields in the Triangle data structure.

Table 15-1 Fields in the Triangle Data Structure

Field	Definition
level	Triangle's LOD level.
tsid	Triangle strip ID.
vert[3]	Coordinates of the triangle's three vertices.
refvert[3]	Coordinates of the triangle's (up to) three reference points.
attr[3]	Pointer to attribute values for each of the triangle's three vertices.
refattr[3]	Pointer to attribute values for each of the triangle's (up to) three reference points.
child[4]	Triangle IDs of the triangle's (up to) four child triangles.
gstateid	GeoState ID.
mask	Specifies whether or not to render the triangle.

Triangle IDs and LOD Levels

Each triangle in the database has an ID. Since one triangle can be replaced by as many as four triangles, *child[4]* is an array of child triangle IDs. The child IDs may be listed in any order in the array. Do not list the same child more than once in the child array.

If a triangle does not have four children, as is the case of the triangle on the left in Figure 15-7, enter the token `PFASD_NIL_ID` in the *child[4]* array where normally you would enter the IDs of the child triangles.

An ASD node may very likely have more than one texture in it, so it contains more than one **pfGeoState**; one for each texture. *gstateid* specifies the **pfGeoState** object the triangle face uses.

There are times when you might like to have a triangle face specified in the structure, but not draw it. For example, you need the triangles of the ground under an airport so that you can place the airport on it. However, since the triangles are covered by the airport, you don't want to render them. *mask* allows you to prevent the rendering of the triangle face specified in the structure.

As shown in Figure 15-8, each triangle is resident in a particular LOD level. *level* defines the LOD of the triangle. If the viewer is moving within one LOD, chances are they need to see other triangles at the same LOD level.

Discontinuous, Neighboring LODs

There are many cases in which you can have neighboring triangles with discontinuous LOD levels, for example, a high-resolution insert of a scene might be LOD level 5 and surrounded by triangles of LOD 1.

When neighboring triangles have discontinuous LOD levels, the lower-resolution triangles must have, as shown in Figure 15-10:

- Reference vertices on all triangle edges.
- `PFASD_NIL_ID` entered in the fields for all four of it's children.

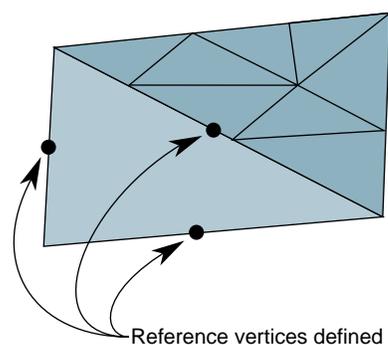


Figure 15-10 Discontinuous, Neighboring LODs

Triangle Strips

You can increase the rendering speed of your application by using triangle strips. Triangle strips are groups of contiguous triangles that together form a strip, as shown in Figure 15-11.

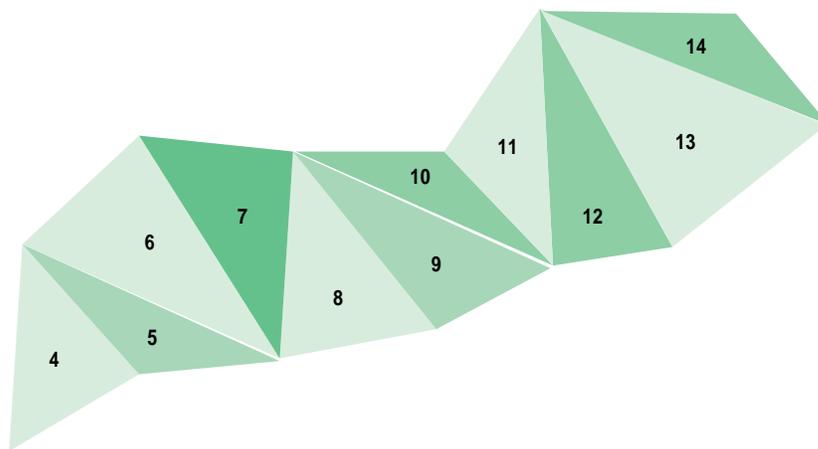


Figure 15-11 Triangle Mesh

Triangle strips improve rendering performance because, after the first triangle in the strip, each additional triangle can be added by defining only one additional vertex.

pfASD does not generate triangle strips dynamically. Triangle strips are pre-generated at modeling time and represented using *tsid* in the pfASDFace structure. Only triangles from the same ASD face tree level can be in the same triangle strip. The *tsid* numbers are sorted at run-time to connect as many triangles from the same triangle strips together as possible. Triangles with consecutive *tsid* values are placed in one triangle strip.

pfASD:

1. Evaluates the LOD structure.
2. Picks the triangles at the desired LODs.
3. Culls the triangles to the visible frustum.
4. Sorts the triangles by their *tsid*.
5. Generates triangle strips of triangles with consecutive *tsid* values.

Figure 15-12 shows an example of a set of triangles with consecutive *tsid* values.

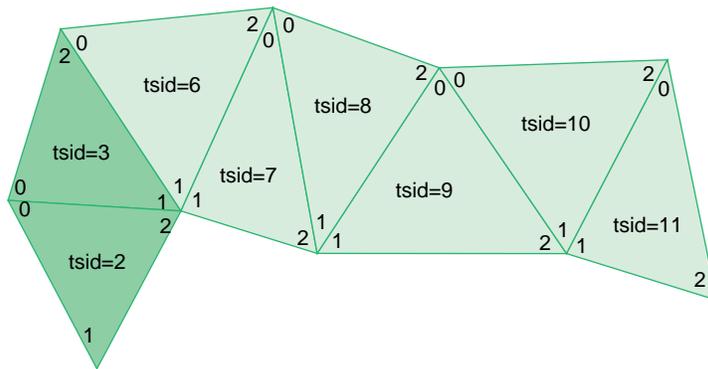


Figure 15-12 Using the *tsid* Field

pfASD generates a triangle strip from the vertices marked 0, 1, and 2 in the triangle with *tsid*=2, followed by the vertex marked 2 in the triangle with *tsid*=3. The triangle with *tsid*=6 marks the beginning of the next triangle strip, vertices marked 0, 1, and 2 in triangle with *tsid*=6, followed by vertices marked 2 from triangles with *tsid* 7, 8, 9, 10, and 11. It is very important to start a triangle strip on an even triangle strip ID. For example, triangles in the first triangle strip can have IDs 0, 1, 2,...; but they can't have 1, 2, 3,... Vertices should be listed in pfASDFace in counter clockwise order, with the last vertex to be the vertex in the triangle strip.

At the termination of a triangle strip, there must be a non-consecutive *tsid* in the next triangle, as shown in Figure 15-12. Assigning the numbers 3 and 6 forces these triangles into separate triangle strips. Assigning all triangles to the same *tsid* would separate all of them into strips with only one triangle.

Note: pfASD sorts all the visible triangles by *tsid*. *tsid* values, therefore, must not overlap in different areas of the surface. pfASD does not check that triangles with consecutive *tsid* values are indeed neighboring.

Vertex and Reference Point Arrays

The vertex and reference point arrays, *vert[3]* and *refvert[3]*, each contain three **pfASDVert**, which are the coordinates of the vertices and reference points. For more information on **pfASDVert**, see “Vertex Data Structure” on page 482.

The order of the vertices and the reference points in the arrays must be counter clockwise, as shown in Figure 15-13.

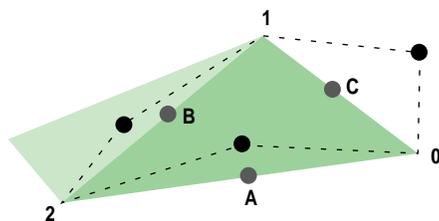


Figure 15-13 Counter Clockwise Ordering of Vertices and Reference Points in Arrays

Any of the vertices can be the first in the array. The first reference point in the array, however, must be the one on the side between the first and second vertex points, for example, the reference point on the hypotenuse of the triangle in Figure 15-13 should not be entered as the first reference point in the *refvert[3]* array because the bottom leg of the triangle contains the first two vertex points entered into the *vert[3]* array.

If a triangle does not have three reference points, as is the case of the triangle on the left in Figure 15-5 (where only the hypotenuse has a reference point), enter the token **PFASD_NIL_ID** in the *refvert[3]* array where normally you would enter the indices of the reference points.

Attributes

Each vertex can have its own set of attributes. The attribute format is described in “Attribute Data Array” on page 480. The arrays, *attr[3]* and *refattr[3]*, point to three vertex attribute array entries and three reference point attribute array entries.

If a vertex or reference point is not assigned an attribute, enter the token `PFASD_NIL_ID` in the *attr[3]* or *refattr[3]* arrays where normally you would enter the pointer to the attribute array.

Attribute Data Array

Each vertex and reference point can be assigned an attribute. An attribute is an interleaved list of floats that consists of normal, color, and texture definitions, as follows:

```
float normal[3];
float normalDif[3];
float Color[4];
float ColorDif[4];
float Tcood [2];
float TcoodDif [2]
```

If any attribute is not defined, it should not be represented in the array, in which case the stride is shorter.

Each attribute has two listings: the values of the attributes at the final positions, and how much they change during morphing. For example, the *normal[3]* array specifies the vector that is normal to the vertex at the final position, while the *normalDif[3]* array specifies the difference between the normal and its final position and the normal at its reference point.

Color[4] and *ColorDif[4]* similarly specify the RGBA values at a vertex, and the color morphing vector.

The texture coordinates, *Tcood [2]* and *TcoodDif [2]*, specify the texture coordinates of vertices at their final position and the texture coordinates of the morphing vector.

Setting the Attributes

The attribute array of floats can contain normal, color, and texture coordinate information, or it can contain any combination of attributes. You specify which of the attributes are in the attribute array of floats by setting the **pfASDAttr()** mask. To specify that you are including some or all of the attribute values in the attribute array, you use *pfASDAttr()* with one or more of the following tokens OR'd together:

- PFASD_NORMALS
- PFASD_COLORS
- PFASD_TCOORDS

For example, to specify normal and color attributes only, use the following statement:

```
pfASDAttr(PFASD_NORMAL | PFASD_COLOR);
```

If certain attributes are not specified in *pfASDAttr*, they should not be included in the attribute array. *pfASD* only takes one set of per-vertex-per-face attributes and one set of overall attributes.

Global Attributes

If you want to use the same attribute value for all normals, colors, or texture coordinates, you can specify a global attribute value rather than making the same entry for each normal, color, or texture coordinate attribute. To specify a global attribute, use the following statement:

```
pfASDAttr(..., PFASD_OVERALL_ATTR, attr);
```

attr, an array of floats, holds a set of attributes and their morphing vectors. You can mix a global attribute with a different attribute that is per vector.

Vertex Data Structure

The vertex data structure, defined as follows, holds the coordinate information of vertices and their vertex vectors.

```
typedef struct pfASDVert
{
    pfVec3 v0, vd;
    int neighborid[2];
    int vertid;
} pfASDVert;
```

Each vertex has an ID, *vertid*, a set of coordinates, *v0*, and a vertex vector, *vd*. The vertex vector is the vector stretching from the final vertex toward the reference point.

In a triangle strip, a line segment is commonly shared by two adjoining triangles, as shown in Figure 15-14.

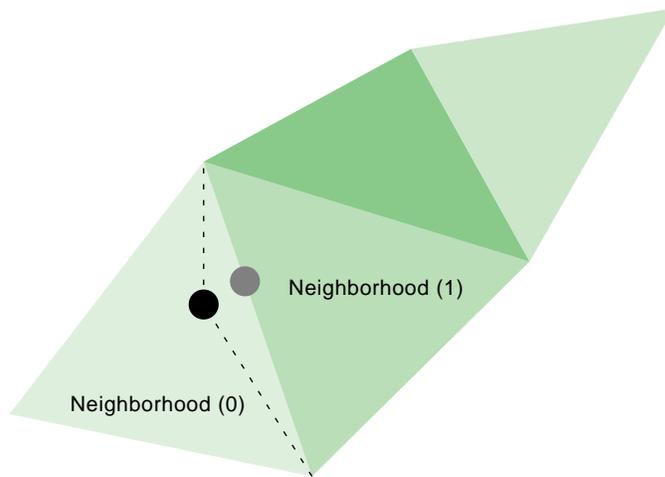


Figure 15-14 Vertex Neighborhoods

The new vertex is shared by the adjoining triangles. Those triangles are referred to as the neighborhoods of the vertex. The neighborhood array contains the triangle IDs of the adjoining triangles in the previous LOD.

If a side is not shared by two triangles, then one of the neighborhood array values should be `PFASD_NIL_ID`.

Default Evaluation Function

The default evaluation function, which returns a value between 0.0 and 1.0, is based on the distance between the vertex and the eyepoint: the farther away a vertex is, the lower its resolution.

To use the default evaluation function, you must fill in the **pfASDLODRange** structure for each LOD.

```
typedef struct pfASDLODRange
{
    float switchin;
    float morph;
} pfASDLODRange;
```

LOD[i].switchin is the far edge of the LOD[i]. Take any vertex of a triangle in LOD[i] and compute the distance between the vertex and eyepoint. If this distance is more than *LOD[i].switchin*, the morphing weight of this vertex is 1.0 (NO_MORPH). If it is less, the morphing weight is calculated against the morphing zone.

LOD[i].morph is the length of the morphing zone from the *LOD[i].switchin* far edge. The morph weight is $(1 - (LOD[i].switchin - dist) / LOD[i].morph)$. If the distance is less than $LOD[i].switchin - LOD[i].morph$, the morph weight is 0.0 (COMPLETE_MORPH).

Overriding the Default Evaluation Function

The evaluation function can be based on many things beside distance. For example, you might implement the evaluation function based on:

- Line of sight—geometries directly in front of the camera have the highest resolution while geometries more peripheral have a lower resolution.
- Direction—high resolution LODs appear only in one direction, for example, given the fuzzy nature of clouds, when a pilot looks straight ahead the clouds do not need to be rendered with great detail. When the pilot looks down, however, you might like them to see the terrain in great detail.
- True size of projected triangle—triangles are replaced when they physically reach a specified size on the projector screen.

- Event driven—an event triggers a change of LODs, for example, when a bomb explodes.
- Shape—specific shapes in the scene, perhaps a tank, could be rendered in higher resolution than the surrounding countryside.

None of these evaluation criteria can use the default evaluation function. Instead you must write your own evaluation function and register it as a callback function with pfASD using the following method:

```
extern void pfASDEvalFunc(pfASD* _asd, pfASDEvalFuncType _eval);
```

The evaluation function you provide, *eval*, must return a float between 0.0 and 1.0 and conform to a fixed format. **pfASDEvalFuncType** takes the argument *vertid*, which is the index of the vertex from the next LOD whose reference position is on this edge. Refer to *asdfly/pfuEvalFunc.c* for examples.

pfASD Queries

pfASD supplies a query mechanism for two kinds of objects:

- Vertices with a down vector.
A vertex query answers the question: Where does the ray through the vertex in the given down direction hit the surface?
- Triangles with a projection vector and a down vector.
A triangle query answers the question: Given a triangle, how does it project onto the current morphing pfASD? Or, given a triangle, supply a list of triangles describing the projection of this triangle on the surface.

pfASD has a mechanism for manipulating arrays of vertices and triangles, and for reporting query results of surface geometries. Query results are kept in a pfFlux buffer. The application may read this buffer directly or connect it to a pfEngine for processing.

These query mechanisms must run in sync with the evaluation function. The query results must be used in the same frame that the morphing status of a pfASD becomes active. To synchronize the behavior of pfASD geometry and query points, you need to set the correct pfFlux flags, as described in “Aligning Light Points Above a pfASD Surface Example” on page 490.

Before describing the technical details of setting up a query array, the following section describes how to use these arrays.

Aligning an Object to the Surface

In the visual simulation arena, you often place objects on surfaces. Since the pfASD surfaces morph, the objects on top must move to remain on the surface. Some objects require only position changes. Others require angle changes as well. A building on top of a mountain side, for example, requires only a position change to match the current altitude of the surface under it. A car standing on the same mountain side, however, requires changing both its position and its angle in order to remain aligned to the surface.

In the case of the building, it is enough to query the intersection between a query ray and the surface. In the case of the car, however, you must also calculate the surface normal at the intersection point.

Casting a Shadow

We often wish to cast the shadow of objects on the surface underneath them. Since the pfASD surface is morphing, we must morph the shadows accordingly. Given a triangle and a projection direction, we want to project the triangle on the surface and tessellate its projection so that we get a 3D representation of the shadow. We can later use these shadow triangles as decals to paint the shadow on the surface.

Generating Decals

Many times you wish to draw decals on a surface. In the context of surfaces, you may wish to add a road as a decal on the morphing surface. To make the road touch the surface, you must tessellate the polygons of the road so they conform to the shape of the surface. To tessellate the road, you project a triangle downwards and then tessellate the result.

Adding a Query Array

To add an array to the pool of queries, you use:

- `pfASD::addQueryArray()` to add an array of vertices.
- `pfASD::addQueryGeoSets()` to add an array of triangles.

Both methods require a `pfFlux` as input. After completing the evaluation of a `pfASD` frame, `pfASD` fills the specified `pfFlux` objects with query results for all the visible query arrays. The query results become relevant at the next `pfFrame` along with the newly-evaluated `pfASD` geometry.

To make sure the query results are used only when their corresponding geometry is active, add the corresponding `pfFlux` and the `pfASD` node to the same sync group using `pfASD::setSyncGroup()` and `pfFlux::setSyncGroup()`.

Using ASD for Multiple Channels

A channel is a view of a scene. There are three approaches to linking multiple channels:

- Each channel uses the same database, the same viewpoint, the same evaluation function, and the same LODs, but the viewing angle is different for each channel.

The effect is multiple channels that together create a continuous view, like that of a horizon. The views of the scenes in each channel move together. For more information on this approach to multiple channels, see “Controlling Video Displays” on page 408.

- Each channel uses the same database, a different viewpoint, the same evaluation function, and potentially different LODs.

The effect is two or more views of the same scene, for example, one view might look along the terrain, another view might look down at the same terrain from above. This approach uses the `pfASD` API for creating multiple channels, as described in “Connecting Channels” on page 487.

- Each channel uses the same database, a different viewpoint, different evaluation functions, and potentially different LODs.

The effect is two or more views of potentially unrelated parts of a scene, for example, if the database is the earth, one view might be of someone traveling around the north pole, another view might be of someone traveling around the south pole.

Because the only thing common to the two views is the database, you need to create two `pfASD` objects; one to handle each view.

The following section explains how to do the second approach to connecting channels.

Connecting Channels

When you have two channels that share the same database and evaluation function and differ only in that they have different viewing angles of the same part of a scene, you can save processing time and save memory by attaching the two channels using `pfChanASDattach()`; `pfChanASDdetach()` detaches two channels.

Making the two channels part of the same pfASD, processing time is improved because only one evaluation function is computed. Having one pfASD instead of two saves memory because two pfASDs requires maintaining two sets of the same scene.

Combining pfClipTexture and pfASD

A pfClipTexture is able to manage very large bodies of data, presenting only the part that is in view of the user. pfASD modifies the pfClipTexture such that the different parts of the pfClipTexture are presented using the correct LOD level.

To use a pfClipTexture as part of a pfASD, use the following procedure:

1. Put the pfClipTexture into a pfGeoState.
2. Set the pfGeoState to a pfASD.
pfASD accepts a list of pfGeoStates.
3. Define the center of the pfClipTexture in one of two ways:
 - Attach a pfuClipCenterNode to a pfASD, as shown in the .im loader
Use pfuTexGenClipCenterNode and convert the eyepoint through texgen into texture space as the clipcenter. This technique should be used when cliptexture is applied using texgen.
Set the proxy box equal to the rough boundary of the pfASD database. the boundary of the pfASD can be queried by calling `pfGetASDDBBox(asd, box)`.
or
 - Use a PRE callback function with pfASD to set the clip center yourself. To see an example, refer to *terrain.c*.
4. If the clip texture is virtual, pfASD automatically sorts geometry into concentric cliprings to support the appropriate cliptexture limit and offset. Set the environment variable, PFASD_CLIPRINGS, to activate this feature. See *libpfdem* and *libpfvft* for examples.

ASD Evaluation Function Timing

The pfASD evaluation function commonly runs as a separate, asynchronous process. This process does not necessarily finish its evaluation when the App-Cull-Draw frame finishes. The new pfASD geometry becomes active (visible) at the end of the pfFrame that follows the completion of the pfASD evaluation.

For example, if Draw frames 0, 1, 2, 3, 4... end at times 100, 200, 300, 400, 500... and the pfASD evaluation finishes at time 320, the new geometry is introduced into the scene graph at time 400, as shown in Figure 15-15.

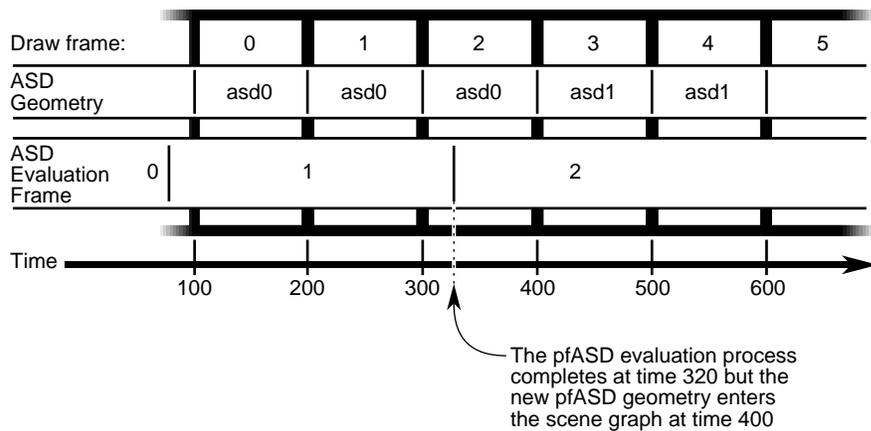


Figure 15-15 pfASD Evaluation Process

In Figure 15-15, it is important to align objects to the old geometry in Draw frame 2, and align to the new geometry in Draw frame 3.

Query Results

The query results must affect the aligned geometry in the same frame that the pfASD geometry becomes active. To achieve this, you must connect both the pfASD node and Matrix-Flux to the same sync group. In this way, when pfASD changes the active surface geometry, it also activates the newly calculated query results.

In general, you should move as much processing to the pfASD process as possible. In Figure 15-15, all the query/alignment operations take place in the pfASD process. Since the entire evaluation is triggered by the query array writing to Result-Flux, the generation of the new pfFCS matrix in Matrix-Flux also takes place in the pfASD process. The only change to the time critical APP-CULL-DRAW sequence is a single `pfFlux::getCurData()` to get the updated pfFCS matrix.

Aligning a Geometry With a pfASD Surface Example

To align some geometry to a pfASD surface using query points, use the following procedure:

1. Pick an anchor point where you want the target geometry to go.
2. Generate a query array containing the anchor point and add it to pfASD.
3. Request pfASD to store the query results in the pfFlux marked *Result-Flux*.
4. Generate an additional pfFlux and connect it to the pfFCS node matrix controlling the target geometry.

Figure 15-16 diagrams this procedure.

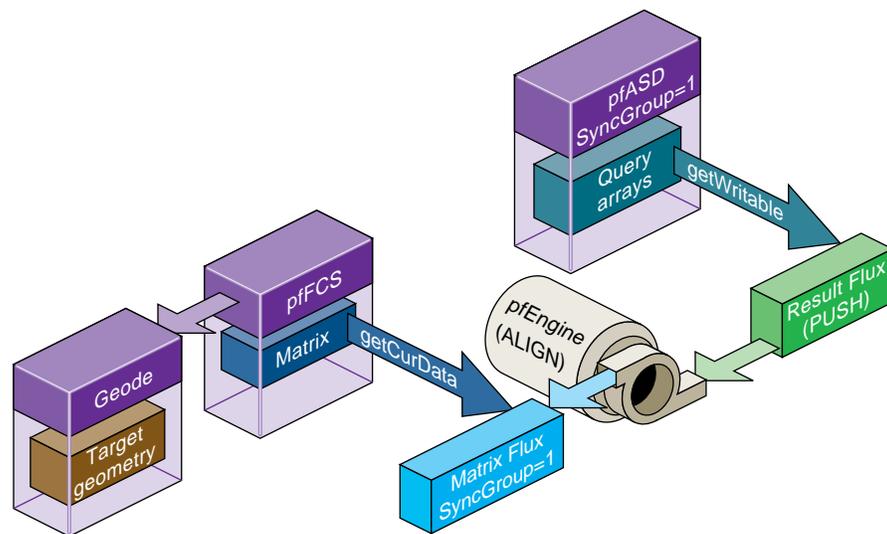


Figure 15-16 Example Setup for Geometry Alignment

At run-time:

1. pfASD starts its frame by evaluating the ASD surface and generating optimized geometry for it.
2. pfASD calculates the query array values.
3. pfASD writes the results into the pfFlux marked *Result Flux*.
4. The write operation triggers a calculation of the pfEngine because the Result-Flux is a PUSH flux.
5. The pfEngine generates a transformation matrix and stores it in the pfFlux marked *Matrix Flux*.
6. The pfFCS node controlling the transformation of the target geometry has a fluxed matrix.
7. When the pfFCS node is traversed, it retrieves the newly-generated matrix from Matrix-flux and uses it to align its child geometry.

Note: If you run the pfASD evaluation function in a separate process, the evaluation of the query arrays may happen asynchronously at some point during the IRIS Performer frame.

Aligning Light Points Above a pfASD Surface Example

The following example, diagramed in demonstrate how to link pfASD queries to a pfEngine. For a GeoSet containing light point primitives, this code places all the primitives at some offset above the surface.

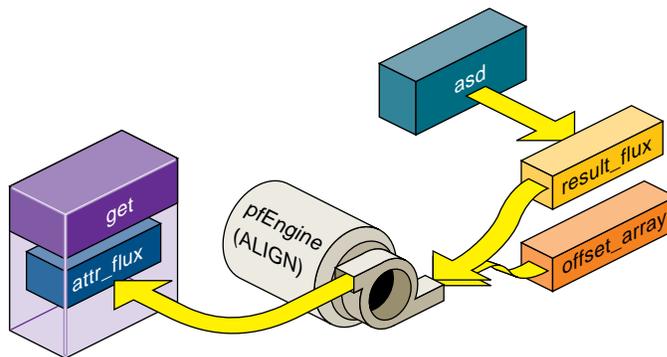


Figure 15-17 Aligning Light Points Above a pfASD Surface

Example 15-1 Aligning Light Points Above a pfASD Surface

```
// Generate a flux for pfASD to store the query results.
results_flux = pfNewFlux(nofLightPoints *
    sizeof(pfVec3), PFFLUX_DEFAULT_NUM_BUFFERS, pfGetSharedArena());

// Make so that writing into this flux will trigger evaluation of
// connected engines.
pfFluxMode(results_flux, PFFLUX_PUSH, PF_ON);

// Generate final flux - this flux will contain the final aligned
// light points.
attr_flux = pfNewFlux(nofLightPoints * 3 * sizeof(float),
    PFFLUX_DEFAULT_NUM_BUFFERS, pfGetSharedArena());

// Add flux to the same syncGroup as its aligning pfASD.
pfFluxSyncGroup(attr_flux, 1);

// Initialize the flux to the unaligned point positions.
// The engine will only modify a portion of the buffer (the Z
// values), so we must initialize the (X,Y) values now.
// Assume vertexList contains the original vertices.
FluxInitData(attr_flux, vertexList);

// Add the array of positions to pfASD. Request position-only
// queries.
query_id = pfASDAddQueryArray(asd_hook, vertexList, down,
    nofLightPoints, PR_QUERY_POSITION, results_flux);

// Get maximum bounding box of the vertex array - this box
// contains all possible positions of the query array points.
pfASDGetQueryArrayPositionSpan(asd, query_id, &box);

// Generate a SUM engine to sum the query vertex results with a
// constant array.
sum_engine = pfNewEngine(PFENG_SUM, pfGetSharedArena());
pfEngineIterations(sum_engine, nofLightPoints, 1);

// Inform pfEngine of its two sources and one destination.
// offset_array should contain a constant offset for each light
// point. We request sum_engine to modify the Z coordinate of
// each light point vertex.
pfEngineSrc(sum_engine, PFENG_SUM_SRC(0), offset_array, NULL,
    0, PF_Z, 3);
pfEngineSrc(sum_engine, PFENG_SUM_SRC(1), results, NULL,
```

```
    0, PF_Z, 3);
pfEngineDst(sum_engine, attr_flux, NULL, PF_Z, 3);

// Generate GeoSet to hold the final aligned geometry.
gset = pfNewGSet(pfGetSharedArena());

// standard pfGeoSet initialization code
// (GeoState, color, NumPrims, etc) omitted.
pfGSetPrimType(gset, PFGS_POINTS);

// Add flux_attr as the COORD3 attribute of the geoset.
pfGSetAttr(gset, PFGS_COORD3, PFGS_PER_VERTEX,
           (void *) attr_flux, NULL);

// Set the GeoSet bounding box statically. This will help avoiding
// recalculation or mis-calculation of bounding boxes for culling.
pfGSetBBox(gset, &box, PFBOUND_STATIC);

// Setup range based evaluation. assume 'center' contains the
// center of box.
pfEngineEvaluationRange(sum_engine, center, 0.0, 40000.0);
pfEngineMode(sum_engine, PFENG_RANGE_CHECK, PF_ON);
```

Paging

Large scale surface simulations require large amounts memory to store high resolution surfaces. For example, the earth sampled from a height of 100m requires tens of gigabytes of disk space. Such large amounts of memory cannot reside entirely in system memory. Consequently, efficient database paging is essential in supporting a 30 Hz frame rate.

A common paging method is to page in tiles. Each area block contains all the LOD information describing an area. The problem with this method of paging is that in a surface that extends far into the distance, the large number of tiles visible to the viewer consumes more memory than is available on a system.

The hierarchical structure of ASD provides a different paging method: LOD paging. Each LOD is divided into a set of blocks; each block representing an area of the scene at a particular resolution. These tiles are paged in independently. All tiles for a single LOD are the same size; tiles for different LODs, however, can be different sizes.

Interest Area

In one LOD, the blocks most likely accessed, according to the view and position of the viewer, are called the interest area of the LOD. It is these blocks that get paged in.

The interest area for an LOD whose resolution is based on range is bounded by the maximum range value for that LOD. The interest area is smaller for higher resolution LODs, larger for lower resolutions LODs. As a result, the memory requirements of ASD are reduced because not all LODs in an area are paged in: triangles closer to the viewer are paged in at a higher resolution LOD than those triangles further from the viewer, as shown in Figure 15-18.

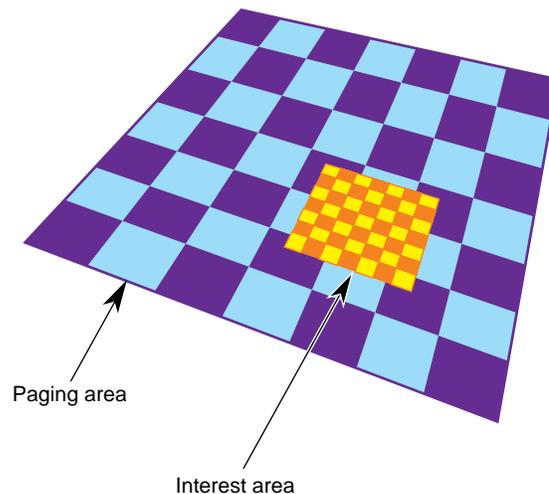


Figure 15-18 Tiles at Different LODs

Each square in Figure 15-18 holds the same amount of information: the large pages hold a large amount of low-resolution information while the small pages hold a small amount of high-resolution information.

If the observer does not make discontinuous jumps in location between 2 frames, you use an algorithm that anticipates what the viewer needs to see next based on the evaluation function. For example, if the evaluation function is based on distance, you would page blocks into memory in the direction you expect the viewer to go and release from memory those pages the viewer is leaving.

Preprocessing for Paging

Preprocessing pages improves performance.

1. Determine the appropriate tiles size for each LOD based on the evaluation function.
2. Assign triangles in each LOD into tiles and store each tile in a paging unit, such as a file.

Assign a triangle to one tile only. Triangles with the same parent node must be assigned to the same tile.

3. Generate a set of fast-paging files for a specific set of paging areas.

When the application is run, it should anticipate the pages the viewer will need and then page them into memory from disk and preprocess them.

Order of Paging

Paging in lower LOD pages before higher LOD pages ensures that a page at some level of LOD is always ready for the viewer. When you travel so fast through a surface that the higher resolution LODs do not have time to load, the surface has a lower resolution, which is what you would expect to see when traveling fast.

Multi-resolution Paging

pfASD supports multi-resolution paging. The format of a paging file, where all of the geometries are in one tile, is described by the following structure:

```
int numfaces
int numverts
/* numfaces of the following */
int faceid1
/* structure of the face faceid1 */
pfASDFace face
/* structure of the face faceid2 */
int faceid2
pfASDFace face
...
/* numfaces of the following */
/* face bounding box of faceid */
pfBox box1
/* face bounding box of faceid2 */
```

```
pfBox box2
...
/* numverts of the following */
int vertid1
/* structure of vertex vertid1 */
pfASDVert vert
int vertid2
/* structure of vertex vertid2 */
pfASDVert vert
...
```

To calculate the paging area, use the following code:

```
page[0] = (int)(lods[i].switchin/tilesize[0]) + lookahead[0];
page[1] = (int)(lods[i].switchin/tilesize[1]) + lookahead[1];
```

lods[i] is the *pfASDLODRange* of **LOD[i]**. *tilesize* is the size of the tile in **LOD[i]**. *lookahead* is the number of extra tiles in one direction to page in to memory to overcome a paging delay

To process the paging tiles into a fast paging format, use **pdfProcessASDTiles()** in *pdfProcASD.c*. **pdfProcessASDTiles()** returns a new set of files as *xxxx.asd*. These files are paged in real-time.

For an example of writing a file, see **pdfWriteFile()** in *libpdfdu/pdfBuildASD.c*.

Chapter 16

“Light Points”

This chapter describes light points and calligraphic lights, which are intensely bright light points.

Light Points

IRIS Performer provides sophisticated light point objects:

- `pfLPointState` lights are emissive objects that do not illuminate their surroundings, such as stars, beacons, strobes, runway edge, and taxiway lights.
- `pfCalligraphic` light points are `pfLPointState` light objects with calligraphic extensions; they are intensely-bright light points that require special display equipment.

Uses of Light Points

Light points are bright points of light that have the following characteristics:

- Intensity
- Directionality
- Attenuation Shape
- Distance computation
- Attenuation through fog
- Size and fading

These attributes make light points excellent for use as stars, beacons, strobes, runway edge and end illumination, and taxiway lights.

For example, three light points with specific directionality may be used to create a VASI light system at an airport that appears:

- Red when the pilot is above the landing glide path.
- Green when the pilot is below the landing glide path.
- White when the pilot is on the landing glide path, as shown in Figure 16-1.



Figure 16-1 VASI Landing Light

Creating a Light Point

To create a light point:

1. Create a `pfGeoSet` of points (`PFGS_POINTS`).

```
pfGeoSet *lpoint = pfNewGSet(arena);
pfGSetPrimType(lpoint, PFGS_POINTS);
```

2. Create a `pfLPState` and define its mode and values.

```
pfLPState *lpstate = pfNewLPState(arena);

pfLPStateMode(lpstate, PFLPS_SIZE_MODE, PFLPS_SIZE_MODE_ON);
pfLPStateVal(lpstate, PFLPS_SIZE_MIN_PIXEL, 0.25f);
pfLPStateVal(lpstate, PFLPS_SIZE_ACTUAL, 0.07f);
pfLPStateVal(lpstate, PFLPS_SIZE_MAX_PIXEL, 4.0f);
```

3. Attach the `pfLPState` to the `pfGeoState` associated with the `pfGeoSet`.

```
pfGStateMode( gstate, PFSTATE_ENLPOINTSTATE, PF_ON);
pfGStateAttr( gstate, PFSTATE_LPOINTSTATE, lpstate);
pfGSetGState( gset, gstate ) ;
```

This `pfGeoSet` must have a `PFGS_COLOR4` attribute binding of `PFGS_PER_VERTEX`.

Setting the Behavior of Light Points

The `pfLPointState` attached to a `pfGeoSet` controls the behavior of all light points in the `pfGeoSet`. For example, the color, position, and direction vector of each light point is set by the color, vertex, and normal stored in the `pfGeoSet`.

You use `pfLPStateMode`, to enable or disable the behaviour, and `pfLPStateVal` to set the following `pfLPointState` values:

- Intensity—setting the intensity of light from no attenuation, 1, to fully attenuated, 0.
- Directionality—specifying the direction and the shape of the emanation of light. The shapes are either a single or a pair of opposite-facing elliptical cones. `pfLPStateShape()` specifies the shape of the emanation.
- Fading—specifying how the light point fades when receding into the distance. Fading is often more realistic than simply shrinking the point size to 0.
- Fog punch-through—specifying how a light point is obscured by fog.
- Size—setting the maximum and minimum size of the light point based on perspective.

The following sections describe how to set these values.

Intensity

The intensity of the light points in a `pfLPointState` can be attenuated using `pfLPStateVal()`, as follows:

```
pfLPStateVal(lpstate, PFLPS_INTENSITY, intensity)
```

The intensity value, *intensity*, must range between zero and one; one, no attenuation, is the default.

The intensity of each light point is defined by its four component colors.

Directionality

Each light point has a normal, which defines the direction of its emanation. By default, all of the light points in a `pfLPointState` point in the same direction. That direction is defined as the “front” of the light point.

If all light points in a `pfGeoSet` share the same normal, use the `PFGS_OVERALL` attribute to optimize the light point computation.

If the light points are directional, the `pfGeoSet` attributes must specify normals.

Enabling Directionality

To enable or disable light point directionality, use the following method:

```
pfLPStateMode(lpstate, PFLPS_DIR_MODE, mode);
```

The *mode* value can be:

- `PFLPS_DIR_MODE_ON`, the default, turns on directionality computation.
- `PFLPS_FOG_MODE_OFF`, disables directionality computation.

To specify whether or not the light point emanates towards the front and back, use the following method:

```
pfLPStateMode(PFLPS_SHAPE_MODE, mode);
```

The *mode* value can be:

- `PFLPS_SHAPE_MODE_UNI`, the default, makes the light point is not visible from the back side.
- `PFLPS_SHAPE_MODE_BI`, makes the light point bidirectional, the behavior is the same for both sides.
- `PFLPS_SHAPE_MODE_BI_COLOR`, makes the light point bidirectional, but if seen from the back side, the light change its color. This color is set using `pfLPStateBackColor()`.

Emanation Shape

The emanation shape is an elliptical cone, as shown in Figure 16-2.

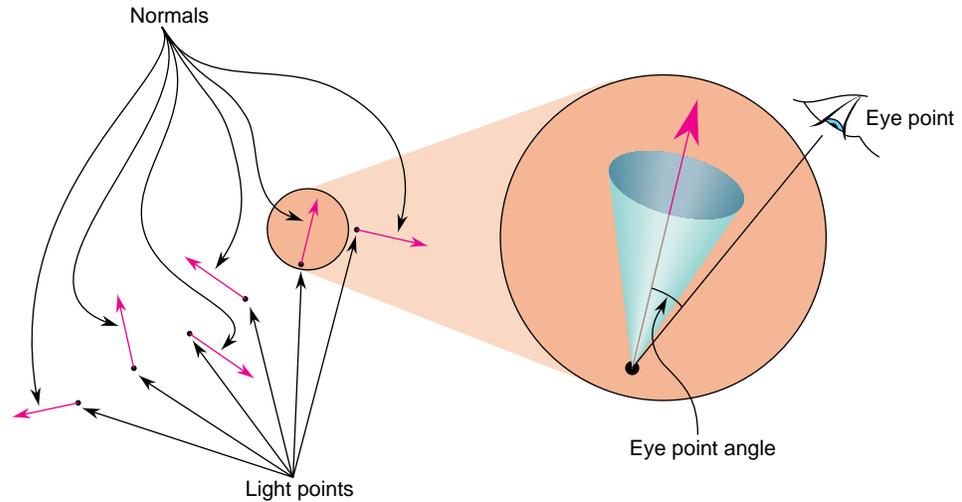


Figure 16-2 Attenuation Shape

Optionally, the intensity of light can fall off from the normal to the edge of the cone.

The direction of emanation is defined along the Y axis and the shape is defined in the local coordinate system. The coordinate system is rotated so that the Y axis aligns with the normal of each light point.

To specify the shape of emanation, use the following method:

```
pfLPStateShape(lpstate, horiz, vert, roll, falloff, ambient)
```

Shape

horiz and *vert* are total-angles (not angles to the normal) in degrees, which specify the horizontal and vertical dimensions of the cone about the normal. The maximum value for these angles is 180 degrees, which creates a non-directional light point. The default values for *horiz* and *vert* is 90 degrees.

Tip: A symmetric cone (where *horiz* and *vert* are equal) is faster to compute than an asymmetric cone.

Rotation

The cone is rotated by *roll* degrees through +Y. The default *roll* value is 0.

Falloff

When the vector from the light's position to the eye point is outside the cone, the light point's intensity is *ambient*. The default *ambient* value is 0.

If the vector from the light's position to the eye point is within the cone, the intensity of the light point is based on the angle between the normal and that vector. The intensity values range from 1.0, when the eye point lies on the normal, to *ambient*, at the edge of the cone. How the light attenuates between the normal and the edge of the cone is specified by *falloff*.

falloff is an exponent that modifies the light point's intensity. A value of 0 indicates that there is no falloff; a value of 1, the default, indicates a linear falloff; values greater than 1 indicate a progressively greater geometric *falloff*, as shown in Figure 16-3.

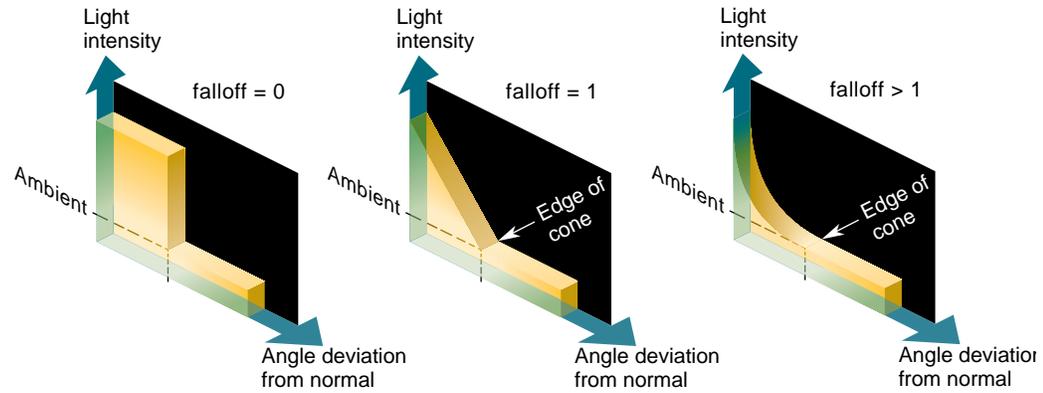


Figure 16-3 Attenuation of Light

Distance

The distance between the light point and the eye point is used when computing the light point's size and intensity through fog. Since these calculations are intensive, IRIS Performer provides an approximation for the distance between the light point and the eye point using the following method:

```
pfLPState(lpstate, PFLPS_RANGE_MODE, mode)
```

The *mode* value can be:

- PFLPS_RANGE_MODE_TRUE, approximates the distance using the depth (Z) difference between the eye and the light point.
- PFLPS_RANGE_MODE_DEPTH, the default, uses the real distance between the eye and the light point.

Tip: The wider the field of vision (FOV), the less accurate is the approximation.

Attenuation through Fog

Light points are visible at greater distance than non-emissive polygons. For that reason, the light points appear to punch-through fog. To account for this higher visibility, you can supply a *punch-through* value in the following method:

```
pfLPStateVal(PFLPS_FOG_SCALE, punch-through);
```

punch-through is a float that is multiplied times the distance. When *punch-through* is less than 1.0, the product of the distance and the *punch-through* value is less than the distance. The revised distance is used in calculating the apparent brightness of the light point; when the *punch-through* is less than 1.0, the light point appears brighter than it otherwise would. The default *punch-through* value is 0.25.

Enabling Punch-Through

To use *punch-through*, you must first enable it using the following method:

```
pfLPStateMode(lpstate, PFLPS_FOG_MODE, mode);
```

The *mode* value can be:

- PFLPS_FOG_MODE_ON, the default, enables fog punch-through computation.
- PFLPS_FOG_MODE_OFF, does not modify the distance before fog is applied.

Size

Light points can exhibit perspective behavior. The following method sets the size of all the light points in a `pfGeoSet`:

```
pfLPStateVal(lpstate, PFLPS_SIZE_ACTUAL, real-size);
```

real-size is a float that is multiplied times the distance. When *real-size* is less than 1.0, the product of the distance and the *real-size* value is less than the distance. The revised distance is used in calculating the apparent size of the light point; when the *real-size* is less than 1.0, the light point appears larger than it otherwise would. The default *real-size* value is 0.25.

Size Limitations

The apparent size of a light point can only range between the minimum and maximum sizes specified by the following lines of code:

```
pfLPStateVal(lpstate, PFLPS_SIZE_MIN_PIXEL, min-size);  
pfLPStateVal(lpstate, PFLPS_SIZE_MAX_PIXEL, max-size);
```

Limiting Size Calculations

To optimize rendering, you can avoid changing the size (`glPointSize`) of each light point when the difference between the new and old sizes is less than a specified amount, called the *threshold*. To set the *threshold* value, use the following method:

```
pfLPStateVal(lpstate, PFLPS_SIZE_DIFF_THRESH, threshold);
```

Enabling Perspective

To use *real-size*, you must first enable it using the following method:

```
pfLPStateMode(lpstate, PFLPS_SIZE_MODE, mode);
```

The *mode* value can be:

- PFLPS_SIZE_MODE_ON, makes *real-size* follow perspective, so that light points closer to the eye are rendered larger than those points farther away.
- PFLPS_SIZE_MODE_OFF, the default value, disables perspective computations.

If perspective is not enabled, **pfGeoSet (pfGSetPntSize)** specifies the size of the rendered light points.

Fading

You can enhance the illusion of perspective by making the light point become more and more transparent as it receded from view using the following method:

```
pfLPStateVal(lpstate, PFLPS_TRANSP_PIXEL_SIZE, transp-size);
```

transp-size is a light point size. When the actual size is smaller than *transp-size*, the light point becomes transparent.

Using fading to simulate perspective is often more realistic than shrinking the light point size; fading avoids the aliasing problems that occur when light points become too small.

Fading Calculation

Fading is calculated as follows:

```
Max(clamp, 1-scale*(transp-size - computed-size)^exp)
```

You set the values in this argument in the following lines of code:

```
pfLPStateVal(lpstate, PFLPS_TRANSP_EXPONENT, exp);  
pfLPStateVal(lpstate, PFLPS_TRANSP_SCALE, scale);  
pfLPStateVal(lpstate, PFLPS_TRANSP_CLAMP, clamp);
```

Enabling Fading

To use fading, you must first enable it using the following method:

```
pfLPStateMode(lpstate, PFLPS_TRANSP_MODE, mode)
```

The *mode* value can be:

- PFLPS TRANSP_MODE_ON, enables fading when the computed size is less than *transp-size*
- PFLPS TRANSP_MODE_OFF, the default, disables fading.

Callbacks

For each light point, two parameters are computed based on the location of the eye point, the location of the light point, and the fog:

- Alpha—specifies the intensity and transparency of a light point. Non-transparent light points have the maximum intensity given by their four color components.
- Size—specifies the diameter of each light point if the perspective mode, PFLPS_SIZE_MODE, is enabled; otherwise, the size is constant for all of the light points in a pfGeoSet.

Instead of accepting the calculations done by IRIS Performer, you can use callback functions to supply your own calculations. Callback functions can be completed:

- Before IRIS Performer calculates the parameters, thus replacing the Performer calculation completely.
- After IRIS Performer calculates the parameters, thus modifying Performer's result.

You enable, disable, and specify the kind of callback used in the following method:

```
pfLPStateMode(lpstate, PFLPS_CALLBACK_MODE, mode)
```

The *mode* value can be:

- PFLPS_CALLBACK_MODE_OFF, the default, means that no callback is attached to *lpstate*
- PFLPS_CALLBACK_MODE_PRE, means that the callback is executed before IRIS Performer has calculated the parameters. Your callback function must compute the size and alpha values for all the light points in the pfGeoSet.
- PFLPS_CALLBACK_MODE_POST, means that the callback is executed after IRIS Performer's computation.

To install a callback on a `pfLPointState` use the following method:

```
pfRasterFunc(lpstate, (void *) yourCallback(pfRasterData*),
             void **userData);
```

userdata is a pointer to the following structure, which is given to your callback and the function itself:

```
typedef struct {
    pfLPointState *lpstate; /* Read Only LPState */
    pfGeoSet *geoset; /* Read Only GeoSet */
    void *userData; /* Provided when setting the callback */
    float *sizes; /* Write Only - resulting sizes */
    float *alphas; /* Write Only - resulting alphas */
} pfRasterData;
```

geoset is the currently-processed `pfGeoSet`. *lpstate* is the `pfLPointState` applied to that `pfGeoSet`. *userData* is the same data provided when declaring the callback.

sizes and *alphas* are pre-allocated arrays that contain the callback function results used by the DRAW process. If you use a pre-callback, you must provide a size and an alpha value for every light point in the `pfGeoSet`. A negative alpha value indicates that the backcolor must be used in place of the light point color.

Example 16-1 provides the skeleton of a raster callback. A more detailed example is on the `pfLPointState` man page.

Example 16-1 Raster Callback Skeleton

```
void myCallback(pfRasterData *rasterData)
{
    pfVec3* vertices;
    unsigned short *vindex;
    pfVec3* norms;
    unsigned short *nindex;
    int nbind;
    pfFog *fog;
    int fogEnabled = 0;
    int i,n;
    int sizeMode;
    pfMatrix ViewMat, InvModelView;

    /* get pointers to the geoset */
    pfGetGSetAttrLists(rasterData->gset,PF3D_COORD3, &vertices, &vindex);
    pfGetGSetAttrLists(rasterData->gset,PF3D_NORMAL3, &norms, &nindex);
```

```
nbind = pfGetGSetAttrBind(rasterData->gset, PFGS_NORMAL3);
/* get matrices */
pfGetViewMat(ViewMat);
pfGetInvModelMat(InvModelMat);

/* get the number of lights */
n = pfGetGSetNumPrims(rasterData->gset);

/* see if there's fog */
fog = pfGetCurFog();
if (pfGetEnable(PFEN_FOG) && fog)
    fogEnabled = 1;

/* get information on the lpstate */
sizeMode = pfGetLPStateMode(rasterData->lpstate, PFLPS_SIZE_MODE);
.....
.....
/* do the computation */
for (i=0; i<n; i++)
{
    /* get the normal */
    if (vindex)
    {
        if (nbind & PFGS_OVERALL)
            nj=nindex[0];
        else if (nbind)
            nj=nindex[i];
        else
            nj=-1; /* this geoset has no normals */

        .....
        rasterData->alphas[i] = ....
        rasterData->sizes[i] = ....
    }
}
```

Multisample, Size, and Alpha

On Infinite Reality, light points of a given size, up to 100 multisamples, have the same number of multisamples, even when the light points cross multiple pixels.

The intensity of a light point is defined by its alpha value. If `pfTransparency` is set to `PFTR_MS_ALPHA_MASK`, the alpha value modifies the number of multisamples lit in a light point. For example, if `alpha = 0.5`, `size = 1.0`, and the number of multisamples per pixel is 8, the number of illuminated multisamples per the light point is 3.0, as shown in Figure 16-4.

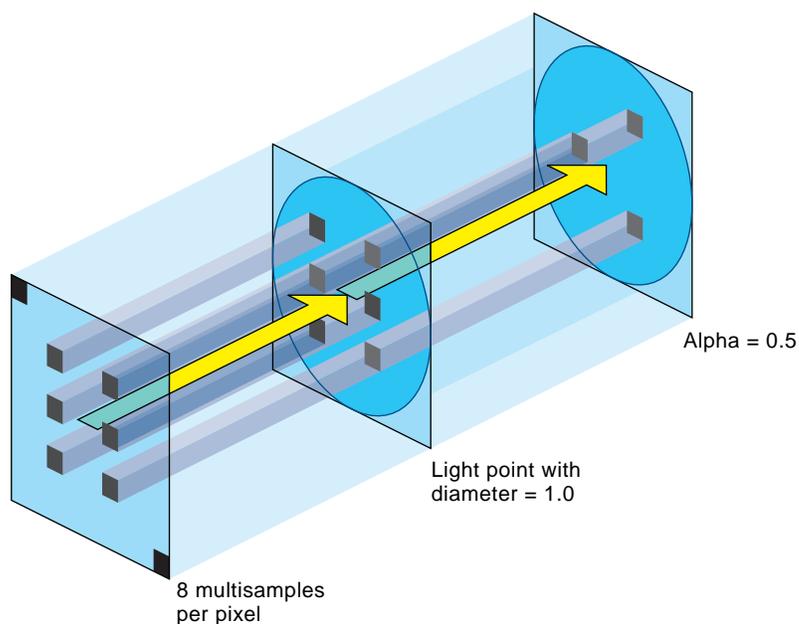


Figure 16-4 Lit Multisamples

The area of a circle with diameter 1.0 is 0.785. The number of multisamples per pixel is given in the frame buffer configuration. If there are 8 multisamples, only 0.785 of them, about 6, are in the light point. Since `alpha = 0.5`, only half of the 6 multisamples are actually lit.

`pfCalligMultisample()` tells `pfCalligraphic` how many multisamples are used in the specified video channel. `pfGetCalligMultisample()` returns the current setting. Make this call as soon as the information is known or changed.

Minimum Number of Multisamples

If your light points move, you must have at least two multisamples lit per light point; if you only have one, the light point is either on or off. This condition creates flicker. With two multisamples, the light point can transition to a different location with one multisample on and the other off.

Reducing CPU Processing Using Textures

Light point computations are expensive. You can replace some of the computation by using a table lookup mechanism and the texture hardware to get an alpha value for each light point. This mechanism uses a precomputed texture and `glTexGen` to approximate:

- Fog attenuation.
- Fading over distance.
- Falloff attenuation when the eye point is not on the normal.

Because only one texture per polygon is supported by the hardware, it is not possible to approximate all three computations at once. The fading and the fog are combined in one texture, however, so it is possible to select both at the same time.

The following methods specify the attenuations:

```
pFLPStateMode(lpstate, PFLPS_DIR_MODE, PFLPS_DIR_MODE_XXX)
pFLPStateMode(lpstate, PFLPS_TRANSP_MODE, PFLPS_TRANSP_MODE_XXX)
pFLPStateMode(lpstate, PFLPS_FOG_MODE, PFLPS_MODE_XXX)
```

XXX is either:

- TEX, for texture lookup.
- ALPHA, for CPU computation.

Default values are equivalent to ALPHA computation.

Tip: Falloff is the most expensive effect to compute on the CPU. For that reason, it is better to use `PFLPS_DIR_MODE_TEX` if the point is not omnidirectional.

Only use textures for low quality light points; textures are approximations with numerous limitations, including incorrect falloff attenuation if the emanation is not symmetric, and incompatibility with callbacks.

Preprocessing Light Points

To optimize your application, you should fork off a light point process to preprocesses your light point computations. The light point process runs in parallel with the DRAW process but on a different CPU. Preprocessing the light points:

- Computes the size and alpha of each light point and passes the result directly to the DRAW process.
- Executes callbacks attached to the `pfLPointState`.

To fork off a light point process, use the `PFMP_FORK_LPOINT` token in `pfMultiprocess()` and call it before `pfConfig()`.

Note: You can start a light point process in *perfly* using the `-m` option and adding 16 to your preferred multiprocess model.

Stage Configuration Callbacks

As with any other IRIS Performer process, callback functions can configure the process stages using:

```
pfStageConfigFunc(-1, PFPROC_LPOINT, ConfigLPoint);
pfConfigStage(-1, PFPROC_LPOINT | PFPROC_XXX ...);
pfChanTravFunc(chan, PFTRAV_LPOINT, LpointFunc);
```

`pfStageConfigFunc()` specifies a callback function, and `pfConfigStage()` triggers it at the start of the current application frame; both are methods in `pfConfig`. Configuration callbacks are typically used for process initialization, for example:

- Assigning non-degrading priorities and locking processes to CPUs.
- Downloading textures in the DRAW stage callback.

`pfStageConfigFunc()` identifies the IRIS Performer stages, such as `PFPROC_ISECT`, `PFPROC_APP`, and `PFPROC_DBASE`, to configure.

`pfChanTravFunc`

The `pfChannel` method, `pfChanTravFunc()`, sets a callback function for either the APP, CULL, DRAW, or Light Point process using one of the following tokens: `PFTRAV_APP`, `PFTRAV_CULL`, `PFTRAV_DRAW` or `PFTRAV_LPOINT`, respectively.

User-data that is passed to these functions by `pfChanData()` is allocated on a per-channel basis by `pfAllocChanData()`.

How the Light Point Process Works

This section explains how the light point process works. All the functions exist in the API, however, all of the processing is done automatically by IRIS Performer.

Note: Light point processing is not done automatically if your application is only using the `libpr` process model.

If the light point process is enabled, a special bin, `PFSORT_LPSTATE_BIN`, is created to sort all of the `pfGeoSets` that have a `pfLPointState` attached to their `pfGeoState`. This bin is directly used as a display list, *LPointBinDL*, as shown in Example 16-2.

All bins, except `PFSORT_LPSTATE_BIN`, are handed to the DRAW process. The DRAW process, after rendering everything in the other bins, renders a ring display list, called *DrawRingDL*, as shown in Example 16-2. The ring display list contains a synchronization mechanism: the DRAW process waits until it sees the `PFDL_END_OF_FRAME` token.

Example 16-2 Preprocessing a Display List - Light Point Process code

```
/* open the draw ring display list */
pfOpenDList(DrawRingDL);

/* preprocess the light points bin. */
/* so the results go in the DrawRingFL */
pfPreprocessDList(LPointBinDL, PFDL_PREPROCESS_LPSTATE);

/* Signal the end of the list to the Draw process */
pfAddDListCmd(PFDL_END_OF_FRAME);

/* close the draw display list */
pfCloseDList(DrawRingDL);
```

Calligraphic Light Points

Calligraphic light points are very bright lights that can be displayed only on specially-equipped display systems. Displaying calligraphic light points requires

- A calligraphic light point board (LPB) with a special device driver. The driver is not part of the IRIS Performer distribution.
- A calligraphic display system.
- Special cables running between the graphics pipe video synchronization and the raster manager (RM) boards on the LPB.
- A platform, such as an InfiniteReality, OnyxIR, or Onyx2, that has a visibility (VISI) bus.

Note: If you are not running on a system that has a VISI bus, or you do not have this optional hardware, you are limited to raster light points, as supported by `pFLPointState`. The functionality described in the remainder of this chapter is not available on your system. Nevertheless, a program and database designed for calligraphic light points can be simulated on a non-calligraphic system.

Unlike raster displays, calligraphic displays direct the display system's electron beam at specified places on the screen. By directing the beam at specified places for specified durations, it is possible to produce extremely bright light sources.

Warning: It is possible to destroy your display system by allowing the electron beam to remain too long on the same screen location either by allotting too long a time or by an application hanging. Extreme caution is required.

Calligraphic Versus Raster Displays

Table 16-1 summarizes the differences between raster and calligraphic displays.

Table 16-1 Raster Versus Calligraphic Displays

Raster	Calligraphic
Requires no special hardware.	Requires special hardware, including a Light Point Board (LPB), cables, and a calligraphic-enabled display system. Applications using calligraphic light points must run on a machine that has a VISI board.
The electron beam sweeps across and down the screen left-to-right and top-to-bottom.	The beam lands only on those parts of the screen where calligraphic lights are located.
The electron beam stays on each pixel the same amount of time.	The electron beams stays on pixels for a variable length of time potentially producing exceedingly bright light sources.
A black dot produces a black pixel.	A black dot produces nothing; it is invisible.
if more than one point is drawn at the same location, only the last point drawn is visible.	Light points are added to whatever light is already falling on the pixel. A calligraphic light does not hide another calligraphic light.
Raster images are displayed within set time intervals, for example, 60 times a second.	When raster and calligraphic are displayed, the calligraphic light points are displayed in whatever time is left after the raster image is scanned. For more information, see "Display Modes" on page 517.
No real dangers associated with raster displays.	A hanging application, for example, can leave the electron beam aimed at a single point on the screen and quickly burn it out. The same result is true if you programmatically light up a pixel for too long.
If the entire image is not drawn to the buffer, frames are dropped until the entire image is ready for display.	If all of the light points are not drawn, frames are not dropped, some light points are just not drawn. (If a raster image is repeated in successive frames, the light points are also repeated.)

Whenever the calligraphic mode renders a black pixel to the screen, it is completely transparent and the raster image shows through.

When a pixel on the screen is targeted for raster and calligraphic light, both the raster and calligraphic light points are displayed at the same pixel thus making it large (raster) and bright (calligraphic).

Display Modes

A calligraphic display system can run in three modes:

- Calligraphic-only
- Mixed mode
- Raster only

In calligraphic-only mode, only calligraphic points can be rendered by the display system.

In mixed mode, both raster and calligraphic images are rendered on the same display system; the raster image is displayed first and the calligraphic image is displayed in whatever time remains before the vertical sync. This mode requires a special video format used by the Video Format Compiler available on the SGI web site at <http://www.sgi.com/Products/software/vfc/>.

You can combine a calligraphic-only display with a raster-only display on the same video channel; the effect is to give the full frame to the calligraphic display so that you can render the maximum number of light points. It is also more expensive and sometimes not convenient for mechanical reasons.

Light point modes are specified by **pflpStateMode()** and one of the following tokens:

- **PFLPS_DRAW_MODE_RASTER**, the default mode, forces the light points to be raster, even if the system has a calligraphic display.
- **PFLPS_DRAW_MODE_CALLIGRAPHIC**, enables the rendering of calligraphic light points on calligraphic display systems.

Maximum Number of Calligraphic Lights

The maximum number of calligraphic lights that can be displayed is related to:

- Raster display time.
- Duration of the calligraphic display time.
- Time spent jumping from one calligraphic light point to another.

The maximum number of calligraphic lights that can be displayed is inversely proportional to the raster display time. For example, in a mixed mode, if the screen refreshes every 1/60th of a second, the calligraphic display time is 1/60th of a second minus the time it takes for the raster mode to draw its image on the screen. The shorter the raster display time, the more calligraphic lights that can be displayed.

At night, it is possible to reduce the time for the raster display, which has the effect of reducing the global raster brightness. Reducing the raster display time increases the maximum number of calligraphic light points that can be displayed. To reduce the raster display time, you need:

- Two different video formats made using the Video Format Compiler.
- Preprogram the projector so it recognizes the format change when it happens on the fly by the application.

Changing the video format is done using the XSGIvc extension.

The maximum number of calligraphic lights that can be displayed is inversely proportional to the draw time of the calligraphic light points. Unlike raster lights, you can control the length of time the electron beam hits a specified location on the display system; the longer the duration, the brighter the light. Also, the longer the duration, the less time is left for drawing other calligraphic light points.

Finally, the time it takes the electron beam to jump between calligraphic light points also adversely affects the maximum number of light points that can be displayed; the more time spent jumping between calligraphic light points, the fewer light points that can be displayed.

LPB Hardware Configuration

A Light Point Board (LPB) is a circuitry card that enables the rendering of calligraphic lights by providing the interface with a calligraphic display. The LPB is:

- Connected to one graphics pipeline only.
- Connected to all the video channels produced by a single pipe.
- Connected to all (1,2 or 4) raster manager (RM) boards of its pipe.

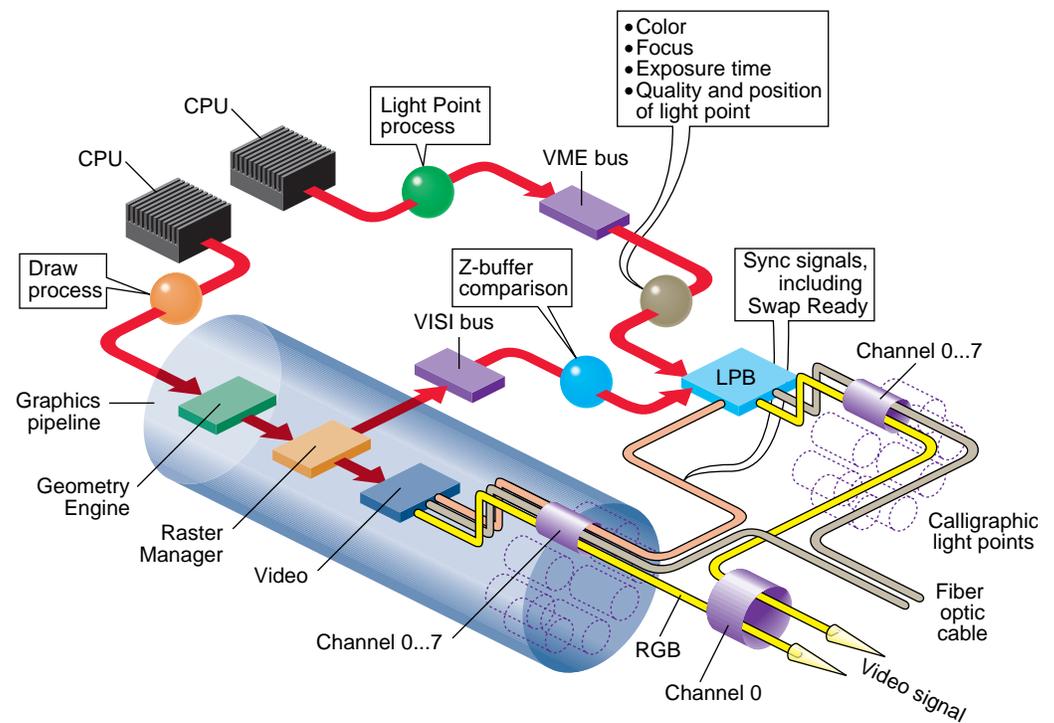


Figure 16-5 Calligraphic Hardware Configuration

That configuration shows that:

- A CPU is used for the light point process so the computation and the communication to the LPB through the VME bus are done in parallel to the DRAW Process. It is mandatory to start a light point process for calligraphic, see “Preprocessing Light Points” on page 513.
- The VME bus transfers to the LPB all of the calligraphic light point information, including the color, focus, exposure time, quality, and position of each calligraphic light point. The only information not transferred by the VME bus is occlusion information, which is supplied by the VISI bus.
- The VISI (visibility) bus specifies whether all, part, or none of a calligraphic light point is displayed. A calligraphic light might be partially displayed, or not at all, if a geometry in the scene is between the light point and the viewer. Each light point has a unique ID; this ID is used to match the information in the VISI bus with the correct light point.

The VISI bus is a connector on each RM board. The Visibility information is available only to the LPB.

Note: The LPB board may be used in a system without a VISI bus (systems prior to InfiniteReality), in which case no Z-buffer information is given to the board, so all light points are 100% visible.

- The LPB uses the vertical and horizontal (not the composite) synchronization signals to trigger the calligraphics display. Use *ircombine* to set the Hsync in place of the composite sync.
- The LPB receives the Swap Ready signal when the raster display has completed drawing to the display buffer so it should also swap it's internal buffers.

If the LPB does not get a Swap Ready signal, the LPB redisplay the same calligraphic light points; since the raster frame is repeated, the calligraphic lights must remain unchanged. Do not forget to connect the SwapReady signal to the light point board, even if you are using a single pipe configuration.

- The LPB receives the VISI and VME bus light point information and combines it and send the result to the calligraphic display.

Visibility Information

All the calligraphic light point information is computed by the light point process and goes directly to the LPB. The only missing information is knowing how much of each light point can be seen. To compute that value:

1. A footprint of the calligraphic light point is sent to the graphic pipe.
2. The footprint is compared against the Z-buffer.
3. The result of the test is sent to the LPB using the VISI bus.

The graphic pipe takes great care that the number of multisamples covered is a constant wherever the light point is. The number of multisamples is not constant after the footprint covers more than 100 multisamples, however. A footprint can cover numerous pixels, but is limited to 256 multisamples by the LPB.

pfCalligZFootPrintSize() sets the diameter of the footprint, **pfGetCalligZFootPrintSize()** returns the diameter. The number of multisamples covered by a footprint is equal to:

$$(n \times \text{size}^2) / (4 \times \text{ms})$$

ms is the number of multisamples per pixel.

Required Steps For Using Calligraphic Lights

To use calligraphic light points, you have to configure the channels on the LPB board and the corresponding channels using *ircombine*. *ircombine* operates on:

- Video format combinations.
- Descriptions of raster sizes and timings used on video outputs.
- Configuration of the underlying frame buffer.

You must also enable the channels on the LPB board before starting the application.

IRIS Performer does not provide direct access to the LPB drivers. You can, however, write a program that does.

Now, in IRIS Performer a few steps are still necessary.

1. Check and open the LPB on each pipe, as follows:

```
pfQueryFeature(PFQFTR_CALLIGRAPHIC, &q)
pfCalligInitBoard(pipe)
```

2. Start a light point process to process the light point calculations, as follows:

```
pfMultiprocess(PFMP_APP_CULL_DRAW | PFMP_FORK_LPOINT);
pfConfig();
```

3. Initialize the IRIS Performer stages, as follows:

```
pfStageConfigFunc(-1, PPROC_LPOINT, ConfigLPoint)
pfFrame();
```

4. Set the callback function in the light point process, as follows:

```
pfChanTravFunc(chan, PFTRAV_LPOINT, LpointFunc);
```

5. Enable the calligraphic display on all of the channels, as follows:

```
pfChanCalligEnable(chan[i], 1);
```

6. Synchronize the VME and VISI bus signals on the LPB, as follows:

```
pfCalligSwapVME(pipe);
pfCalligSwapVME(pipe);
```

You now have calligraphic light points in your application if you have calligraphic light points in your database.

Customizing LPB Initialization

Instead of using the default initialization, IRIS Performer provides a set of functions that allow your application to customize the initialization of the LPB.

pfInitBoard() opens the LPB device and retrieves the current configuration. This function returns TRUE if successful, FALSE otherwise. You can also use **pfIsBoardInit()** to determine if the board has been initialized. Each LPB must be initialized before calling **pfConfig()**.

pfCalligCloseBoard() closes the device.

Note: The board number and the pipe number are the same because there is only one board per pipe.

To access to the LPB directly, return its ID using **pfGetCalligDeviceID()**. The ID allows you to make direct calls to the LPB driver.

pfGetCalligInfo() returns a pointer to the configuration information structure maintained by the LPB driver. To use this structure, *LPB_info*, you must include the driver *lpb.h* file before any IRIS Performer include files.

Note: *lpb.h* is not distributed with IRIS Performer; it is part of the LPB driver distribution.

Once a board is initialized, you can find out how much memory is available and divide it up between all of the enabled channels on the pipe. You can return the total amount of LPB memory in bytes by calling **pfGetCalligBoardMemSize()**.

By default, each channel receives the same amount of memory. To set up a different partitioning of memory, use **pfCalligPartition()**.

You can attach a **pfCalligraphic** to a specific **pfChannel** using the following code:

```
pfCalligraphic *callig = pfNewCallig(arena)
pfCalligChannel(callig, pipe, chan)
```

callig can then be attached to the **pfPipeVideoChannel** using **pfPVChanCallig()**.

You can also set the **pfCalligraphic** on individual **pfChannels** using **pfChanCallig()**. You must enable calligraphic light point processing on the specified channels so the **GangSwap** mechanism is correctly handled by IRIS Performer, as follows:

```
pfChanCalligEnable(chan, 1);
```

Note: The video channel number does not have to be the same channel number as the calligraphic board.

pfCalligWin() changes the resolution of the X and Y data accepted by the projector. The default values are for an EIS projector (2^{16}). If you have a conversion interface between the LPB and your projector, the scaling may already be done by the conversion interface. You can use **pfCalligWin()** to display calligraphic points on only part of the screen, or to make multiple viewports.

pfCalligXYSwap() switches the X and Y axes in the display. You can also reverse the X or Y axes by giving negative width and height values in **pfCalligWin()**.

Accounting for Projector Differences

Some display systems, such as the EIS projector, can calculate:

- Slew values, the time for the electron beam to go from one calligraphic point to another.
- Gamma correction, which takes into account that projectors differ in the colors they project.

If your system cannot perform those calculations, the light point board can calculate those values for your application.

Slew Values

A slew table is two dimensional; it gives the time, in nanoseconds, it takes the electron beam to go from one calligraphic point to another on one axis. A default, generic slew table, which contains conservative values, is loaded in the LPB when it is initialized.

The longer the slew time, the longer the electron beam has to reach a calligraphic light point on the display; any consequent wobble can dampen out in that time providing a very stable light point. Conversely, longer slew times subtract from the total time in which calligraphic light points can be drawn. Consequently, longer slew times could mean that fewer calligraphic points are drawn per frame.

There are eight slew tables defined by the `pfCalligSlewTableEnum`. For each axis, there are three slew tables: one table for high-quality (very stable) light points, one table for medium-quality (slightly shorter slew times) light points, and another for low-quality (very short slew times) light points.

You specify the drawing quality using `pfLPStateVal()` with one of the following mode values:

- `PFLPS_QUALITY_MODE_HIGH`
- `PFLPS_QUALITY_MODE_MEDIUM`
- `PFLPS_QUALITY_MODE_LOW`

Two other tables are used when the defocus value changes in between two points; one table is used for high-quality light points, another table for medium- and low-quality light points.

```
typedef enum {
    pfXSlewQuality0 = 0, /* High quality on the X axis */
    pfXSlewQuality1 = 1, /* Medium quality on the X axis */
    pfXSlewQuality2 = 2, /* Low quality on the X axis */
    pfYSlewQuality0 = 3, /* High quality on the Y axis */
    pfYSlewQuality1 = 4, /* Medium quality on the Y axis */
    pfYSlewQuality2 = 5, /* Low quality on the Y axis */
    pfDefocusQuality0 = 6, /* High quality if focus change */
    pfDefocusQuality1 = 7 /* Medium and Low quality if focus change */
} pfCalligSlewTableEnum;
```

To load or upload customized slew tables, use the following methods:

- **pfCalligDownloadSlewTable()**; downloads a specified slew table into the LPB.
- **pfCalligUploadSlewTable()**; returns a slew table.

Color Correction

Each projector has its own color characteristics; a light point that appears blue on one projector might appear aqua on another. To color correct the projected images, the light point board maintains one gamma table per channel. Each gamma table consists of three one-dimensional tables, one for each color component.

```
typedef enum {
    pfRedGammaTable = 0,
    pfGreenGammaTable = 1,
    pfBlueGammaTable = 2
} pfCalligGammaTableEnum;
```

The default value provided by IRIS Performer is a linear ramp that can be modified with the following methods:

- **pfCalligDownloadGammaTable()** downloads a specified gamma table into the LPB.
- **pfCalligUploadGammaTable()** returns a gamma table.

Callbacks

Like raster lights, calligraphic light points can have a callback function attached to the `pfLPointState` that can occur before (PRE) or after (POST) the light point processing. The calligraphic and raster callback functions compute different parameters.

If the stress test determines that a calligraphic light point is not going to be drawn as a raster light point, the calligraphic callback is not be call; the raster callback is called instead if set. For more information about the stress test, see “Significance” on page 528.

To install a Calligraphic callback on a `pfLPointState` you use a line of code similar to the following:

```
pfCalligFunc(lpstate, (void *) yourCallback(pfCalligData*),
             void **userData);
```

`userData` is a user pointer given to your callback identifying the callback function and the following structure:

```
typedef struct {
    pfLPointState *lpstate; /* Read Only LPState */
    pfGeoSet *geoset; /* Read Only GeoSet */
    void *userData; /* Provided when setting the callback */
    unsigned short *index; /* Read Write - index visible lpoints */
    int *n; /* Read Write - # of visible lpoints */
    pfVec3 *coords2D; /* Read Write - screen space X,Y,Z */
    float *intensity; /* Write Only - resulting intensity */
    float **focus; /* Write Only - optional (de)focus */
    float **drawTime; /* Write Only - optional drawTime */
} pfCalligData;
} pfRasterData;
```

`geoset` is the `pfGeoSet` that is currently preprocessed. `lpstate` is the `pfLPointState` applied to that `pfGeoSet`. `userData` is the same as the data provided when declaring the callback.

`index` is a preallocated vector that points to light points that are visible. Even in a PRE callback the light points are projected on the screen before the user callback is called; the points outside of the screen are not in the index vector. See the man page on how to use the index vector in a Callback.

`n` is a pointer to the number of elements in the `index` vector.

`coords2D` contains the coordinates of the light points on the screen, including the Z coordinates in screen space. The original coordinates can be accessed through the

`pfGeoSet`. It is legal to change the values in `coord2D` in the callback, for example, to align the points on a grid.

`intensity` is a pre-allocated vector that contains the intensity of individual light points. A PRE callback must compute `intensity`.

`focus` is a NULL pointer. It is possible to provide an individual `focus` value for each point by:

1. Allocating from the arena an array of floats of size n .
2. Filling the array with the focus values.
3. Setting focus to point to that array.

You should not allocate an array in real-time; instead, allocate temporary memory beforehand and use `userData` to pass the memory address to the callback.

`drawTime` is a NULL pointer. With it you can provide an array of floats that give a draw time for each light point.

Frame to Frame Control

Before calling `pfLPoint()` in the light point process callback function, you can change the parameters in a `pfCalligraphic` object on a frame by frame basis, as shown in Example 16-3.

Example 16-3 Setting pfCalligraphic Parameters

```
myLPointFunc(pfChannel *chan, void *data)
{
    pfCalligraphic *calligraphic = pfGetCurCallig();

    if (calligraphic != NULL)
    {
        pfCalligFilterSize(calligraphic, FilterSizeX, FilterSizeY);
        pfCalligDefocus(calligraphic, Defocus);
        pfCalligRasterDefocus(calligraphic, rasterDefocus);
        pfCalligDrawTime(calligraphic, DrawTime);
        pfCalligStress(calligraphic, Stress)
    }
    pfLPoint();
}
```

FilterSizeX and *FilterSizeY* set the debunching distances along each axis. A filter size of 0 disables the debunching along that axis. Debunching can also be disabled on the `pfLPointState`. For more information about debunching, see “Debunching” on page 529.

Defocus sets the defocus applied to all calligraphic light points, unless a callback function returns a defocus array. In that case, each light point has a callback defocus value regardless of the one set on the `pfCalligraphic` object.

In a raster plus calligraphic video mode, a calligraphic system usually has the capability to apply a global defocus to the raster image, which is specified by the *rasterDefocus* parameter passed to the projector. This parameter affects the entire image, not just the raster light points.

For more information about defocus, see “Defocussing Calligraphic Objects” on page 529.

DrawTime is the time, in nano seconds, in which all calligraphic light points must be drawn, unless a callback returns a drawTime array, which controls individual draw times. The overall effect of changing the draw time is to reduce or increase the intensity of all calligraphic light points.

The *Stress* value is compared against the *significance* value of a `pfLPointState` to determine whether the light points are displayed as calligraphic or raster. The *Stress* value should be as stable as possible to avoid having points going from raster to calligraphic or from calligraphic to raster each frame. For more information about stress, see “Significance” on page 528.

Significance

If there is not enough time to draw all of the calligraphic light points, some calligraphic light points can either not be drawn or, instead, drawn as raster light points, depending on the stress value of the calligraphic light point, described in “Frame to Frame Control” on page 527, and the *significance* value of the `pfLPointState`.

The stress value of a calligraphic light point is compared against the *significance* value of the `pfLPointState`. If the *significance* is greater or equal than the stress, the light is rendered as a calligraphic, otherwise the light is rendered as a raster light.

To set the significance, use `pfLPStateVal(lpstate, PFLPS_SIGNIFICANCE, significance)`.

Debunching

Debunching eliminates some calligraphic points when they occur close together on the display system. Bunched calligraphic light points can create a heap effect, or worse, burn the display system where there is a group of calligraphic light points.

The debunching distances are set in pfCalligraphic on the X and Y axis, as described in “Frame to Frame Control” on page 527.

If two points in a pfGeoSet are within the debunching distance, the point with the lowest intensity is not rendered.

If you do not want a pfLPState to be affected by debunching, you can disable it using **pfLPStateMode()** with the PFLPS_DEBUNCHING_MODE_OFF mode; PFLPS_DEBUNCHING_MODE_ON, the default, enables debunching.

Defocussing Calligraphic Objects

Defocussing a calligraphic light point is often done to produce a specific lighting effect, for example, to simulate rainy conditions, light points should appear defocussed. The defocus is set within pfCalligraphic (see “Frame to Frame Control” on page 527) for all light points for one Frame, but it is possible to clamp the defocussing values by setting a *min_defocus* and a *max_defocus* value in the pfLPState using the following methods:

```
pfLPStateVal(lpstate, PFLPS_MIN_DEFOCUS, min_defocus);
pfLPStateVal(lpstate, PFLPS_MAX_DEFOCUS, max_defocus);
```

Using pfCalligraphic Without pfChannel

pfCalligraphic is a libpr object, so programs based only on libpr can have access to pfCalligraphic without having access to a pfChannel, which is a libpf object. This section describes what pfChannel does automatically with pfCalligraphic objects.

The LPB is connected to the VME bus and the VISI bus. Both buses contain information for calligraphic light points buffered in the LPB. VISI and VME busses load their information into the LPB buffer. The SwapReady connection to the graphic pipe synchronizes the activity on the VISI bus; SwapReady tells the board when **glXSwapBuffers()** is called, and that at the next VSync, the next frame should be displayed.

pfCalligSwapVME() performs the same synchronization for the VME bus; whenever you call **pfSwapPWinBuffers()** you must first call **pfCalligraphicSwapVME()**, otherwise the light point board will not be synchronized with the rest of the system.

Tip: To resynchronize the LPB, make two consecutive calls to **pfCalligSwapVME()**, for example, *perfly* makes these calls after the IRIS Performer logo has been displayed.

Note: These synchronization mechanisms are handled automatically in libpf, unless you override the channel swap buffer and call **pfSwapPWinBuffers()**.

Timing Issues

The SwapReady signal should always occur after a VME Swap signal. If this does not happen, the light point board starts a TooLate timer and two things may happen:

- The LPB starts to draw the buffer assuming the VME Swap signal has been lost. In this instance, not all of the calligraphic lights are rendered. **pfCalligraphic** handles this exception by making sure the LPB buffer always contains an end-of-buffer token at the end of the valid data.
- The VME Swap signal is received shortly after the Swap Ready, making the LPB behave normally.

The LPB needs some time before it can accept new information from the VME, and the VISI bus needs some time after it has received the corresponding swap command. **pfWaitForVmeBus()** and **pfWaitForVisiBus()** allow the application to wait for the board to get ready before sending it new information.

Light Point Process and Calligraphic

The light point process is the same whether the light points are raster or calligraphic. The only difference is that, with calligraphic light points, **pfCalligraphic** has to be selected before calling **pfPreprocessDList**, which is done automatically by **pfChannel**.

pfSelectCalligraphic() selects the channel and LPB board to which the calligraphic light points are sent. **pfGetCurCalligraphic()** returns the current value set by **pfSelectCalligraphic()**.

Debugging Calligraphic Lights on Non-Calligraphic Systems

If you are developing on a non-calligraphics-enabled system but would like to see the effects of your pfCalligraphics programming, you can set the environment variable, *PF_LPOINT_BOARD*. In this mode, the LPB is simulated, the calligraphic computations are performed, and raster light points are displayed in place of the calligraphic lights with the following limitations:

- Calligraphic defocus has no effect.
- A calligraphic light point size is defined with the Z-footprint.

Calligraphic Light Example

Example 16-4 shows a sample implementation of calligraphic lights. You can find the source code in *perf/sample/pguide/libpf/C/callig.c*.

Example 16-4 Calligraphic Lights

```
#include <stdlib.h>
#include <Performer/pf.h>
#include <Performer/pfutil.h>
#include <Performer/pfdu.h>

static NumScreens=1;
static NumPipes=1;

static void ConfigPipeDraw(int pipe, uint stage);
static void OpenPipeWin(pfPipeWindow *pw);
static void OpenXWin(pfPipeWindow *pw);
static void DrawChannel(pfChannel *chan, void *data);

/*
 * Usage() -- print usage advice and exit. This
 * procedure is executed in the application process.
 */
static void
Usage (void)
{
    pfNotify(PFNFY_FATAL, PFNFY_USAGE, "Usage: multipipe file.ext
    ...\n");
}
```

```
        exit(1);
    }
    int
    main (int argc, char *argv[])
    {
        float        t = 0.0f;
        pfScene      *scene;
        pfPipe       *pipe[4];
        pfChannel    *chan[4];
        pfNode root;
        pfSphere sphere;
        int loop;

        /* Initialize Performer */
        pfInit();
        pfuInitUtil();

        /* specify the number of pfPipes */
        /* Configure and open GL windows */
        if ((NumScreens = ScreenCount(pfGetCurWSConnection())) > 1)
        {
            NumPipes = NumScreens;
        }

        pfMultipipe (NumPipes);

        /* Initialize Calligraphic HW */
        for (loop=0; loop < NumPipes; loop++)
        {
            int q;
            pfQueryFeature(PFQFTR_CALLIGRAPHIC, &q);
            if (!q)
            {
                pfNotify(PFNFY_NOTICE, PFNFY_RESOURCE, "Calligraphic points
are NOT supported on this platform");
            }

            if (pfCalligInitBoard(loop) == TRUE)
            {
                /* get the memory size */
                pfNotify(PFNFY_NOTICE, PFNFY_RESOURCE, "StartCalligraphic:
board(%d) has %d Bytes of memory", 0, pfGetCalligBoardMemSize(loop));
            }
            else
            {
```

```
        pfNotify(PFNFY_NOTICE, PFNFY_RESOURCE, "Could not init
calligraphic board %d", loop);
    }
}

/* Force Multiprocessor mode to use the light point process */
pfMultiprocess(PFMP_APP_CULL_DRAW | PFMP_FORK_LPOINT);

/* Load all loader DSO's before pfConfig() forks */
if (argc > 1)
    pfdInitConverter(argv[1]);

/* Configure multiprocessing mode and start parallel processes.*/

pfConfig();
/* Append to PFPATH additional standard directories where geometry
and textures exist */

scene = pfNewScene();
if (argc > 1)
{
    if (!(getenv("PFPATH")))
pfFilePath("../data:../data:../data:/usr/share/Performer/data");

    /* Read a single file, of any known type. */
    if ((root = pfdLoadFile(argv[1])) == NULL)
    {
        pfExit();
        exit(-1);
    }

    /* Attach loaded file to a pfScene. */
    pfAddChild(scene, root);

    /* determine extent of scene's geometry */
    pfGetNodeBSphere (scene, &bsphere);
    /* Create a pfLightSource and attach it to scene. */
    pfAddChild(scene, pfNewLSource());
}

for (loop=0; loop < NumPipes; loop++)

pfPipeWindow *pw;
```

```
char str[PF_MAXSTRING];

pipe[loop] = pfGetPipe(loop);
pfPipeScreen(pipe[loop], loop);
pw = pfNewPWin(pipe[loop]);
pfPWinType(pw, PFPWIN_TYPE_X);
sprintf(str, "IRIS Performer - Pipe %d", loop);
pfPWinName(pw, str);
if (NumScreens > 1)
{
    pfPWinOriginSize(pw, 0, 0, 300, 300);
} else
    pfPWinOriginSize(pw, (loop&0x1)*315, ((loop&0x2)>>1)*340, 300,
300);

    pfPWinConfigFunc(pw, OpenPipeWin);
    pfConfigPWin(pw);

}

/* set up optional DRAW pipe stage config callback */
pfStageConfigFunc(-1 /* selects all pipes */, PFPROC_DRAW /* stage
bitmask */, ConfigPipeDraw);
pfConfigStage(-1, PFPROC_DRAW);

pfFrame();

/* Create and configure pfChannels - by default, channels are
placed in the first window on their pipe */

for (loop=0; loop < NumPipes; loop++)
{
    chan[loop] = pfNewChan(pipe[loop]);
    pfChanScene(chan[loop], scene);
    pfChanFOV(chan[loop], 45.0f, 0.0f);
    pfChanTravFunc(chan[loop], PFTRAV_DRAW, DrawChannel);
    pfChanCalligEnable(chan[loop], 1);
    /* synchronize the lpoint board with the swap ready signal */
    pfCalligSwapVME(loop);
    pfCalligSwapVME(loop);
}

/* Simulate for twenty seconds. */
while (t < 30.0f)
```

```

    {
        pfCoord view;
        float      s, c;

        /* Go to sleep until next frame time. */
        pfSync();
        /* Initiate cull/draw for this frame. */
        pfFrame();

        pfSinCos(45.0f*t, &s, &c);
        pfSetVec3(view.hpr, 45.0f*t, -10.0f, 0);
        pfSetVec3(view.xyz, 2.0f * bsphere.radius * s, -2.0f *
        bsphere.radius * c, 0.5f * bsphere.radius);
        for (loop=0; loop < NumPipes; loop++)
            pfChanView(chan[loop], view.xyz, view.hpr);
    }

    /* Terminate parallel processes and exit. */
    pfExit();
    return 0;
}

/* ConfigPipeDraw() --
 * Application state for the draw process can be initialized
 * here. This is also a good place to do real-time
 * configuration for the drawing process, if there is one.
 * There is no graphics state or pfState at this point so no
 * rendering calls or pfApply*() calls can be made.
 */

static void
ConfigPipeDraw(int pipe, uint stage)
{
    pfPipe *p = pfGetPipe(pipe);
    int x, y;

    pfNotify(PFNFY_NOTICE, PFNFY_PRINT, "Initializing stage 0x%x of
    pipe %d on screen %d, connection \"%s\"", stage,
    pipe, pfGetPipeScreen(p), pfGetPipeWSConnectionName(p));

    pfGetPipeSize(p, &x, &y);
    pfNotify(PFNFY_NOTICE, PFNFY_PRINT, "Pipe %d size: %dx%d", pipe,
    x, y);
}

```

```
/*
 * OpenPipeWin() -- create a GL window: set up the
 * window system, IRIS GL, and IRIS Performer. This
 * procedure is executed for each window in the draw process
 * for that pfPipe.
 */

void
OpenXWin(pfPipeWindow *pw)
{
    /* -1 -> use default screen or that specified by shell DISPLAY
    variable */
    pfuGLXWindow *win;
    pfPipe *p;

    p = pfGetPWinPipe(pw);
    if (!(win = pfuGLXWinopen(p, pw, "TESTIN")))
        pfNotify(PFNFY_FATAL, PFNFY_RESOURCE, "OpenXPipeline: Could not
        create GLX Window.");

    win = win; /* suppress compiler warn */
}

static void
OpenPipeWin(pfPipeWindow *pw)
{
    pfPipe *p;
    pfLight *Sun;

    p = pfGetPWinPipe(pw);

    /* open the window on the specified screen. By default,
    * if a screen has not yet been set and we are in multipipe mode,
    * a window of pfPipeID i will now open on screen i
    */
    pfOpenPWin(pw);
    pfNotify(PFNFY_NOTICE, PFNFY_PRINT,
    PipeWin of Pipe %d opened on screen %d",
    pfGetId(p), pfGetPipeScreen(p));

    /* create a light source in the "south-west" (QIII) */
    Sun = pfNewLight(NULL);
}
```

```
    pfLightPos(Sun, -0.3f, -0.3f, 1.0f, 0.0f);
}

static void
DrawChannel (pfChannel *channel, void *data)
{
    static int first = 1;

    if (first)
    {
        first = 0;
        pfNotify(PFNFY_NOTICE, PFNFY_PRINT, "Calligraphics: 0x%p",
pfGetChanCurCallig(channel));
    }

    /* erase framebuffer and draw Earth-Sky model */
    pfClearChan(channel);

    /* invoke Performer draw-processing for this frame */
    pfDraw();
}
```


“Math Routines”

This chapter details IRIS Performer’s comprehensive set of mathematical functions.

Math Routines

This chapter describes the IRIS Performer math routines. Math routines let you create, modify, and manipulate vectors, matrices, line segments, planes, and bounding volumes such as spheres, boxes, and cylinders.

Vector Operations

A basic set of mathematical operations is provided for setting and manipulating floating point vectors of length 2, 3, and 4. The types of these vectors are `pfVec2`, `pfVec3` and `pfVec4`, respectively. The components of a vector are denoted by `PF_X`, `PF_Y`, `PF_Z`, and `PF_W` with indices of 0, 1, 2, and 3, respectively. In the case of 4-vectors, the `PF_W` component acts as the homogeneous coordinate in transformations.

IRIS Performer supplies macro equivalents for many of the routines described in this section. Inlining the macros instead of calling the routines can substantially improve performance. The C++ interface provides the same, fast performance as the inlined macros.

Table 17-1 lists the routines, what they do (in mathematical notation), and the macro equivalents (where available) for working with 3-vectors. Most of the same operations are also available for 2-vectors and 4-vectors, substituting “2” or “4” for “3” in the routine names. The only operations not available for 2-vectors are vector cross-products, point transforms, and vector transforms; the only operations unavailable for 4-vectors are vector cross-products and point transforms, that is, there are no such routines as `pfCrossVec2()`, `pfCrossVec4()`, `pfXformPt2()`, `pfXformPt4()`, or `pfXformVec2()`.

Note: For the duration of this chapter, bold lowercase letters represent vectors and bold uppercase letters represent matrices. “ \times ” indicates cross product, “ \cdot ” denotes dot product, and vertical bars indicate the magnitude of a vector.]

Table 17-1 Routines for 3-Vectors

Routine	Effect	Macro Equivalent
pfSetVec3(d, x, y, z)	$\mathbf{d} = (x, y, z)$	PFSET_VEC3
pfCopyVec3(d, v)	$\mathbf{d} = \mathbf{v}$	PFCOPY_VEC3
pfNegateVec3(d,v)	$\mathbf{d} = -\mathbf{v}$	PFNEGATE_VEC3
pfAddVec3(d, v1, v2)	$\mathbf{d} = \mathbf{v}_1 + \mathbf{v}_2$	PFADD_VEC3
pfSubVec3(d, v1, v2)	$\mathbf{d} = \mathbf{v}_1 - \mathbf{v}_2$	PFSUB_VEC3
pfScaleVec3(d, s, v)	$\mathbf{d} = s\mathbf{v}$	PFSCALE_VEC3
pfAddScaledVec3(d, v1, s, v2)	$\mathbf{d} = \mathbf{v}_1 + s\mathbf{v}_2$	PFADD_SCALED_VEC3
pfCombineVec3(d,s1,v1,s2,v2)	$\mathbf{d} = s_1\mathbf{v}_1 + s_2\mathbf{v}_2$	PFCOMBINE_VEC3
pfNormalizeVec3(d)	$\mathbf{d} = \mathbf{d} / \mathbf{d} $	none
pfCrossVec3(d, v1, v2)	$\mathbf{d} = \mathbf{v}_1 \times \mathbf{v}_2$	none
pfXformPt3(d, v, m)	$\mathbf{d} = \mathbf{vM}$, where $\mathbf{v} = (v_x, v_y, v_z)$ and \mathbf{M} is the 4×3 submatrix.	none
pfFullXformPt3(d, v, M)	$\mathbf{d} = \mathbf{vM} / d_w$, where $\mathbf{v} = (v_x, v_y, v_z, 1)$	none
pfXformVec3(d, v, M)	$\mathbf{d} = \mathbf{vM}$, where $\mathbf{v} = (v_x, v_y, v_z, 0)$	none
pfDotVec3(v1, v2)	$\mathbf{v}_1 \cdot \mathbf{v}_2$	PFDOT_VEC3
pfLengthVec3(v)	$ \mathbf{v} $	PFLENGTH_VEC3
pfSqrDistancePt3(v1, v2)	$ \mathbf{v}_2 - \mathbf{v}_1 ^2$	PFSQR_DISTANCE_PT3
pfDistancePt3(v1, v2)	$ \mathbf{v}_2 - \mathbf{v}_1 $	PFDISTANCE_PT3
pfEqualVec3(v1, v2)	returns TRUE if $\mathbf{v}_1 = \mathbf{v}_2$, FALSE otherwise	PFEQUAL_VEC3
pfAlmostEqualVec3(v1,v2,tol)	returns TRUE if each element of \mathbf{v}_1 is within tol of the corresponding element of \mathbf{v}_2 , FALSE otherwise	PFALMOST_EQUAL_VEC3

Matrix Operations

A `pfMatrix` is a 4x4 array of floating-point numbers that is used primarily to specify a transformation in homogeneous coordinates (x, y, z, w) . Transforming a vector by a matrix means multiplying the matrix on the right by the row vector on the left.

Table 17-2 describes the IRIS Performer mathematical operations that act on matrices.

Table 17-2 Routines for 4x4 Matrices

Routine	Effect	Macro Equivalent
<code>pfMakeIdentMat(d)</code>	$\mathbf{D} = \mathbf{I}$	PFMAKE_IDENT_MAT
<code>pfMakeVecRotVecMat(d,v1,v2)</code>	$\mathbf{D} = \mathbf{M}$ such that $\mathbf{v}_2 = \mathbf{v}_1\mathbf{M}$. $\mathbf{v}_1, \mathbf{v}_2$ normalized.	none
<code>pfMakeQuatMat(d, q)</code>	$\mathbf{D} = \mathbf{M}$, where \mathbf{M} is the rotation of the quaternion q .	none
<code>pfMakeRotMat(d, deg, x, y, z)</code>	$\mathbf{D} = \mathbf{M}$, where \mathbf{M} rotates by deg around (x, y, z)	none
<code>pfMakeEulerMat(d, h, p, r)</code>	$\mathbf{D} = \mathbf{RPH}$, where \mathbf{R}, \mathbf{P} , and \mathbf{H} are the transforms for roll, pitch, and heading.	none
<code>pfMakeTransMat(d, x, y, z)</code>	$\mathbf{D} = \mathbf{M}$, where \mathbf{M} translates by (x, y, z)	PFMAKE_TRANS_MAT
<code>pfMakeScaleMat(d, x, y, z)</code>	$\mathbf{D} = \mathbf{M}$, where \mathbf{M} scales by (x, y, z)	PFMAKE_SCALE_MAT
<code>pfMakeCoordMat(d, c)</code>	$\mathbf{D} = \mathbf{M}$, where \mathbf{M} rotates by (h, p, r) and translates by (x, y, z) , with $h, p, r, x, y,$ and z all specified by c	none
<code>pfGetOrthoMatQuat(s, q)</code>	returns, in q , a quaternion with the rotation specified by s .	none
<code>pfGetOrthoMatCoord(s, d)</code>	returns, in d , the rotation and translation specified by s	none
<code>pfSetMatRow(d, r, x, y, z, w)</code>	Set r th row of \mathbf{D} equal to (x, y, z, w)	PFSET_MAT_ROW
<code>pfGetMatRow(m, r, x, y, z, w)</code>	$(*x, *y, *z, *w) = r$ th row of \mathbf{M}	PFGET_MAT_ROW

Table 17-2 (continued) Routines for 4x4 Matrices

Routine	Effect	Macro Equivalent
pfSetMatCol(d, c, x, y, z, w)	Set <i>c</i> th column of D equal to (x , y , z , w)	PFSET_MAT_COL
pfGetMatCol(m, c, x, y, z, w)	(*x, *y, *z, *w) = <i>c</i> th column of M	PFGET_MAT_COL
pfSetMatRowVec3(d, r, v)	Set <i>r</i> th row of D equal to v	PFSET_MAT_ROWVEC3
pfGetMatRowVec3(m, r, d)	d = <i>r</i> th row of M	PFGET_MAT_ROWVEC3
pfSetMatColVec3(d, c, v)	Set <i>c</i> th column of D equal to v	PFSET_MAT_COLVEC3
pfGetMatColVec3(m, c, d)	d = <i>c</i> th column of M	PFGET_MAT_COLVEC3
pfCopyMat(d, m)	D = M	PFCOPY_MAT
pfAddMat(d, m1, m2)	D = M ₁ + M ₂	none
pfSubMat(d, m1, m2)	D = M ₁ - M ₂	none
pfMultMat(d, m1, m2)	D = M ₁ M ₂	none
pfPostMultMat(d, m)	D = DM	none
pfPreMultMat(d, m)	D = MD	none
pfTransposeMat(d, m)	D = MT	none
pfPreTransMat(d, m, x, y, z)	D = TM , where T translates by (<i>x</i> , <i>y</i> , <i>z</i>)	none
pfPostTransMat(d, x, y, z, m)	D = MT , where T translates by (<i>x</i> , <i>y</i> , <i>z</i>)	none
pfPreRotMat(d, deg, x, y, z, m)	D = RM , where R rotates by <i>deg</i> around (<i>x</i> , <i>y</i> , <i>z</i>)	none
pfPostRotMat(d, m, deg, x, y, z)	D = MR , where R rotates by <i>deg</i> around (<i>x</i> , <i>y</i> , <i>z</i>)	none
pfPreScaleMat(d, x, y, z, m)	D = SM , where S scales by (<i>x</i> , <i>y</i> , <i>z</i>)	none
pfPostScaleMat(d, m, x, y, z)	D = MS , where S scales by (<i>x</i> , <i>y</i> , <i>z</i>)	none
pfInvertFullMat(d, m)	D = M ⁻¹ for general matrices	none
pfInvertAffMat(d, m)	D = M ⁻¹ , with M affine	none

Table 17-2 (continued) Routines for 4x4 Matrices

Routine	Effect	Macro Equivalent
pfInvertOrthoMat(d, m)	$\mathbf{D} = \mathbf{M}^{-1}$, with \mathbf{M} orthogonal	none
pfInvertOrthoNMat(d, m)	$\mathbf{D} = \mathbf{M}^{-1}$, with \mathbf{M} orthonormal	none
pfInvertIdentMat(d, m)	$\mathbf{D} = \mathbf{M}^{-1}$, with \mathbf{M} equal to the identity matrix	none
pfEqualMat(d, m)	returns TRUE if $\mathbf{D} = \mathbf{M}$, FALSE otherwise	PFEQUAL_MAT
pfAlmostEqualMat(d, m, tol)	returns TRUE if each element of \mathbf{D} is within <i>tol</i> of the corresponding element of \mathbf{M} , FALSE otherwise	PFALMOST_EQUAL_MAT

Some of the math routines that take a matrix as an argument are restricted to affine, orthogonal, or orthonormal matrices, these restrictions being noted by Aff, Ortho and OrthoN, respectively. (If such a restriction isn't noted in a *libpr* routine name, the routine can take a general matrix.)

An affine transformation is one that leaves the homogeneous coordinate unchanged—that is, in which the last column is (0,0,0,1). An orthogonal transformation is one that preserves angles. It can include translation, rotation, and uniform scaling, but no shearing or nonuniform scaling. An orthonormal transformation is an orthogonal transformation that preserves distances; that is, one that contains no scaling.

In the visual simulation library, *libpf*, most routines require the matrix to be orthogonal, although this isn't noted in the routine names.

The standard order of transformations for a hierarchical scene involves postmultiplying the transformation matrix for a child by the matrix for the parent. For instance, assume your scene involves a hand attached to an arm attached to a body. To get a transformation matrix H for the hand, postmultiply the arm's transformation matrix (A) by the body's (B): $H = AB$. To transform the hand object (at location h in hand coordinates) to body coordinates, calculate $h' = hH$.

Example 17-1 Matrix and Vector Math Examples

```
/*
 * test Rot of v1 onto v2
 */
{
    pfVec3 v1, v2, v3;
    pfMatrix m1;

    MakeRandomVec3(v1);
    MakeRandomVec3(v2);
    pfNormalizeVec3(v1);
    pfNormalizeVec3(v2);
    pfMakeVecRotVecMat(m1, v1, v2);
    pfXformVec3(v3, v1, m1);
    AssertEqVec3(v3, v2, "Arb Rot To");
}

/*
 * test inversion of Affine Matrix
 */
{
    pfVec3 v1, v2, v3;
    pfMatrix m1, m2, m3;

    MakeRandomVec3(v3);
    pfMakeScaleMat(m2, v3[0], v3[1], v3[2]);
    pfPreMultMat(m1, m2);

    MakeRandomVec3(v1);
    pfNormalizeVec3(v1);
    MakeRandomVec3(v2);
    pfNormalizeVec3(v2);
    pfMakeVecRotVecMat(m1, v1, v2);
    s = pfLengthVec3(v2)/pfLengthVec3(v1);
    pfPreScaleMat(m1, s, s, s, m1);

    MakeRandomVec3(v1);
    pfNormalizeVec3(v1);
    MakeRandomVec3(v2);
    pfNormalizeVec3(v2);
    pfMakeVecRotVecMat(m2, v1, v2);

    MakeRandomVec3(v3);
    pfMakeTransMat(m2, v3[0], v3[1], v3[1]);
}
```

```

pfPreMultMat(m1, m2);

pfInvertAffMat(m3, m1);
pfPostMultMat(m3, m1);
AssertEqMat(m3, ident, "affine inverse");

```

Quaternion Operations

A `pfQuat` is the IRIS Performer data structure (a `pfVec4`) whose for floating point values represent the components of a quaternion. Quaternions have many beneficial properties. The most relevant of these is their ability to represent 3D rotations in a manner that allows relatively simple yet meaningful interpolation between rotations. Much like multiplying two matrices, multiplying two quaternions results in the concatenation of the transformations. For more information on quaternions, see the article by Sir William Rowan Hamilton “*On quaternions; or on a new system of imaginaries in algebra,*” in the *Philosophical Magazine*, xxv, pp. 10-13 (July 1844), or refer to the sources noted in the `pfQuat(3pf)` reference page.

The properties of spherical linear interpolation makes quaternions much better suited than matrices for interpolating transformation values from keyframes in animations. The most common usage then is to use `pfSlerpQuat()` to interpolate between two quaternions representing two rotational transformations. The quaternion that results from the interpolation can then be passed to `pfMakeQuatMat()` to generate a matrix for use in a subsequent IRIS Performer call such as `pfDCSMat()`. While converting a quaternion to a matrix is relatively efficient, converting a matrix to a quaternion with `pfGetOrthoMatQuat()` is expensive and should be avoided when possible.

Because a `pfQuat` is also a `pfVec4`, all of the `pfVec4` routines and macros may be used on `pfQuats` as well.

Table 17-3 Routines for Quaternions

Routine	Effect	Macro Equivalent
<code>pfMakeRotQuat(q, a, x, y, z)</code>	Sets <code>q</code> to rotation of <code>a</code> degrees about <code>(x, y, z)</code>	none
<code>pfGetQuatRot(q, a, x, y, z)</code>	Sets <code>*a</code> to angle and <code>(*x, *y, *z)</code> to axis of rotation represented by <code>q</code>	none
<code>pfConjQuat(d, q)</code>	<code>d = conjugate of q</code>	<code>PFCONJ_QUAT</code>

Table 17-3 (continued) Routines for Quaternions

Routine	Effect	Macro Equivalent
pfLengthQuat(q)	returns length of q	PLENGTH_QUAT
pfMultQuat(d, q1, q2)	$d = q1 * q2$	PFMULT_QUAT
pfDivQuat(d, q1, d2)	$d = q1 / q1$	PFDIV_QUAT
pfInvertQuat(d, q1)	$d = 1 / q1$	
pfExpQuat(d, q)	$d = \exp(q)$	none
pfLogQuat(d, q)	$d = \ln(q)$	none
pfSlerpQuat(d, t, q1, q2)	d = interpolation with weight t between q1 (t=0.0) and q2 (t=1.0)	none
pfSquadQuat(d, t, q1, q2, a, b)	d = quadratic interpolation between q1 and q2	none
pfQuatMeanTangent(d, q1, q2, q3)	d = mean tangent of q1, q2 and q3.	none

Example 17-2 Quaternion Example

```

/*
 * test quaternion slerp
 */

pfQuat q1, q2, q3;
pfMatrix m1, m2, m3, m3q;
pfVec3 axis;
float angle1, angle2, angle, t;

MakeRandomVec3(axis);
pfNormalizeVec3(axis);
angle1 = -drand48()*90.0f;
angle2 = drand48()*90.0f;
t = drand48();

pfMakeRotMat(m1, angle1, axis[0], axis[1], axis[2]);
pfMakeRotQuat(q1, angle1, axis[0], axis[1], axis[2]);
pfMakeQuatMat(m3q, q1);

```

```

pfMakeRotMat(m2, angle2, axis[0], axis[1], axis[2]);
pfMakeRotQuat(q2, angle2, axis[0], axis[1], axis[2]);
pfMakeQuatMat(m3q, q2);
AssertEqMat(m2, m3q, "make rot quat q2");

angle = (1.0f-t) * angle1 + t * angle2;
pfMakeRotMat(m3, angle, axis[0], axis[1], axis[2]);

pfMakeRotQuat(q1, angle1, axis[0], axis[1], axis[2]);
pfMakeRotQuat(q2, angle2, axis[0], axis[1], axis[2]);
pfSlerpQuat(q3, t, q1, q2);
pfMakeQuatMat(m3q, q3);
AssertEqMat(m3q, m3, "quaternion slerp");
{

```

Matrix Stack Operations

IRIS Performer allows you to create a stack of transformation matrices, which is called a `pfMatStack`.

Table 17-4 lists and describes the matrix stack routines. Note that none of these routines has a macro equivalent. The matrix at the top of the matrix stack is denoted "TOS," for "Top of Stack."

Table 17-4 Matrix Stack Routines

Routine	Operation
<code>pfNewMStack</code>	Allocate storage.
<code>pfResetMStack</code>	Reset the stack.
<code>pfPushMStack</code>	Duplicate the TOS and push it on the stack.
<code>pfPopMStack</code>	Pop the stack.
<code>pfPreMultMStack</code>	Premultiply the TOS by a matrix.
<code>pfPostMultMStack</code>	Postmultiply the TOS by a matrix.
<code>pfLoadMStack</code>	Set the TOS matrix.
<code>pfGetMStack</code>	Get the TOS matrix.

Table 17-4 (continued) Matrix Stack Routines

Routine	Operation
pfGetMStackTop	Get a pointer to the TOS matrix.
pfGetMStackDepth	Return the current depth of the stack.
pfPreTransMStack	Premultiply the TOS by a translation.
pfPostTransMStack	Postmultiply the TOS by a translation.
pfPreRotMStack	Premultiply the TOS by a rotation.
pfPostRotMStack	Postmultiply the TOS by a rotation.
pfPreScaleMStack	Premultiply the TOS by a scale factor.
pfPostScaleMStack	Postmultiply the TOS by a scale factor.

Creating and Transforming Volumes

libpr provides a number of volume primitives, including sphere, box, cylinder, half-space (plane), and frustum. *libpf* uses the frustum primitive for a view frustum, and uses other volume primitives for bounding volumes:

- pfNodes use bounding spheres.
- pfGeoSets use bounding boxes.
- Segments use bounding cylinders.

Defining a Volume

This section describes how to define geometric volumes.

Spheres

Spheres are defined by a center and a radius, as shown by the `pfSphere` structure's definition:

```
typedef struct {
    pfVec3 center;
    float radius;
} pfSphere;
```

A point \mathbf{p} is in the sphere with center \mathbf{c} and radius \mathbf{r} if $|\mathbf{p} - \mathbf{c}| \leq r$.

Axially Aligned Boxes

An axially aligned box is defined by its two corners with the smallest and largest values for each coordinate. Its edges are parallel to the X, Y, and Z axes. It's represented by the `pfBox` data structure:

```
typedef struct {
    pfVec3 min;
    pfVec3 max;
} pfBox;
```

A point (x, y, z) is in the box if $min_x \leq x \leq max_x$, $min_y \leq y \leq max_y$, and $min_z \leq z \leq max_z$.

Cylinders

A cylinder is defined by its center, radius, axis, and half-length, as shown by the definition of the `pfCylinder` data structure:

```
typedef struct {
    pfVec3 center;
    float radius;
    pfVec3 axis;
    float halfLength;
} pfCylinder;
```

A point \mathbf{p} is in the cylinder with center \mathbf{c} , radius \mathbf{r} , axis \mathbf{a} , and half-length h , if $|(\mathbf{p} - \mathbf{c}) \cdot \mathbf{a}| \leq h$ and $|\mathbf{p} - \mathbf{c} - ((\mathbf{p} - \mathbf{c}) \cdot \mathbf{a}) \mathbf{a}| \leq r$.

Half-spaces (Planes)

A half-space is defined by a plane with a normal pointing away from the interior. It's represented by the `pfPlane` data structure:

```
typedef struct {  
    pfVec3 normal;  
    float offset;  
} pfPlane;
```

A point **p** is in the half-space with normal **n** and offset **d** if $\mathbf{p} \cdot \mathbf{n} \leq d$.

Frusta

Unlike the other volumes, a `pfFrustum` isn't an exposed structure. You can allocate storage for a `pfFrustum` using `pfNewFrustum()` and you can set the frustum using `pfMakePerspFrustum()` or `pfMakeOrthoFrustum()`.

Creating Bounding Volumes

The easiest and most efficient way to create a volume is to use one of the bounding operations. The routines in Table 17-5 create a bounding volume that encloses other geometric objects.

Table 17-5 Routines to Create Bounding Volumes

Routine	Bounding Volume
<code>pfBoxAroundPts</code>	Box enclosing a set of points
<code>pfBoxAroundBoxes</code>	Box enclosing a set of boxes
<code>pfBoxAroundSpheres</code>	Box enclosing a set of spheres
<code>pfCylAroundSegs</code>	Cylinder around a set of segments
<code>pfSphereAroundPts</code>	Sphere around a set of points
<code>pfSphereAroundBoxes</code>	Sphere around a set of boxes
<code>pfSphereAroundSpheres</code>	Sphere around a set of spheres

Bounding volumes can also be defined by extending existing volumes, but in many cases the tightness of the bounds created through a series of extend operations is substantially inferior to that of the bounds created with a single **pf*Around*()** operation.

Table 17-6 lists and describes the routines for extending bounding volumes.

Table 17-6 Routines to Extend Bounding Volumes

Routine	Operation
pfBoxExtendByPt	Extend a box to enclose a point.
pfBoxExtendByBox	Extend a box to enclose another box.
pfSphereExtendByPt	Extend a sphere to enclose a point.
pfSphereExtendBySphere	Extend a sphere to enclose a sphere.

Transforming Bounding Volumes

Transforming the volumes with an orthonormal transformation—that is, with no skew or nonuniform scaling, is straightforward for all of the volumes except for the axially aligned box. A straight transformation of the vertices doesn't suffice because the new box would no longer be axially aligned, so an aligned box must be created that encloses the transformed vertices. Hence a transformation of a box isn't generally reversed by applying the inverse transformation to the new box.

Table 17-7 lists and describes the routines that transform bounding volumes.

Table 17-7 Routines to Transform Bounding Volumes

Routine	Operation
pfOrthoXformPlane	Transform a plane or half-space.
pfOrthoXformFrust	Transform a frustum.
pfXformBox	Transform and extend a bounding box.
pfOrthoXformCyl	Transform a cylinder.
pfOrthoXformSphere r	Transform a sphere.

Intersecting Volumes

IRIS Performer provides a number of routines that test for intersection with volumes.

Point-Volume Intersection Tests

The point-volume intersection test returns PFIS_TRUE if the specified point is in the volume and PFIS_FALSE otherwise. Table 17-8 lists and describes the routines that test a point for inclusion within a bounding volume.

Table 17-8 Testing Points for Inclusion in a Bounding Volume

Routine	Test
pfBoxContainsPt	Point inside a box
pfSphereContainsPt	Point inside a sphere
pfCylContainsPt	Point inside a cylinder
pfHalfSpaceContainsPt	Point inside a half-space
pfFrustContainsPt	Point inside a frustum

Volume-Volume Intersection Tests

IRIS Performer provides a number of volume-volume tests that are used internally for bounding-volume tests when culling to a view frustum or when testing a group of line segments against geometry in a scene (see “Intersecting With pfGeoSets” on page 558). You can intersect spheres, boxes, and cylinders against half-spaces and against frustums for culling. You can intersect cylinders against spheres for testing grouped segments against bounding volumes in a scene.

Table 17-9 lists and describes the routines that test for volume intersections.

Table 17-9 Testing Volume Intersections

Routine	Action: Test if A Inside B
pfHalfSpaceContainsSphere	Sphere inside a half-space
pfFrustContainsSphere	Sphere inside a frustum
pfSphereContainsSphere	Sphere inside a sphere
pfSphereContainsCyl	Cylinder inside a sphere
pfHalfSpaceContainsCyl	Cylinder inside a half-space
pfFrustContainsCyl	Cylinder inside a frustum
pfHalfSpaceContainsBox	Box inside a half-space
pfFrustContainsBox	Box inside a frustum
pfBoxContainsBox	Box inside a box

The volume-volume intersection tests are designed to quickly locate empty intersections for rejection during a cull. If the complete intersection test is too time-consuming, the result PFIS_MAYBE is returned, to indicate that the two volumes might intersect.

The returned value is a bitwise OR of tokens, as shown in Table 17-10.

Table 17-10 Intersection Results

Test Result	Meaning
PFIS_FALSE	No intersection
PFIS_MAYBE	Possible intersection
PFIS_MAYBE PFIS_TRUE	A contains at least part of B
PFIS_MAYBE PFIS_TRUE PFIS_ALL_IN	A contains all of B

This arrangement allows simple code such as that shown in Example 17-3.

Example 17-3 Quick Sphere Culling Against a Set of Half-Spaces

```
long
HSSContainsSphere(pfPlane **hs, pfSphere *sph, long numHS)
{
    long i, isect;

    isect = ~0;

    for (i = 0 ; i < numHS ; i++)
    {
        isect &= pfHalfSpaceContainsSphere(sph,hs[i]);
        if (isect == PFIS_FALSE)
            return isect;
    }
    /* if not ALL_IN all half spaces, don't know for sure */
    if (!(isect & PFIS_ALL_IN))
        isect &= ~PFIS_TRUE;
    return isect;
}
```

Creating and Working With Line Segments

A `pfSeg` represents a line segment starting at position *pos*, extending for a distance *length* in the direction *dir*:

```
typedef struct {
    pfVec3 pos;
    pfVec3 dir;
    float length;
} pfSeg;
```

The routines that operate on `pfSegs` assume that *dir* is of unit length and that *length* is positive; otherwise, the results of operations are undefined.

You can create line segments in three different ways:

- Specify a point and a direction directly in the structure—**pfSeg()**.
- Specify two endpoints: **pfMakePtsSeg()**.
- Specify one endpoint and an orientation in polar coordinates—**pfMakePolarSeg()**.
- Specify starting and ending distances along an existing segment—**pfClipSeg()**.

Intersection tests are the most important operations that use line segments. You can test the intersection of segments with volumes (half-spaces, spheres, and boxes), with 2D geometry (planes and triangles), and with geometry inside **pfGeoSets**.

Intersecting With Volumes

IRIS Performer supports intersections of segments with three types of convex volumes. **pfHalfSpaceIsectSeg()** intersects a segment with the half-space defined by a plane with an outward facing normal. **pfSphereIsectSeg()** intersects with a sphere and **pfBoxIsectSeg()** intersects with an axially aligned box.

The intersection test of a segment and a convex volume can have one of five results:

- The segment lies entirely outside the volume.
- The segment lies entirely within the volume.
- The segment lies partially inside the volume with the starting point inside.
- The segment lies partially inside the volume with the ending point inside.
- The segment lies partially inside the volume with both endpoints outside.

As with the volume-volume tests, the segment-volume intersection routines return a value that is the bitwise OR of some combination of the tokens **PFIS_TRUE**, **PFIS_ALL_IN**, **PFIS_START_IN**, and **PFIS_MAYBE**. (When **PFIS_TRUE** is set **PFIS_MAYBE** is also set for consistency with those routines that do quick intersection tests for culling.)

The functions take two arguments that return the distances along the segment of the starting and ending points. The return values are designed so that you can AND them together for testing for the intersection of a segment against the intersection of a number of volumes. For example, a convex polyhedron is defined as the intersection of a set of half-spaces. Example 17-4 shows how to intersect a segment with a polyhedron.

Example 17-4 Intersecting a Segment With a Convex Polyhedron

```

long
HSSIsectSeg(pfPlane **hs, pfSeg *seg, long nhs, float *d1,
           float *d2)
{
    long retval = 0xffff;
    for (long i = 0 ; i < nhs ; i++)
    {
        retval &= pfHalfSpaceIsectSeg(hs[i], seg, d1, d2);
        if (retval == 0)
            return 0;
        pfClipSeg(seg, *d1, *d2);
    }
    return retval;
}

```

Note that these **routines** do not actually clip the segment. If you want the segment to be clipped to the interior of the volume, you must call **pfClipSeg()**, as in the example above.

Intersecting With Planes and Triangles

Intersections with planes and triangles are simpler than those with volumes. **pfPlaneIsectSeg()** and **pfTriIsectSeg()** return either **PFIS_TRUE** or **PFIS_FALSE**, depending on whether an intersection has occurred. The distance of the intersection along the segment is returned in one of the arguments.

Intersecting With pfGeoSets

You can intersect line segments with the drawable geometry that's within **pfGeoSets** by calling **pfGSetIsectSegs()**. The operation is very similar to that of **pfNodeIsectSegs()**, except that rather than operating on an entire scene graph, only the triangles within the **pfGeoSet** are "traversed."

pfGSetIsectSegs() takes a **pfSegSet** and tests to see whether any of the segments intersect the polygons inside the specified **pfGeoSet**. By default, information about the closest intersection along each segment is returned as a set of **pfHit** objects, one for each line segment in the request. Each **pfHit** object indicates the location of the intersection, the normal, and what element was hit. This element identification includes the index of the primitive within the **pfGeoSet** and the triangle index within the primitive (for **tristrips** and **quads** primitives), as well as the actual triangle vertices.

You can also extract information from a `pfHit` object using `pfQueryHit()` and `pfMQueryHit()`. (See “Intersection Requests: `pfSegSets`” and “Intersection Return Data: `pfHit` Objects” in Chapter 4 for more information about `pfSegSets` and `pfHit` objects.) The principal difference between those routines and `pfGSetIsectSegs()` is that with `pfGSetIsectSegs()` information concerning the *libpf* scene graph (such as transformation, geode, name, and path) is never used.

Two types of intersection testing are possible, as shown in Table 17-11.

Table 17-11 Available Intersection Tests

Test Name	Function
PFTRAV_IS_GSET	Intersect the segment with the bounding box of the <code>pfGeoSet</code> .
PFTRAV_IS_PRIM	Intersect the segment with the polygon-based primitives inside the <code>pfGeoSet</code> .

You can use `PFTRAV_IS_GSET` for crude collision detection and `PFTRAV_IS_PRIM` for fine-grained testing. You can enable both bits and dynamically choose whether to go down to the primitive level by using a discriminator callback (see “Discriminator Callbacks”). `pfGSetIsectSegs()` performs only primitive-level testing for `pfGeoSets` consisting of triangles (`PFGS_TRIS`), quads (`PFGS_QUADS`), and tristrips (`PFGS_TRISTRIPS`), and all are decomposed into triangles.

Intersection Masks

Each `pfGeoSet` has an intersection mask that you set using `pfGSetIsectMask()`. The mask in the `pfGeoSet` is useful when `pfGeoSets` are embedded in a larger data structure; it allows you to define `pfGeoSets` to belong to different classes of geometry for intersection—for example, water, ground, foliage. `pfGSetIsectSegs()` also takes a mask, and an intersection test is performed only if the bitwise AND of the two masks is nonzero.

Discriminator Callbacks

If a callback is specified in **pfGSetIsectSegs()** function is invoked when a successful intersection occurs, either with the bounding box of the **pfGeoSet** or with a primitive. The discriminator can decide what action to take based on the information about the intersection contained in a **pfHit** object. The return value from the discriminator determines whether the current intersection is valid and should be copied into the return structure, whether the rest of the geometry in the **pfGeoSet** is examined, and whether the segment should be clipped before continuing.

Unless the return value includes the bit **PFTRAV_IS_IGNORE**, the intersection is considered successful and is copied into the array of **pfHit** structures for return.

The bits of the **PFTRAV_*** tokens determine whether to continue, as shown in Table 17-12.

Table 17-12 Discriminator Return Values

Result	Meaning
PFTRAV_CONT	Continue examining geometry inside the pfGeoSet .
PFTRAV_PRUNE	Terminate the traversal now.
PFTRAV_TERM	Terminate the traversal now.

The bits **PFTRAV_IS_CLIP_END** and **PFTRAV_IS_CLIP_START** cause the segment to be clipped at the end or at the start using the intersection point. By default, in the absence of a discriminator, segments are end-clipped at each successful intersection at the finest level (bounding box or primitive level) requested. Hence, the closest intersection point is always returned.

The discriminator is passed a **pfHit**. You can use **pfQueryHit()** to examine information about the intersection, including which segment number within the **pfSegSet** the intersection is for and the current segment as clipped by previous intersections.

General Math Routine Example Program

Example 17-5 demonstrates the use of many of the available IRIS Performer math routines.

Example 17-5 Intersection Routines in Action

```

/*
 * simple test of pfCylIsectSeg
 */
{
    pfVec3 tmpvec;
    pfSetVec3(pt1, -2.0f, 0.0f, 0.0f);
    pfSetVec3(pt2, 2.0f, 0.0f, 0.0f);

    pfMakePtsSeg(&seg1, pt1, pt2);

    pfSetVec3(cyll.axis, 1.0f, 0.0f, 0.0f);
    pfSetVec3(cyll.center, 0.0f, 0.0f, 0.0f);
    cyll.radius = 0.5f;
    cyll.halfLength = 1.0f;

    isect = pfCylIsectSeg(&cyll, &seg1, &t1, &t2);

    pfClipSeg(&clipSeg, &seg1, t1, t2);
    AssertFloatEq(clipSeg.length, 2.0f, "clipSeg.length");
    pfSetVec3(tmpvec, 1.0f, 0.0f, 0.0f);
    AssertVec3Eq(clipSeg.dir, tmpvec, "clipSeg.dir");
    pfSetVec3(tmpvec, -1.0f, 0.0f, 0.0f);
    AssertVec3Eq(clipSeg.pos, tmpvec, "clipSeg.pos");
}
/*
 * simple test of pfTriIsectSeg
 */
{
    pfVec3 tr1, tr2, tr3;
    pfSeg seg;
    float d = 0.0f;
    long i;

    for (i = 0 ; i < 30 ; i++)
    {
        float alpha = 2.0f * drand48() - 0.5f;
        float beta = 2.0f * drand48() - 0.5f;
        float lscale = 2.0f * drand48();
    }
}

```

```
float target;
long shouldisect;

MakeRandomVec3(tr1);
MakeRandomVec3(tr2);
MakeRandomVec3(tr3);
MakeRandomVec3(pt1);
pfCombineVec3(pt2, alpha, tr2, beta, tr3);
pfCombineVec3(pt2, 1.0f, pt2, 1.0f - alpha - beta, tr1);

pfMakePtsSeg(&seg, pt1, pt2);
target = seg.length;
seg.length = lscale * seg.length;

isect = pfTriIsectSeg(tr1, tr2, tr3, &seg, &d);
shouldisect = (alpha >= 0.0f &&
              beta >= 0.0f &&
              alpha + beta <= 1.0f &&
              lscale >= 1.0f);
if (shouldisect)
    if (!isect)
        printf("ERROR: missed\n");
    else
        AssertFloatEq(d, target, "hit at wrong distance");
else if (isect)
    printf("ERROR: hit\n");
}

/*
 * simple test of pfCylContainsPt
 */
{
    pfCylinder cyl;
    pfVec3 pt;
    pfVec3 perp;

    pfSetVec3(cyl.center, 1.0f, 10.0f, 5.0f);
    pfSetVec3(cyl.axis, 0.0f, 0.0f, 1.0f);
    pfSetVec3(perp, 1.0f, 0.0f, 0.0f);
    cyl.halfLength = 2.0f;
    cyl.radius = 0.5f;

    pfCopyVec3(pt, cyl.center);
    if (!pfCylContainsPt(&cyl, pt))
        printf("center of cylinder not in cylinder!!!!\n");
}
```

```
    pfAddScaledVec3(pt, cyl.center, 0.9f*cyl.halfLength,
                    cyl.axis);
    if (!pfCylContainsPt(&cyl, pt))
        printf("0.9*halfLength not in cylinder!!!!\n");

    pfAddScaledVec3(pt, cyl.center, -0.9f*cyl.halfLength,
                    cyl.axis);
    if (!pfCylContainsPt(&cyl, pt))
        printf("-0.9*halfLength not in cylinder!!!!\n");

    pfAddScaledVec3(pt, cyl.center, -0.9f*cyl.halfLength,
                    cyl.axis);
    pfAddScaledVec3(pt, pt, 0.9f*cyl.radius, perp);
    if (!pfCylContainsPt(&cyl, pt))
        printf(printf("-0.9*halfLength not in cylinder!!\n"));

    pfAddScaledVec3(pt, cyl.center, 0.9f*cyl.halfLength,
                    cyl.axis);
    pfAddScaledVec3(pt, pt, -0.9f*cyl.radius, perp);
    if (!pfCylContainsPt(&cyl, pt))
        printf("-0.9*halfLength not in cylinder!!!!\n");

    pfAddScaledVec3(pt, cyl.center, 1.1f*cyl.halfLength,
                    cyl.axis);
    if (pfCylContainsPt(&cyl, pt))
        printf("1.1*halfLength in cylinder!!!!\n");

    pfAddScaledVec3(pt, cyl.center, -1.1f*cyl.halfLength,
                    cyl.axis);
    if (pfCylContainsPt(&cyl, pt))
        printf("-1.1*halfLength in cylinder!!!!\n");

    pfAddScaledVec3(pt, cyl.center, -0.9f*cyl.halfLength,
                    cyl.axis);
    pfAddScaledVec3(pt, pt, 1.1f*cyl.radius, perp);
    if (pfCylContainsPt(&cyl, pt))
        printf("1.1*radius in cylinder!!!!\n");

    pfAddScaledVec3(pt, cyl.center, 0.9f*cyl.halfLength,
                    cyl.axis);
    pfAddScaledVec3(pt, pt, -1.1f*cyl.radius, perp);
    if (pfCylContainsPt(&cyl, pt))
        printf("1.1*radius in cylinder!!!!\n");
}
```


“Statistics”

This chapter discusses the various kinds of available statistics on the performance of your application.

Statistics

This chapter describes the IRIS Performer profiling utilities. Statistics are available on nearly every aspect of IRIS Performer's operation and can be used to diagnose both functionality and performance problems, as well as for writing benchmarks and for load management. For more detailed information on interpreting statistics to tune the performance of your application, refer to Chapter 19, "Performance Tuning and Debugging."

To collect most IRIS Performer statistics, all you have to do is enable them; IRIS Performer then collects them automatically for you in `pfStats` and `pfFrameStats` data structures (for *libpr* and *libpf*, respectively). You can query the contents of these structures from your program, or write the data to files. A *libpf* application can also display the contents of a `pfFrameStats` structure in a channel by calling `pfDrawChanStats()` or `pfDrawFStats()`. The statistics drawn for a channel are the statistics accumulated in the channel's own `pfFrameStats`. Such a display isn't necessary for statistics collection. The pointer to the `pfFrameStats` structure for a channel can be gotten with `pfGetChanFStats()`. You can then control which statistics for the channel are being accumulated.

Most of the IRIS Performer demo programs display some subset of these statistics. This chapter first explains some of the complex graphical displays and then discusses how to display statistics from a *libpf*-based application. Subsequent sections explain how to access and manipulate statistics from within an application. Topics include enabling and disabling statistics classes, printing, querying, and copying statistics data, as well as some basic examples showing common uses of statistics. At the end of this chapter is a discussion of the different statistics classes for *libpr* and *libpf*, along with details of their use.

Interpreting Statistics Displays

Many types of statistics can be displayed in a channel. Most such displays consist simply of labeled numbers and are fairly self-explanatory; however, some of the displays, such as the stage timing graph, warrant further explanation.

IRIS Performer tracks the time spent in the application, cull, and draw stages of the rendering pipeline. The basic statistics display shows a timing graph for each stage of the past several frames, as well as showing the current frame rate and load information. This profiling diagram is useful for optimizing both the database and application structure.

Figure 18-1 shows a sample stage timing graph from an IRIS Performer demo program. It might be helpful to refer to a running example as well—by turning on a statistics display in *perfly*, for instance—while reading this section.

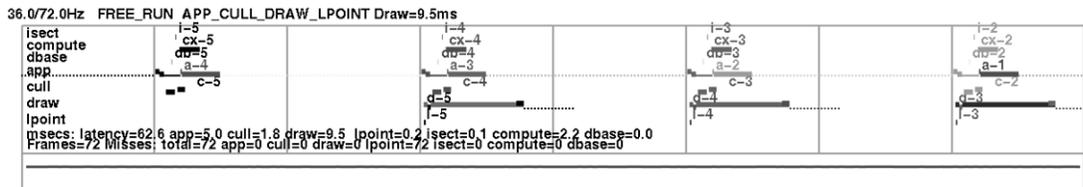


Figure 18-1 Stage Timing Statistics Display

The statistics diagram in Figure 18-1 is the simplest of the standard statistics displays. There are several other standard display formats, each emphasizing other classes of statistics. Statistics collection, though highly optimized, can take extra time in IRIS Performer operations. Because of this, you have a great deal of fine control over exactly what statistics are currently being collected and what statistics are being displayed. Statistics are divided into *classes* (separated into vertically stacked boxes in a display), and into *modes* within each class. The next several sections describe the classes shown in a typical statistics display.

Status Line

The top line of a standard statistics display, above the box that the rest of the statistics are drawn in, shows the current average frame rate followed by a slash and the target frame rate. (To set a target frame rate, call **pfFrameRate()**.) The rest of that status line indicates what frame-rate control method you’re using (FLOAT, FREE, LIMIT, or LOCK—for details, see “Achieving the Frame Rate” in Chapter 5), your multiprocess model (set with **pfMultiprocess()**), and the average time (in milliseconds) spent in the channel draw callback. An optional part of the status line indicates the number of triangles in the scene.

Stage Timing Graph

The main part of the timing display is the stage timing graph, occupying the top portion of the statistics display. The red vertical lines (the darker ones in Figure 18-1) mark video retrace intervals, which occur at the video refresh rate of the system (commonly 60 times per second); a *field* is the period of time between two video retrace boundaries. The green vertical lines (the lighter ones in the figure) indicate frame boundaries. Note that frame boundaries are always on field boundaries and are an integral number of fields.

The segmented horizontal line segments in the top portion of the timing graph show the time taken by each of the IRIS Performer pipeline stages and additional processes: i (intersection), a (application), c (cull), d (draw), l(lpoint, db(dbase) and cx(compute) for each of the four frames shown (0 through 3). On screen, all stages belonging to a given frame are drawn in one color; different colors indicate different frames. You will notice that the application lines show a change in color. This point is where `pfFrame()` returned and is the start of the next application frame. At that point is a label for the stage name, and the age of the frame being represented. The stages of the most recent frame, at the right of the graph, are marked a0, c0, and d0; previous frames have higher numbers (so “a-1” indicates the application stage of the immediately previous frame).

All stages performed by the same IRIX process are connected by vertical lines. If two stages are performed by different processes, they are not connected by a vertical line. In most multiprocessing modes, a stage of one frame occurs at the same time as another stage for a different frame, so that (for instance) d0 is directly below c-1 in the graph. The exception is the PFMP_CULLoDRAW model, in which the cull and draw stages for a given frame are performed in tandem; in this mode d0 is directly below c0 in the graph. (In Figure 18-1, the PFMP_APPCULLDRAW model was used and all stages are part of separate processes.)

These stage timings are helpful when choosing a process model and balancing the cull and draw tasks for a database. Furthermore, the timing graph can show you how close you are to an improvement in frame rate as you view the database.

The timing lines for each stage are broken into pieces displayed at slightly different heights and thicknesses to show the time taken by significant subtasks within each stage. Raised segments reflect time spent in user code, intermediate lines reflect time spent in IRIS Performer code, and lowered lines reflect time waiting on other operations.

Figure 18-2 illustrates the parts of a draw-stage timing line. Note that this figure isn't drawn to scale; sizes are exaggerated in order to discuss the individual parts more easily.

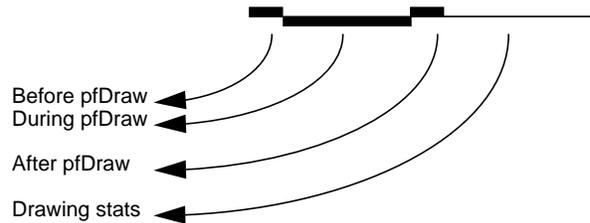


Figure 18-2 Conceptual Diagram of a Draw-Stage Timing Line

The following explains the potential displayed elements of each stage line in the timing graph. Note that if you run your app or perfly you may not see some parts if the corresponding operations are not needing to be done.

The application stage is divided into five subsegments, starting at the point where **pfFrame()** returns and the new application frame is beginning:

- The time spent in the application's main loop between the **pfFrame()** call and the **pfSync()** call (highest segment in application line, drawn as a thick, bright line).
- The time spent cleaning the scene graph from application changes during **pfSync()**; drawn as mid-height thick, bright line. This will also include the time for **pfAppFrame()** which is called from **pfSync()** if not already called for the current frame by the user. **pfSequences** are also evaluated as part of **pfAppFrame()**.
- The time spent sleeping in **pfSync()** while waiting for the next field or frame boundary (depending on **pfPhase** and process model); the lowest point in the application line, drawn as a thin pale dotted line. Note that in single process with **pfPhase** of **FREE_RUN**, there will be a sleep period to wait for the swapbuffer of the draw to complete before continuing with the application since any other graphics call would effective force such a sleep anyway and in a place where its timing effect could not be measured.
- The time spent in the application code between calling **pfSync()** and calling **pfFrame()**; drawn as bright raised line. This is the critical path section and this line should be as small as possible or non-existent.
- The time spent in **pfFrame()** cleaning the scene graph after any changes that might have been made in the previous subsegment, and then checking intersections; drawn as mid-height thick bright line. This line should typically be very small or non-existent as it is part of the critical path and implies database changes between **pfSync()** and **pfFrame()** which would be an expensive place to do such changes.

- The time spent waiting while the cull and other downstream process copy updated information from the application and then starting the downstream stages on the now-finished frame (drawn as a low thin line). The end of this line is where `pfFrame()` returns and the user main application section (or post frame section) starts again.

The cull stage is divided into only two subsegments:

- The time spent receiving updates from the application (in some multiprocessing models, this overlaps with the last subsegment of the application stage). This time is displayed for all channels even though it is only done one time. This is drawn as a lowered thick line.
- The time spent in the channel cull callback for the given channel, including time spent in `pfCull()` (drawn as raised line). Note that there may be a large space between this and the update line if there are multiple channels on the same `pfPipe` that are processed first.

The draw stage has potentially six subsegments:

- The time spent in the channel draw callback before the call to `pfDraw()` (a very short thick dark raised segment. This will include the time for your call to `pfClearChan()`. However, under normal circumstances, this segment should barely be visible at all). Operations taking place during this time should only be latency-critical since they are holding off the draw for the current frame.
- The time spent by IRIS Performer traversing the scene graph in `pfDraw()`; drawn as lowered bright thick segment. This should typically be the largest segment of the draw line.
- The time spent in the channel draw callback after `pfDraw()` (another short thick dark raised segment;). On InfiniteReality, if graphics pipeline timing statistics have been enabled (`PPFSTATS_ENGFXPFTIMES`), this line will include the time to finish the fill for this channel. Otherwise, it only includes the time for the CPU to execute and send graphics commands and graphics pipeline processing from this channel could impact the timing of other channels.
- The time to rendering raster light points computed by a forked `lpoint` process. This is drawn as a very raised bright line and if it exists will be the highest point in the draw line.

- The last channel drawn on the pipe will include the time for the graphics pipeline to finish its drawing. Even if you have no operations after `pfDraw()` in your draw callback, this line for the last channel might look quite long, particularly if you are very fill-limited and do not have InfiniteReality graphics pipeline statistics enabled. It is possible for rendering calls issued in the previous section to fill up the graphics FIFO and have calls issued on this section have to wait while the graphics pipeline processes the commands and FIFO drains, making the time look longer than expected. If there is no forked `lpoint` process, this line will be combined with the post-draw line of the last `pfChannel`.
- The time spent waiting for the graphics pipeline to finish drawing the current frame, draw the channel statistics (for all channels), and make the call to swap color buffers. This is drawn as a pale dotted line. The hardware will complete the swapbuffers upon the following vertical field or frame line.

Below the stage timing lines, the average time for each stage (in milliseconds) is shown. Note that the time given for the draw stage is the same as the time shown for the draw stage on the status line above the statistics box.

Load and Stress

The lower portion of the channel statistics diagram shows the recent history of graphics load and stress management. The load measure is based on the amount of time taken to draw previous frames in the channel relative to the specified goal frame time. A wavy red horizontal line is drawn to show the last three seconds of graphics load. A pair of white horizontal lines represent the upper and lower bounds of graphics load for invoking stress management. Thus, when the red line wanders outside the boundaries set by the white lines, stress management is invoked.

Stress management causes scaling of LODs in the database to meet the target frame rate with maximum scene detail. The last three seconds of stress are shown in white while stress management is running. Thus, the channel statistics graph can be used to tune the upper and lower bounds of the hysteresis band for invoking stress management and for tuning LODs of objects in the database.

CPU Statistics

The CPU statistics keep track of system usage and requires that the corresponding hardware statistics be enabled:

```
pfEnableStatsHw(PFSTATSHW_ENCPU);
```

The percentage of time CPUs spend idle, busy, in user code, and waiting on the Graphics Pipeline, or on the swapping of memory is calculated. The statistics packages counts the number of

- context switches (process and graphics)
- system calls
- times the graphics FIFO is found to be full
- times a CPU went to sleep waiting on a full graphics FIFO
- graphics pipeline IOCTLs issued (by the system)
- swapbuffers seen

All of these statistics are computed over an elapsed period of time.

Note: Use an interval of at least one second.

PFSTATSHW_CPU_SYS

This mode calculates the above CPU statistics for the entire system. This mode is enabled by default.

PFSTATSHW_CPU_IND

This mode enables calculates the above CPU statistics for each individual CPU; it is much more expensive than using just the summed statistics.

CPU statistics, illustrated (with some other statistics) in Figure 18-3, give you information on system usage and load. The numbers shown correspond exactly to numbers given by *osview*; they're updated every update period just like other statistics (see "Setting Update Rate" on page 585 for information on how to change the update rate). These numbers represent averages (per second) across all CPUs; thus, if one or more CPUs is busy with some other task, the CPU statistics shown may not accurately reflect IRIS Performer CPU use. Note that the top line of the CPU statistics panel shows the total number of frames during the last update period, and the total time elapsed during that period.

RTMon Statistics

The IRIX kernel collects timestamps via the rtmon daemon, rtmond(1). IRIS Performer will issue rtmon timestamps for all operations in the timing graph if the rtmon statistics are enabled via pfStatsClass(PFFSTATS_ENRTMON, PF_ON).

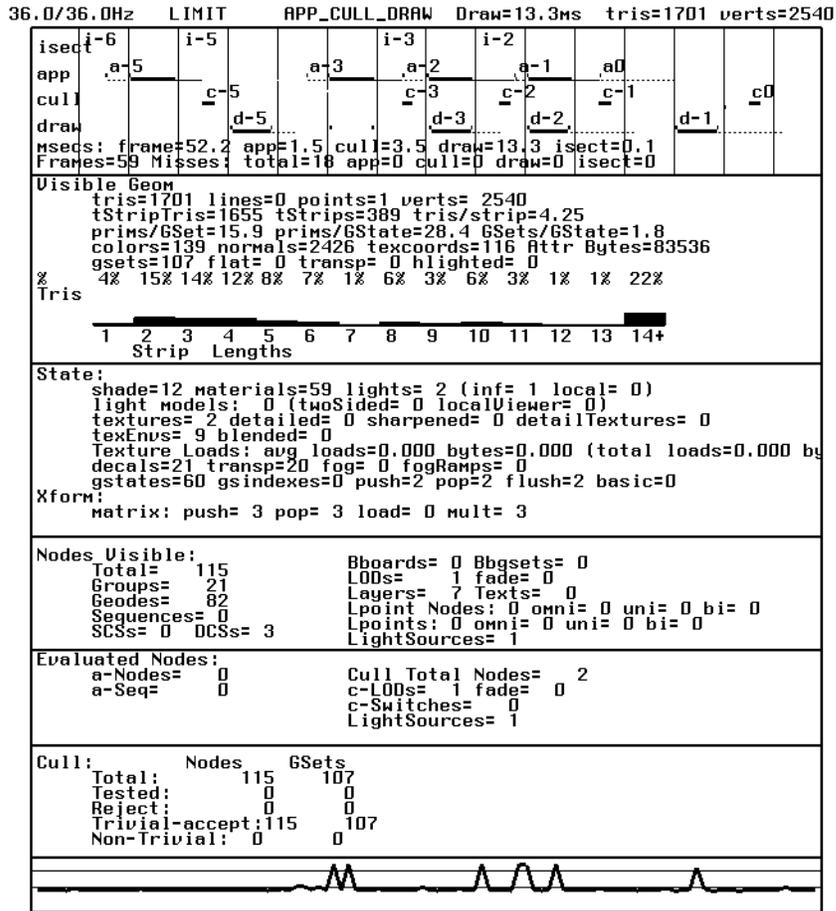


Figure 18-3 Other Statistics Classes

Rendering Statistics

Several other classes of statistics can be shown, each representing a different aspect of rendering performance. Some of these classes show:

- Data about visible geometry, including a histogram showing the percentage of triangles in the scene that are part of strips of a given length (from 1 to 14). Quads are counted as strips of length two; independent triangles count as strips of length one. This histogram is mostly useful as a diagnostic to see how well your database is structured for drawing efficiency; if it shows too many very short strips you may want to go back and restructure your database. (As a general rule of thumb, consider a “very short strip” to be one that’s less than 4 triangles long but that number may vary depending on your database). To enable these statistics on a channel do:

```
pfFStatsClass(pfGetChanFStats(chan),
             PFSTATS_ENGFX, PFSTATS_ON);
```

- A summary of the graphics state operations (including loading of textures), and of the number of operations that have recently been performed on the transformation stack (also part of the GFX stats class), the number of *libpf* nodes being drawn, in several categories (including billboards, light points, and geodes), plus the number of nodes of each type evaluated in the application and cull stages which can be enabled with

```
pfFStatsClass(pfGetChanFStats(chan),
             PFSTATS_ENDB, PFSTATS_ON);
```

- Cull statistics, including how many nodes and *pfGeoSets* are being tested, how many are accepted, and how many are rejected by the *libpf* culling task, enabled with

```
pfFStatsClass(pfGetChanFStats(chan),
             PFFSTATS_ENDB, PFSTATS_ON);
```

- Graphics pipeline timing statistics showing the time spent rendering as measured by the graphics pipeline. This timing is then used internally for more accurate load management. This is supported by InfiniteReality graphics platforms.

```
pfFStatsClass(pfGetChanFStats(chan),
             PFSTATSHW_ENGFXPIPE_TIMES, PFSTATS_ON);
```

Fill Statistics

The fill statistics display indicates how many millions of pixels have been drawn since the last statistics update. (For information on setting the length of time between statistics updates, see “Setting Update Rate” on page 585). It also computes the average *depth complexity* of the image, which is the average number of times each pixel was touched per frame.

The depth complexity of a scene is also be displayed in the main channel. Each pixel will be colored according to how many times that pixel was written to during display, rather than according to the current rendering modes. The colors used range from dark blue (not written to at all) to bright pink (written over many times). This color scheme is used in calculating fill statistics; the coloring is done whenever you gather fill statistics, even when you aren't displaying the totals in your channel statistics display.

Stencil planes are used to store the number of times a pixel is written and thus to calculate fill statistics. If n stencil planes are available, no more than 2^n writes to any given pixel will be counted. By default, the calculation of fill statistics uses three stencil planes; to change that default, call `pfStatsHwAttr()`.

Fill statistics are part of the *libpr* `pfStats` statistics but can be enabled on both `pfStats` and `pfFrameStats` classes. To enable fill statistics you simply do:

```
pfStatsClass(statsptr,  
             PFSTATSHW_ENGFPIPE_FILL, PFSTATS_ON);
```

To enable fill statistics for a channel's `pfFrameStats` do:

```
pfFStatsClass(pfGetChanFStats(chan),  
             PFSTATSHW_ENGFPIPE_FILL, PFSTATS_ON);
```

Examples of fill statistics can be found in `perfly` and in `/usr/share/Performer/src/pguide/libpr/C/fillstats.c`.

Collecting and Accessing Statistics in Your Application

If you just want to bring up a statistics display in your application, you may not need to know details about the data structures used for statistics. If, however, you want to do more complicated statistics-handling (including collecting statistics without displaying them), you need more advanced information. This section provides a general overview of statistics manipulation, followed by subsections containing specific information.

If you use *libpf*, a wide variety of statistics-manipulation functions is available. If you use *libpr*; however, you must do some things on your own. For instance, you have to bind your own `pfStats` structure in which to accumulate statistics.

Furthermore, you can't access some kinds of statistics except through *libpf* calls—for instance, you can't get culling statistics using *libpr* calls. If you want full access to statistics, you must use *libpf*. There are, however, *libpr* routines that allow you to do your own cumulative totaling and averaging of collected statistics.

To create your own statistics display, enable the statistics classes you want to use and disable any modes you don't want to use. Then enable any relevant hardware, if necessary, with `pfEnableStatsHw()`.

To ensure the accuracy of timing with your rendering statistics, you want to flush the graphics pipeline before calling `pfGetTime()`. You can do this in IRIS GL with `finish()` and in OpenGL with `glFinish()`. These calls are expensive and shouldn't be done more than at the start and end of drawing in frame.

Displaying Statistics Simply

To put up a simple statistics display, all you have to do is call the function `pfDrawChanStats()` and pass it a pointer to the `pfChannel` whose statistics you want to display. The `pfDrawChanStats()` routine can be called from any process within the application; the statistics will be displayed in the channel specified.

If you want to display one channel's statistics in another channel, call `pfDrawFStats()`; for an example of this technique, as well as the enabling and disabling of every statistics class, see the statistics programming example in the file `/usr/share/Performer/src/pguide/libpf/C/stats.c`.

By default, a statistics display shows all enabled statistics. If you want to show only a subset of the statistics you're collecting, call `pfChanStatsMode()` with an enabling bitmask indicating which classes are to be displayed.

Enabling and Disabling Statistics for a Channel

For efficiency, you may want to turn off statistics collection for a given channel when you're not displaying that channel's statistics. In particular, the stage timing statistics are enabled by default, so if you're using a channel whose statistics you don't care about, you should disable statistics for that channel. To turn off statistics for a channel, call:

```
pfFStatsClass(pfGetChanFStats(chan),  
             PFSTATS_ALL, PFSTATS_OFF);
```

Use the same function with different parameters to enable all or specific classes of statistics for a channel. You can specify which classes to enable in order to minimize statistics collection overhead.

Statistics in *libpr* and *libpf*—*pfStats* Versus *pfFrameStats*

libpf statistics accumulate into a *pfFrameStats* structure to later be displayed, printed, queried, or otherwise operated on. The *pfFrameStats* structure actually contains four buffers of statistics: a buffer for the previous frame's statistics, a buffer of averaged statistics for the previous update period, a buffer of accumulated statistics for the current update period, and a buffer of statistics being accumulated for the current frame.

The *pfFrameStats* structure is built upon the *libpr* *pfStats* structure, so the *pfFrameStats* API includes routines to duplicate the functionality of *pfStats*. The duplicated API exists because the routines cannot be intermixed. *pfStats* routines can only be used on *pfStats* structures and *pfFrameStats* routines can only be called with *pfFrameStats* structures. However, *pfstats* classes and class modes (designated with the *PFSTATS_* prefix) can be enabled on a *pfFrameStats* structure.

The *pfStats* statistics classes include the system and hardware statistics for the graphics pipeline and the CPU, as well the pixel fill statistics and rendering statistics on geometry, graphics state, and matrix transformations. Some of the *libpr* statistics commands, such as ***pfEnableStatsHw(PFSTATSHW_ENGFPIPE_FILL)***, require an active graphics context and thus should only be called from the draw process. However, these commands are usually never necessary in a *libpf* application because the *pfFrameStats* operation will handle these commands automatically.

Statistics Class Structures

The `pfFrameStats` structure and the `pfStats` structure are both inherited from the `pfObject` structure. Thus, you can use the `pfObject` routines (**`pfCopy()`**, **`pfPrint()`**, **`pfDelete()`**, **`pfUserData()`**, **`pfGetType()`**, and so on) with `pfStats` and `pfFrameStats` structures. However, some `pfObject` routines will not support all of the semantics of a `pfStats` or `pfFrameStats` structure, so some `pfStats` versions of a few of these routines take extra arguments. These routines will have a `pfFrameStats` version as well. In particular, **`pfCopyStats()`** and **`pfCopyFStats()`** should be used to copy `pfStats` and `pfFrameStats` structures, respectively.

Routines that have “FStats” in their names (rather than just “Stats”) expect to be passed a full `pfFrameStats` structure rather than a `pfStats` structure. The `pfFrameStats` API includes additional routines beyond `pfStats` for supporting `libpf` statistics. For example, **`pfDrawFStats()`** to display statistics in a channel and **`pfFStatsCountNode()`** to accumulate the static database statistics for the scene graph rooted at the provided node. Additionally, `pfFrameStats` has special support for the multiprocessed environment of `libpf` and ensures that the statistics operations are all done in the correct process. All modifying of a `pfFrameStats` structure, including enabling and disabling of classes, printing, and copying, should all be done in the application process. **`pfDrawFStats()`** and **`pfDrawChanStats()`** can be called in either the application process or the draw process.

Statistics Rules of Use

Enabling and disabling of statistics and setting of modes and attributes on a statistics structure should always be done in the application process; the settings will automatically be passed down the process pipeline. To enable classes of statistics on a `pfFrameStats`, call **`pfFStatsClass()`** and provide a statistics structure, a bitmask of statistics-enabling tokens (tokens with “STATS_EN” in their names) for the desired classes, and the token `PFSTATS_ON`. Obtain the statistics structure from the desired channel by calling **`pfGetChanFStats()`**. For example,

```
pfFStatsClass(pfGetChanFStats(chan), PFFSTATS_ENCULL |
             PFFSTATS_ENDB, PFSTATS_ON);
```

enables the cull statistics and database statistics classes, leaving settings alone for any other classes. Notice that the classes specific to `pfFrameStats` have a `PFFSTATS_` prefix. You can use `PFSTATS_SET` instead of `PFSTATS_ON` to enable only the specified classes (disabling any others that might already be enabled).

Statistics Tokens

There are five main types of statistics tokens:

- Statistics class enable bitmasks, used for selecting a set of classes to enable with **pfStatsClass()**. Class enables and disables are specified with bitmasks. Each statistics class has an enable token: a PFSTATS_EN* token that can be OR-ed with other statistics enable tokens and the result passed in to enable and disable statistics operations. These bitmasks are also used when printing with **pfPrint()** or copying with **pfCopy()** and **pfCopyStats()**, as well as with the **pfResetStats()**, **pfClearStats()**, **pfAverageStats()**, and **pfAccumulateStats()** routines (and their pfFrameStats counterparts). These tokens are of the form PFSTATS_EN* and PFFSTATS_EN* for pfStats and pfFrameStats class respectively. The PFSTATS_ALL token will select all statistics classes, and also all statistics buffers in the case of a pfFrameStats structure. The token PFSTATS_EN_MASK selects all pfStats classes and the token PFFSTATS_EN_MASK selects all pfFrameStats statistics classes, which includes all pfStats classes.
- Value tokens, used to specify how to set a value for a specified pfStats or pfFrameStats class enable or mode. Value tokens include PFSTATS_ON, PFSTATS_OFF, and PFSTATS_DEFAULT. Another value token, PFSTATS_SET, is used to specify that the entire class enable or mode bitmask should be set to the specified mask. These tokens are used in conjunction with the class bitmasks and the class name tokens for **pfStatsClass()** and **pfStatsClassMode()**.
- Class name tokens, used to name a specific class. For instance, these tokens can be passed to **pfStatsClassMode()** to set individual modes of a statistics class.
- Class mode tokens, of which each statistics class has its own, and which have the form PFSTATS_class_mode and PFFSTATS_class_mode for pfStats and pfFrameStats class modes, respectively.
- Statistics query tokens, used with **pfQueryStats()**, **pfMQueryStats()**, **pfQueryFStats()**, and **pfMQueryFStats()**. These tokens are of the form PFSTATSVAL_* and PFFSTATSVAL_* and have matching pfStatsVal* types for holding the returned data. The token PFFSTATS_BUF_MASK selects the pfFrameStats statistics buffers.

Statistics Buffers

You can only access the PREV and CUM statistics buffers from the IRIS Performer application process. Statistics from desired buffers in other processes should be queried in the application process and then passed down the process pipeline, which you can do using the channel data utility.

The AVG buffer is copied down the process pipeline at the end of each update period and so is available to be queried by other processes. The CUR statistics buffer is the current working area and contains the statistics accumulated so far from previous stages current frame; the contents of the CUR buffer is very dependent on the multiprocess configuration (but is almost always empty in the application process, so queries should access the PREV buffer). Statistics that are added to the CUR buffer via copying, accumulation, or immediate mode collection (such as with **pfStatsCountGSet()** and **pfStatsCountNode()**) will be propagated down the process pipeline and then back up to the application process to be included in the PREV buffer.

In a *libpf* application, most statistics collection is completely automatic. The application must simply enable the desired classes of statistics via **pfStatsClass()** and/or **pfStatsClassMode()**.

The IRIS Performer processes are responsible for actually opening the **pfFrameStats** structure in which to accumulate the enabled statistics classes, as well as for managing any statistics hardware resources. All types of *libpf* statistics can be accumulated without ever making specific calls to open a structure for accumulation or enabling statistics hardware.

When using only *libpr* statistics, however, one must explicitly open a **pfStats** structure for statistics accumulation by calling **pfOpenStats()**.

Hardware statistics resources must also be managed by an application using only *libpr* statistics. Statistics function calls that have “HW” in their names, such as **pfEnableStatsHw()** and **pfStatsHwAttr()**, directly access system hardware (such as graphics hardware and CPU); be careful to make such calls only from the relevant process. **pfEnableStatsHw()** expects PFSTATSHW_EN* bitmask tokens. Statistics classes which have corresponding statistics hardware have a PFSTATSHW_ prefix in their token names.

In a *libpf* application, IRIS Performer takes care of enabling the correct hardware modes that correspond to enabled classes of statistics. For more information about specific statistics classes, see the **pfFrameStats(3pf)** and **pfStats(3pf)** reference pages.

Reducing the Cost of Statistics

Collecting and displaying statistics can have a big impact on performance. This section describes ways to reduce that impact.

Enabling Only Statistics of Interest

Each channel has its Process Frame Times (PFTIMES) statistics class enabled by default. This class maintains a short history of process frames times, as well as averaging frame times over the default update period of two seconds.

To minimize unnecessary overhead, turn off statistics on channels when you're not using them. To turn off all statistics for a channel, call **pfFStatsClass()** in the application process with the statistics structure of the given channel:

```
pfFStatsClass(pfGetChanFStats(chan), PFSTATS_ALL,  
             PFSTATS_OFF);
```

Each statistics class has default mode settings. The short history of process frame time is used to draw the timing graph. By default, this history consists of four frames of each IRIS Performer process (app, cull, draw, intersections).

Maintaining this short history of statistics can be disabled by calling **pfStatsClassMode()** with the token **PFSTATS_PFTIMES_HIST**:

```
pfStatsClassMode(fstats, PFSTATS_PFTIMES,  
                PFSTATS_PFTIMES_HIST, PFSTATS_OFF);
```

This is useful if you're only interested in the average frame times of each task with minimal overhead and you don't need to display the timing graph. However, for most applications, the overhead incurred by keeping the timing history is not noticeable.

Controlling Update Rate

The update rate controls how often statistics are averaged and new results are made available in the AVG buffer for display or query. Change the update rate by calling

```
pfFStatsAttr(fstats, {PFSTATS_UPDATE_FRAMES,  
                    PFSTATS_UPDATE_SECS}, val);
```

When the update rate is nonzero, statistics are accumulated every frame. When the update period is set to zero, no statistics accumulation or averaging is done and only statistics in the PREV and CUR buffers are maintained.

When statistics are accumulated and averaged, the averaging happens only in the application process, but accumulation is done in each IRIS Performer process.

Statistics Output

Once you've collected some statistics, you need to be able to access and manipulate them.

Printing

To print the contents of `pfStats` and `pfFrameStats` structures, use the general `pfPrint()` routine. The verbosity-level parameter to `pfPrint()` sets the level of detail to use in printing statistics. Statistics class-enable bitmasks can be used to select a subset of statistics to print. For instance, to print only the enabled statistics:

```
pfPrint(stats, pfGetStatsClass(stats, PFSTATS_ALL),  
        PFPRINT_VB_INFO, 0);
```

When printing the contents of `pfFrameStats` structures, you can select which buffers are to be printed: PREV, CUR, AVG, or CUM. The selected statistics from all selected buffers are printed. The following call prints the currently enabled statistics from the previous frame and from the averaged statistics buffer:

```
pfPrint(stats, PFFSTATS_BUF_PREV | PFFSTATS_BUF_AVG |  
        pfGetStatsClass(stats, PFSTATS_ALL),  
        PFPRINT_VB_INFO, 0);
```

Copying

You can copy entire `pfStats` and `pfFrameStats` structures with the general `pfCopy()` command. `pfCopy()` copies all of the statistics data, as well as information on mode settings and which classes are enabled. The source and destination structures must be of the same type. If both statistics structures are `pfFrameStats` structures, then all statistics from all buffers are copied.

The **pfCopyStats()** and **pfCopyFStats()** routines copies only statistics data (not class enables or mode settings) and accepts a class enable bitmask to select statistics classes for the copy. For example:

```
pfCopyStats(statsA, statsB, pfGetStatsClass(statsB,  
PFSTATS_ALL));
```

For a **pfFrameStats** structure, a **PFSTATS_BUF_*** token can be included in the stats enable bitmask to select the buffer to be accessed. If no buffer is specified, the CUR buffer is used. For example,

```
pfCopyFStats(fstats, stats, PFFSTATS_BUF_PREV |  
pfGetStatsClass(stats, PFSTATS_ALL));
```

copies the currently enabled classes of *stats* to the PREV **pfStats** in *fstats*.

In this case, it's an error to select more than one statistics buffer, so **PFSTATS_ALL** cannot be used as the select. If you specify two **pfFrameStats** structures, the buffer select is used for both structures; if you select multiple buffers then each selected statistics class from each selected buffer is copied. The **pfCopyFStats()** routine allows you to copy between two different buffers of two **pfFrameStats** structures.

This routine takes explicit specification of **PFSTATS_BUF_*** selects for source and destination. Any **PFSTATS_BUF_*** included with the class enable bitmask is simply ignored, making it safe to specify **PFSTATS_ALL**. This routine will not accept a **pfStats** structure.

Querying

pfQueryStats() and **pfMQueryStats()** (and corresponding **pfFrameStats** versions) can be used to get values of out a **pfStats** or **pfFrameStats** structure and into an exposed structure.

These routines are useful when you want to use specific statistics for your own custom load management or for benchmarking, and you can use them to implement your own custom statistics utility routines. **pfQueryStats()** and **pfMQueryStats()** both take a **pfStats** (or **pfFrameStats** for **pfQueryFStats()** and **pfMQueryFStats()**) and return the number of bytes written to the provided destination buffer. **pfQueryStats()** takes a token that specifies a single query, while **pfMQueryStats()** expects a token buffer for multiple queries. If an error is encountered, both query routines immediately halt and return with the total number of bytes successfully written.

There are specific tokens for querying individual values or entire classes of statistics. The query tokens are of the form `PFSTATSVAL_*` and `PFSTATSVAL_*`, and the corresponding exposed structure names are of the form `pfStatsVal*` and `pfFStatsVal*`. Queries on `pfFrameStats` structures with `PFSTATSVAL_*` tokens expect a `PFSTATS_BUF_*` select token to be ORed with the query select. It's an error to include more than one `pfFrameStats` buffer select token. If no buffer select token is provided, the CUR buffer will be queried. The statistics query tokens and structures are defined in *prstats.h* and *pfstats.h*.

Customizing Displays

The standard statistics displays have several parameters hard-wired in. For instance, you can't change the colors used in such displays. If you want to use different colors, you'll have to use your own display routines.

Setting Update Rate

To set the frequency at which statistics are automatically collected, use `pfFStatsAttr()`. See the `pfFrameStats(3pf)` reference page for details. If you want to turn off cumulative statistics collection (and thus running averages) entirely, set the update rate to zero. (Note that doing this will change your statistics display; in particular, your actual frame rate will be changed and other averages will not be displayed.)

The pfStats Data Structure

The `pfStats` data structure contains four statistics buffers: one for current statistics, one for previous statistics, one for cumulative statistics, and one for averages.

If you're using *libpf* calls to have IRIS Performer keep track of statistics for you, you should always look at the previous-stats buffer; the current-stats buffer is kept in a state of flux, and if you look at it you're likely to find meaningless numbers there.

If, on the other hand, you're using *libpr* and keeping track of your own statistics, the current-stats buffer does contain accurate information.

Statistics Examples

This section contains some examples of statistics calls.

Setting statistics class enables and modes

Set all stats class enables on a `pfStats` to their default values:

```
pfStatsClass(stats, PFSTATS_ALL, PFSTATS_DEFAULT);
```

Set all modes for the `PFSTATS_GFX` class on a `pfFrameStats` to their default values:

```
pfFStatsClassMode(fstats, PFSTATS_GFX, PFSTATS_ALL,  
PFSTATS_DEFAULT);
```

Note that `pfStatsClassMode()` takes a class name as its class specifier (second argument) and not a bitmask. However, you can use `PFSTATS_CLASS` to refer to the modes of all classes;

```
pfFStatsClassMode(fstats, PFSTATS_MODE, PFSTATS_ALL,  
PFSTATS_DEFAULT);
```

sets all modes of all `pfStats` classes to their default values. For `pfFrameStats` classes, there is `PFSTATS_CLASS`:

Set the entire class enable mask to all `PFSTATS_ALL`, effectively enabling all statistics classes:

```
pfFStatsClass(fstats, PFFSTATS_ALL, PFSTATS_SET);
```

Force off all modes of the `PFSTATS_GFX` class of a `pfStats`:

```
pfStatsClassMode(stats, PFSTATS_GFX, PFSTATS_OFF,  
PFSTATS_SET);
```

To track triangle strip lengths on a `pfFrameStats`, enable the graphics statistics class mode:

```
pfFStatsClassMode(fstats, PFSTATS_GFX,  
PFSTATS_GFX_TSTRIP_LENGTHS, PFSTATS_ON);
```

“Performance Tuning and Debugging”

This chapter explains how to use performance measurement and debugging tools and provides hints for deriving maximum performance from your applications.

Performance Tuning and Debugging

This chapter provides some basic guidelines to follow when tuning your application for optimal performance. It also describes how to use debugging tools like *pixie*, *prof*, *gldebug*, and *glprof* to debug and tune your applications. It concludes with some specific notes on tuning applications on systems with RealityEngine graphics.

Performance-Tuning Overview

This section contains some general performance-tuning principles. Some of these issues are discussed in more detail later in this chapter.

- Remember that high performance doesn't come by accident. You must design your programs with speed in mind for optimal results.
- Tuning graphical applications, particularly IRIS Performer applications, requires a pipeline-based approach. You can think of the graphics pipeline as comprising three separate stages; the pipeline runs only as fast as the slowest stage, so improving the performance of the pipeline requires improving the slowest stage's performance. The three stages are:
 - The host (or CPU) stage, in which routines are called and general processing is done by the application. This stage can be thought of as a software pipeline, sometimes called the *rendering pipeline*, itself comprising up to three sub-stages—the application, cull, and draw stages—as discussed at length throughout this guide.
 - The transformation stage, in which transformation matrices are applied to objects to position them in space (this includes matrix operations, setting graphics modes, transforming vertices, handling lighting, and clipping polygons).
 - The fill stage, which includes clearing the screen and then drawing and filling polygons (with operations such as Gouraud shading, z-buffering, and texture mapping).

- You can estimate your expected frame rate based on the makeup of the scene to be drawn and graphics speeds for the hardware you're using. Be sure to include fill rates, polygon transform rates, and time for mode changes, matrix operations, and screen clear in your calculations.
- Measure both the performance of complex scenes in your database and of individual objects and drawing primitive to verify your understanding of the performance requirements.
- Use the IRIS Performer diagnostic statistics to evaluate how long each stage takes and how much it does. See Chapter 18, "Statistics," for more information. These statistics are referred to frequently in this chapter.
- Use system tools to help profile and analyze your application. The IRIS GL *glprof* utility (described in "Using glprof to Find Performance Bottlenecks" on page 610) will profile the rendering of an IRIS GL programs and show what was drawn and help figure out what stage of the graphics hardware pipeline is the significant bottleneck.
- Tuning an application is an incremental process. As you improve one stage's performance, bottlenecks in other stages may become more noticeable. Also, don't be discouraged if you apply tuning techniques and find that your frame rate doesn't change—frame rates only change by a field at a time (which is to say in increments of 16.67 milliseconds for a 60 Hz display), while tuning may provide speed increases of finer granularity than that. To see performance improvements that don't actually increase frame rate, look at the times reported by IRIS Performer statistics on the cull and draw processes (see Chapter 18 for more information).
- See the graphics library books listed in the "Bibliography" on page xxxvi for information about how to get peak performance from your graphics hardware, beyond what IRIS Performer does for you.

How IRIS Performer Helps Performance

IRIS Performer uses many techniques to increase application performance. Knowing about what IRIS Performer is doing and how it affects the various pipeline stages may help you write more efficient code. This section lists some of the things IRIS Performer can do for you.

Draw Stage and Graphics Pipeline Optimizations

During drawing, IRIS Performer

- Sets up an internal record of what routines and rendering methods are fastest for the current graphics platform. This information can be queried in any process with **pfQueryFeature()**. You can use this information at run time when setting state properties on your **pfGeoStates**.
- Has machine-dependent fast options for commands that are very performance sensitive. Use the **_ON** and **_FAST** mode settings whenever possible to get machine-dependent high-performance defaults. Some examples include:
 - **pfAntialias(PFAA_ON)**
 - **pfTransparency(PFTR_ON)**
 - **pfDecal(PFDECAL_BASE_FAST)**
 - **pfTexFilter(tex, filt, PFTEX_FAST)**
 - **pfTevMode(tev, PFTEV_FAST)**
- Sets up default modes for drawing, multiprocessing, statistics, and other areas, that are chosen to provide high scene quality and performance. Some rendering defaults differ from GL defaults: backface elimination is enabled by default (**pfCullFace(PFCF_BACK)**) and lighting materials use **lmcolor()** in IRIS GL and **glColorMaterial()** in OpenGL to minimize the number of materials required in a database (**pfMtlColorMode(mtl, side, PFMTL_CMODE_AD)**).
- Uses a large number of specialized routines for rendering different kinds of objects extremely quickly. There's a specialized drawing routine for each possible **pfGeoSet** configuration (each choice of primitive type, attribute bindings, and index selection). Each time you change from one **pfGeoSet** to another, one of these specialized routines is called. However, this happens even if the new **pfGeoSet** has the same configuration as the old one, so larger **pfGeoSets** are more efficient than smaller ones—the function-call overhead for drawing many small **pfGeoSets** can reduce performance. As a rule of thumb, a **pfGeoSet** should contain at least 4 triangles, and preferably between 8 and 64. If the **pfGeoSet** is too large, it can reduce the efficiency of other parts of the process pipeline.

- Caches state changes, because applying state changes is costly in the draw stage. IRIS Performer accumulates state changes until you call one of the **pfApply*()** functions, at which point it applies all the changes at once. Note that this differs from the graphics libraries, in which state changes are immediate. If you have several state changes to make in IRIS Performer, set up all the changes before applying them, rather than using the one-change-at-a-time approach (with each change followed by an apply operation) that you might expect if you're used to graphics library programming.
- Evaluates state changes lazily—that is, it avoids making any redundant changes. When you apply a state change, IRIS Performer compares the new graphics state to the previous one to see if they're different. If they are, it checks whether the new state sets any modes. If it does, IRIS Performer checks each mode being set to see whether it's different from the previous setting. To take advantage of this feature, share `pfGeoStates` and inherit states from the global state wherever possible. Set all the settings you can at the global level and let other nodes inherit those settings, rather than setting each node's attributes redundantly. To do this within a database, you can set up `pfGeoStates` with your desired global state and apply them to the `pfChannel` or `pfScene` with **pfChanGState()** or **pfSceneGState()**. You can do this through the database loader utilities in *libpfd* trivially for a given scene with **pfdMakeSharedScene()**, or have more control over the process with **pfdDefaultGState()**, **pfdMakeSceneGState()**, and **pfdOptimizeGStateList()**.
- Provides an optimized immediate mode rendering display list data type, `pfDispList`, in *libpr*. The `pfDispList` type reduces host overhead in the drawing process and requires much less memory than a graphics library display list. *libpf* uses `pfDispLists` to pass results from the cull process to the draw process when the `PFMP_CULL_DL_DRAW` mode is turned on as part of the multiprocessing model. For more information about display lists, see “Display Lists” in Chapter 9; for more information about multiprocessing, see “Successful Multiprocessing With IRIS Performer” in Chapter 5.

Cull and Intersection Optimizations

To help optimize culling and intersection, IRIS Performer

- Provides **pfFlatten()** to resolve instancing (via cloning) and static matrix transformations (by pre-transforming the cloned geometry). It can be especially important to flatten small pfGeoSets; otherwise matrix transformations must be applied to each small pfGeoSet at significant computational expense. Note that flattening resolves only static coordinate systems, not dynamic ones, but that where desired, pfDCS nodes can be converted to pfSCS nodes automatically using the IRIS Performer utility function **pfFreezeTransforms()**, which allows for subsequent flattening. Using **pfFlatten()**, of course, increases performance at the cost of greater memory use. Further, the function **pfCleanTree()** can be used to remove needless nodes: identity matrix pfSCS nodes, single child pfGroup nodes, and the like.
- Uses bounding spheres around nodes for fast culling—the intersection test for spheres is much faster than that for bounding boxes. If a node’s bounding sphere doesn’t intersect the viewing frustum, there’s no need to descend further into that node. There are bounding boxes around pfGeoSets; the intersection test is more expensive but provides greater accuracy at that level.
- Provides the pfPartition node type to partition geometry for fast intersection testing. Use a pfPartition node as the parent for anything that needs intersection testing.
- Provides level-of-detail (LOD) capabilities in order to draw simpler (and thus cheaper) versions of objects when they’re too far away for the user to discern small details.
- Allows intersection performance enhancement via precomputation of polygon plane equations within pfGeoSets. This pre-computation is in the form of a traversal that is nearly always appropriate—only in cases of non-intersectable or dynamically changing geometry might these cached plane equations be disadvantageous. This optimization is performed by **pfCollideSetup()** using the PFTRAV_IS_CACHE bit mask value.
- Sorts pfGeoSets by graphics state in the cull process, in order to minimize state changes and flatten matrix transformations, when *libpf* creates display lists to send to the draw process (as occurs in the PFMP_CULL_DL_DRAW multiprocessing mode). This procedure takes extra time in the cull stage, but can greatly improve performance when rendering a complex scene that uses many pfGeoStates. The sorting is enabled by default; it can be turned off and on by calling the function **pfChanTravMode(chan, PFTRAV_CULL, mode)** and including or excluding the PFCULL_SORT token. See “pfChannel Traversal Modes” in Chapter 4 and “Sorting the Scene” in Chapter 4 for more information on sorting.

Application Optimizations

During the application stage, IRIS Performer

- Divides the application process into two parts: the latency-critical section (which includes everything between **pfSync()** and **pfFrame()**), where last-minute latency-critical operations are performed before the cull of the current frame can start; and the noncritical portion, after **pfFrame()** and before **pfSync()**. The critical section is displayed in the channel statistics graph drawn with **pfDrawChanStats()**.
- Provides an efficient mechanism to automatically propagate database changes down the process pipeline, and provides **pfPassChanData()** for passing custom application data down the process pipeline.
- Minimizes overhead copying database changes to the cull process by accumulating unique changes and updating the cull once inside **pfFrame()**. This updated period is displayed in the MP statistics of the channel statistics graph drawn with **pfDrawChanStats()**.
- Provides a mechanism for performing database intersections in a forked process: pass the **PFMP_FORK_ISECT** flag to **pfMultiprocess()** and declare an intersection callback with **pfIsectFunc()**.
- Provides a mechanism for performing database loading and editing operations in a forked process, such as the DBASE process: pass the **PFMP_FORK_DBASE** flag to **pfMultiprocess()** and declare an intersection callback with **pfDBaseFunc()**.

Specific Guidelines for Optimizing Performance

While IRIS Performer provides inherent performance optimization, there are specific techniques you can use to increase performance even more. This section contains some guidelines and advice pertaining to database organization, code structure and style, managing system resources, and rules for using IRIS Performer.

Graphics Pipeline Tuning Tips

Tuning the graphics pipeline requires identifying and removing bottlenecks in the pipeline. You can remove a bottleneck either by minimizing the amount of work being done in the stage that has the bottleneck or, in some cases, by reorganizing your rendering to more effectively distribute the workload over the pipeline stages. This section contains specific tips for finding and removing bottlenecks in each stage of the graphics pipeline. For more information on this topic, refer to the graphics library documentation (see “Bibliography” on page xxxvii for information on ordering these books).

Host Bottlenecks

Here are some ways to minimize the time spent in the host stage of the graphics pipeline:

- Function calls, loops, and other programming constructs require a certain amount of overhead. To make such constructs cost-effective, make sure they do as much work as possible with each invocation. For instance, drawing a `pfGeoSet` of triangle strips involves a nested loop, iterating on strips within the set and triangles within each strip; it therefore makes sense to have several triangles in each strip and several strips in each set. If you put only two triangles in a `pfGeoSet`, you’ll spend all that loop overhead on drawing those two triangles, when you could be drawing many more with little extra cost. The channel statistics can display (as part of the graphics statistics) a histogram showing the percentage of your database that is drawn in triangle strips of certain lengths.
- Only bind vertex attributes that are actually in use. For example, if you bind per-vertex colors on a set of flat-shaded quads, the software will waste work by sending those colors to the graphics pipeline, which will ignore them. Similarly, it’s pointless to bind normals on an unlit `pfGeoSet`.
- Nonindexed drawing has less host overhead than indexed drawing because indexed drawing requires an extra memory reference to get the vertex data to the graphics pipeline. This is most significant for primitives that are easily host-limited, such as independent polygons or very short triangle strips. However, indexed drawing can be very helpful in reducing the memory requirements of a very large database.
- Enable state sorting for `pfChannels` (this is the default). By sorting, the CPU does not need to examine as many `pfGeoStates`. The graphics channel statistics can be used to report the `pfGeoSet`-to-`pfGeoState` drawing ratio.

Transform Bottlenecks

A transform bottleneck can arise from expensive vertex operations, from a scene that's typically drawn with many very tiny polygons, from a scene modeled with inefficient primitive types, or from excessive mode or transform operations. Here are some tips on reducing such bottlenecks:

- Connected primitives will have better vertex rates than independent primitives, and quadrilaterals are typically much more efficient in vertex operations than independent triangles are.
- The expensive vertex operations are generally lighting calculations. The fastest lighting configuration is always one infinite light. Multiple lights, local viewing models, and local lights have (in that order) dramatically increasing cost. Two-sided lighting also incurs some additional transform cost. On some graphics platforms, texturing and fog can add further significant cost to per-vertex transformation. The channel graphics statistics will tell you what kinds of lights and light models are being used in the scene.
- Matrix transforms are also fairly expensive, and definitely more costly than one or two explicit scale, translate, or rotate operations. When possible, flatten matrix operations into the database with **pfFlatten()**.
- The most frequent causes of mode changes are **shademodel()** (or **glShadeModel()**), textures, and object materials. The speed of these changes depends on the graphics hardware; however, material changes do tend to be expensive. Sharing materials among different objects can be increased with the use of **pfMtlColorMode()** that is **PFMTL_CMODE_AD** by default. However, on some older graphics platforms (such as the **Elan**, **Extreme**, and **VGX**), the use of **pfMtlColorMode()** (which actually calls the IRIS GL function **lmcolor()** or the OpenGL function **glColorMaterial()**) has some associated per-vertex cost and should be used with some caution.
- If your cull stage is not a bottleneck, make sure your **pfChannels** sort the scene by graphics state. Even if you are running in single process mode, the extra time taken to sort the database is often more than offset by the savings in rendering time. See "Sorting the Scene" in Chapter 4 for more details on how to configure sorting.

Fill Bottlenecks

Here are some methods of dealing with fill-stage bottlenecks:

- One technique to hide the cost of expensive fill operations is to fill the pipeline from the back forward so that no part is sitting idle waiting for an upstream stage to finish. The last stage of the pipeline is the fill stage, so by drawing backgrounds or clearing the screen via **pfClearChan()** first, before **pfDraw()**, you can keep the fill stage busy. In addition, if you have a couple of large objects that reliably occlude much of the scene, drawing them very early on can both fill up the back-end stage and also reduce future fill work, because the occluded parts of the scene will fail a z-buffer test and will not have to write z values to the z-buffer or go on to more complex fill operations.
- Use the **pfStats** fill statistics (available for display through the channel statistics) to visualize your depth complexity and get a count of how many pixels are being computed each frame.
- Be aware of the cost of any fill operations you use and their relative cost on the relevant graphics hardware configuration. Quick experiments you can do to test for a fill limitation include:
 - Rendering the scene into a smaller window, assuming that doing so will not otherwise affect the scene drawn (a non-zero **pfChannel** LOD scale will cause a change in object LODs when you shrink the window).
 - Using **pfOverride()** to force the disabling of an expensive fill mode.

If either of these tests causes a significant reduction in the time to draw the scene, then a significant fill bottleneck probably exists.

Note: Some features may invoke expensive modes that need to be used with caution on some hardware platforms. **pfAntialias()** and **pfTransparency()** enable blending if multisampling isn't available. Globally enabling these functions on machines without multisampling can produce significant performance degradation due to the use of blending for an entire scene. Blending of even opaque objects incurs its full cost. **pfDecal()** may invoke stenciling (particularly if you have requested the decal mode **PFDECAL_BASE_HIGH_QUALITY** or if there is no faster alternative on the current hardware platform), which can cause performance degradations on some system. **pfFeature()** can be used to verify the availability and speed of these features on the current graphics platform.

- The cost of specific fill operations can vary greatly depending on the graphics hardware configuration. As a rule of thumb, flat shading is much faster than Gouraud shading because it reduces both fill work and the host overhead of specifying per-vertex colors. Z-buffering is typically next in cost, and then stencil and blending. On a **RealityEngine**, the use of multisampling can add to the cost of some of these operations, specifically z-buffering and stenciling. See “Multisampling” on page 620 for more information. Texturing is considered free on **RealityEngine** and **Impact** systems but is relatively expensive on a **VGX** and is actually done in the host stage on lower-end graphics platforms, such as **Extreme** and **XZ**. Some of the low-end graphics platforms also implement z-buffering on the host.
- You may not be able to achieve benchmark-level performance in all cases for all features. For instance, if you frequently change modes and you use short triangle strips, you get much less than the peak triangle mesh performance quoted for the machine. Fill rates are sensitive to both modes, mode changes, and polygon sizes. As a general rule of thumb, assume that fill rates average around 70% of peak on general scenes to account for polygon size and position as well as for pipeline efficiency.

Process Pipeline Tuning Tips

These simple tips will help you optimize your IRIS Performer process pipeline:

- Use **pfMultiprocess()** to set the appropriate process model for the current machine.
- You usually shouldn't specify more processes with **pfMultiprocess()** than there are CPUs on the system. The default multiprocess mode (PFMP_DEFAULT) attempts an optimal configuration for the number of unrestricted CPUs. However, if there are fewer processors than significant tasks (consider APP, CULL, DRAW, ISECT, DBASE) you will want experiment with the different two-process models to find the one that will yield the best overall frame rate. Use of **pfDrawChanStats()**, described in Chapter 18, “Statistics,” will greatly help with this task.
- Put only latency-critical tasks between the **pfSync()** and **pfFrame()** calls. For example, put latency-critical updates, like changes to the viewpoint, after **pfSync()** but before **pfFrame()**. Put time-consuming tasks, such as intersection tests and system dynamics, after **pfFrame()**.
- You will also want to refer to the IRIS REACT™ documentation for setting up a real-time system.

- For maximum performance, use the IRIS Performer utilities in *libpfutil* for setting non-degrading priorities and isolating CPUs (**pfuPrioritizeProcs()**, **pfuLockDownProc()**, **pfuLockDownApp()**, **pfuLockDownCull()**, **pfuLockDownDraw()**). These facilities require that the application runs with root permissions. The source code for these utilities is in */usr/share/Performer/src/lib/libpfutil/lockcpu.c*. For an example of their use, see the sample source code in */usr/share/Performer/src/pguide/libpf/C/bench.c*. For more information about priority scheduling and real-time programming, see the chapter of the *IRIX System Programming Guide* entitled “Using Real-Time Programming Features.” and the IRIX REACT technical report.
- Make sure you aren’t generating any floating-point exceptions. Floating-point exceptions can cause an individual computation to incur tens of times its normal cost. Furthermore, a single floating point exception can lead to many further exceptions in computations that use the exceptional result and can even propagate performance degradation down the process pipeline. IRIS Performer will detect and tell you about the existence of floating point exceptions if your **pfNotifyLevel()** is set to `PFNFY_INFO` or `PFNFY_DEBUG`. You can then run your application in `dbx` and your application will stop when it encounters an exception, enabling you to trace the cause.
- Make sure the main pipeline (APP, CULL, DRAW processes) do not make per-frame memory allocations or deallocations (asynchronous processes like DBASE can do per-frame allocations). You can use the `libdmalloc` runtime malloc debugging library’s tracing feature to verify that no memory allocation routines are being called. See the “Memory Corruption and Leaks” section later in this chapter for more about `libdmalloc`.
- Minimize the amount of channel data allocated by **pfAllocChanData()** and call **pfPassChanData()** only when necessary to reduce the overhead of copying the data. Copying pointers instead of data is often sufficient.

Cull Process Tips

Here are a couple of suggestions for tuning the cull process:

- The default channel culling mode enables all types of culling. If your cull process is your most expensive task, you may want to consider doing less culling operations. When doing database culling, always use view-frustum culling (PFCULL_VIEW), and usually use graphics library mode database sorting (PFCULL_SORT) and pfGeoSet culling (PFCULL_GSET) as well:

```
pfChanTravMode(chan, root,  
               PFCULL_VIEW | PFCULL_GSET | PFCULL_SORT);
```

A cull-limited application might realize a quick gain from turning off pfGeoSet culling. If you think your database has few textures and materials, you might turn off sorting. However, if possible it would be better to try improving cull performance by improving database construction. “Efficient Intersection and Traversals” on page 602 discusses optimizing cull traversals in more detail.

- Look at the channel culling statistics for:
 - A large amount of the database being traversed by the culling process and being trivially rejected as not being in the viewing frustum. This can be improved with better spatial organization of the database.
 - A large number of database nodes being non-trivially culled. This can be improved with better spatial organization and breakup of large pfGeodes and pfGeoSets.
 - A surprising number of LODs in their fade state (the fade computations can be expensive, particularly if channel stress management has been enabled).
- Balance the database hierarchy with the scene complexity: the depth of the hierarchy, the number of pfGeoStates, and the depth of culling. See “Balancing Cull and Draw Processing with Database Hierarchy” on page 604 for details.
- pfNodes that have significant evaluation in the cull stage include pfBillboards, pfLightPoints, pfLightSources, and pfLODs.

Draw Process Tips

Here are some suggestions specific to the draw process:

- Minimize host work done in the draw process before the call to **pfDraw()**. Time spent before the call to **pfDraw()** is time that the graphics pipeline is idle. Any graphics library (or X) input processing or mode changes should be done after **pfDraw()** to take effect the following frame.
- Use only one **pfPipe** per hardware graphics pipeline and preferably one **pfPipeWindow** per **pfPipe**. Use multiple channels within that **pfPipeWindow** to manage multiple views or scenes. It's fairly expensive to simultaneously render to multiple graphics windows on a single hardware graphics pipeline and is not advisable for a real-time application.
- Pre-define and pre-load all of the textures in the database into hardware texture memory by using a **pfApplyTex()** function on each **pfTexture**. You can do this texture-applying in the **pfConfigStage()** draw callback or (for multipipe applications to allow parallelism) the **pfConfigPWin()** callback. This approach avoids the huge performance impact that results when textures are encountered for the first time while drawing the database and must then be downloaded to texture memory. Utilities are provided in *libpfutil* to apply textures appropriately; see the **pfuDownloadTexList()** routine in the distributed source code file */usr/share/Performer/src/lib/libpfutil/tex.c*. The *perfly* application demonstrates this; see the *perfly* source file *generic.c* in either the C-language (*/usr/share/Performer/src/sample/C/common*) or C++ language (*/usr/share/Performer/src/sample/C++/common*) versions of *perfly*.
- Minimize the use of **pfSCSs** and **pfDCSs** and nodes with draw callbacks in the database since aggressive state sorting is kept local to subtrees under these nodes.
- Don't do any graphics library input handling in the draw process. Instead, use X input handling in an asynchronous process. IRIS Performer provides utilities for asynchronous input handling in *libpfutil* with source code provided in */usr/share/Performer/src/lib/libpfutil/input.c*. For a demonstration of asynchronous X input handling, see provided sample applications, such as *perfly*, and also the distributed sample programs */usr/share/Performer/src/pguide/libpf/C/motif.c* and */usr/share/Performer/src/pguide/libpfui/C/motifxformer.c*.

Efficient Intersection and Traversals

Here are some tips on optimizing intersections and traversals:

- Use `pfPartition` nodes on pieces of the database that will be handed to intersection traversal. These nodes impose spatial partitioning on the subgraph beneath them, which can dramatically improve the performance of intersection traversals.
Note: Subgraphs under `pfDCS`, `pfLOD`, `pfSwitch`, and `pfSequence` nodes are not partitioned so intersection traversals of these subgraphs will not be affected.
- Use intersection caching. For static objects, enable intersection caching at initialization—first call `pfNodeTravMask()`, specifying intersection traversal (`PFTRAV_ISECT`), and then include `PFTRAV_IS_CACHE` in the mode for intersections. You can turn this mode on and off for dynamic objects as appropriate.
- Use intersection masks on nodes to eliminate large sections of the database when doing intersection tests. Note that intersections are `sproc()`-safe in the current version of IRIS Performer; you can check intersections in more than one process.
- Bundle segments for intersections with bounding cylinders. You can pass as many as 32 segments to each intersection request. If the request contains more than a few segments and if the segments are close together, the traversal will run faster if you place a bounding cylinder around the segments using `pfCylAroundSegs()` and pass that bounding cylinder to `pfNodeIsectSegs()`. The intersection traversal will use the cylinder rather than each segment when testing the segments against the bounding volumes of nodes and `pfGeoSets`.

Database Concerns

Optimizing your databases can provide large performance increases.

libpr Databases

The following tips will help you achieve peak performance when using *libpr*:

- Minimize the number of `pfGeoStates` by sharing as much as possible.
- Initialize each mode in the global state to match the majority of the database, in order to set as little local state for individual `pfGeoStates` as possible.
- Use triangle strips wherever possible; they produce the largest number of polygons from a given number of vertices, so they use the least memory and are drawn the fastest of the primitive types.

- Use the simplest possible attribute bindings and use flat-shaded primitives wherever possible. If you're not going to need an object's attributes, don't bind them—anything you bind will have to be sent to the pipeline with the object.
- Flat-shaded primitives and simple attribute bindings reduce the transformation and lighting requirements for the polygon. Note that the flat-shaded triangle-strip primitive renders faster than a regular triangle strip, but you have to change the index by two to get the colors right (that is, you need to ignore the first two vertices when coloring). See “Attribute Bindings” in Chapter 8 for more information.
- Use nonindexed drawing wherever possible, especially for independent polygon primitives and short triangle strips.
- When building the database, avoid fragmentation in memory of data to be rendered. Minimize the number of separate data and index arrays. Keep the data and index arrays for pfGeoSets contiguous and try to keep separate pfGeoSets contiguous to avoid small, fragmented **pfMalloc()** memory allocations.
- The ideal size of a pfGeoSet (and of each triangle strip within the pfGeoSet) depends a great deal on the specific CPU and system architecture involved; you may have to do benchmarks to find out what's best for your machine. For a general rule of thumb, use at least 4 triangles per strip on any machine, and 8 on most. Use 5 to 10 strips in each pfGeoSet, or a total of 24 to 100 triangles per pfGeoSet.

libpf Databases

When you're using *libpf*, the following tips can improve the performance of database tasks:

- Use **pfFlatten()**, especially when a pfScene contains many small instanced objects and billboards. Use **pfdCleanTree()** and (if application considerations permit) **pfdFreezeTransforms()** to minimize the cull traversal processing time and maximize state sorting scope.
- Initialize each mode in the scene pfGeoState to match the majority of the database, in order to set as little local state for individual pfGeoStates as possible. The utility function **pfdMakeSharedScene()** provides an easy to use mechanism for this task.
- Minimize the number of very small pfGeoSets (that is, those containing four or fewer total triangles). Each tiny pfGeoSet means another bounding box to test against if you're culling down to the pfGeoSet level (that is, when PFCULL_GSET is set with **pfChanTravMode()**) as well as another item to sort during culling. (If your pfGeoSets are large, on the other hand, you should definitely cull down to the pfGeoSet level.)

- Be sparing in the use of pfLayers. Layers imply that pixels are being filled with geometry that is not visible. If fill performance is a concern, this should be minimized in the modeling process by cutting layers into their bases when possible. However, this will produce more polygons which require more transform and host processing so it should only be done if it will not greatly increase database size.
- Make the hierarchy of the database spatially coherent so that culling will be more accurate and geometry that is outside the viewing frustum will not be drawn. (See Figure 4-3 for an example of a spatially organized database.)

Balancing Cull and Draw Processing with Database Hierarchy

Construct your database to minimize the draw-process time spent traversing and rendering the culled part of the database without the cull-process time becoming the limiting performance factor. This process involves making tradeoffs as a simpler cull means a less efficient draw stage. This section describes these tradeoffs and some good rules to follow to give you a good start.

If the cull and draw processes are performed in parallel, the goal is to minimize the larger of the culling and drawing times. In this case, an application can spend approximately the same amount of time on each task. However, if both culling and drawing are performed in the same process, the goal is to optimize the sum of these two times, and both processes must be streamlined to minimize the total frame time. Important parameters in this optimization include the number of pfGeoSets, the average branching factor of the database hierarchy, and the enabled channel culling traversal modes. The **pfDrawChanStats()** function (see Chapter 18, “Statistics”) can easily provide diagnostic information to aid in this tuning.

The average number of immediate children per node can directly affect the culling process. If most nodes have a high number of children, the bounding spheres are more likely to intersect the viewing frustum and all those nodes will have to be tested for visibility. At the other extreme, a very low number of children per node will mean that each bounding sphere test can only eliminate a small part of the database and so many nodes may still have to be traversed. A good place to start is with a quad-tree type organization where each node has about four children and the bounding geometry of sibling nodes are adjacent but have minimal intersection. In the ideal case, projected to a two-dimensional plane on the ground, the spatial extent of each node and its parents would form a hierarchy of boxes.

The transition from pfGeodes to pfGeoSets is an important point in the database structure. If there are many very small pfGeoSets within a single pfGeode, not culling down to pfGeoSets can actually improve overall frame time because the cost of drawing the tiny pfGeoSets may be small relative to the time spent culling them. Adding more pfGeodes to break up the pfGeoSets can help by providing a slightly more accurate cull at less cost than considering each pfGeoSet individually. In addition, pfGeodes are culled by their bounding spheres, which is faster than the culling of pfGeoSets which are culled by their bounding boxes.

The size (both spatial extent and number of triangles) can also directly impact culling and drawing performance. If pfGeoSets are relatively large, there will be fewer to cull so pfGeoSet culling can probably be afforded. pfGeoSets with more triangles will draw faster. However, pfGeoSets with larger spatial extent are more likely to have geometry that is being drawn that is outside of the viewing frustum which wastes time in the graphics stage. Breaking up some of the large pfGeoSets can improve graphics performance by allowing a more accurate cull.

With some added cost to the culling task, the use of Level-of-Detail nodes (pfLODs) can make a tremendous difference in graphics performance and image quality. LODs allow objects to be automatically drawn with a simplified version when they are in a state that yields little contribution to the scene (such as being far from the eyepoint). This allows you to have many more objects in your scene than if you always were drawing all objects at full complexity. However, you do not want the cull to be testing all LODs of an object every frame when only one will be used. Again, proper use of hierarchy can help. pfLODs (non-fading) can be inserted into the hierarchy with actual object pfLODs grouped beneath them. If the parent LOD is out of range for the current viewpoint, the child LODs will never be tested. The pfLODs of each object can be placed together under a pfGroup so that no LOD tests for the object will be done if the object is outside of the viewing frustum.

Calling **pfFlatten()**, **pfFreezeTransforms()**, or **pfCleanTree()** to remove extraneous nodes can often help culling performance. Use **pfFlatten()** to de-instance and apply pfSCS node transformations to leaf geometry—resulting in less work during the cull traversal. This will allow both better database sorting for the draw, and also better caching of matrix and bounding information which can speed up culling. When these scene graph modifications are not acceptable, you may reduce cull time by turning off culling of pfGeoSets but this will directly impact rendering performance by forcing the rendering of geometry that is outside the viewing frustum.

Tip: Making the scene into a graphics library object in the draw callback can show the result of the cull, which can give a visual check of what is actually being sent to the graphics subsystem. Check for objects that are far from the viewing frustum, which can indicate that the `pfGeodes` or `pfGeoSets` need to be broken up. Additionally, the rendering time of the GL object should be compared to the `pfDraw()` rendering time to see if the `pfGeoSets` have enough triangles in them to not incur host overhead. Alternately, the view frustum can be made larger than that used in the cull to allow simple *cull volume visualization* during real-time simulation. The IRIS Performer sample program *perfly* supports this option. Press the `z` key while in *perfly* to enable cull volume visualization and inspect the resulting images for excessive off-screen geometric content. Such content is a clear sign that the database could profitably be further subdivided into smaller components.

The code fragment in Example 19-1, taken from the sample program `/usr/share/Performer/src/pguide/libpf/C/bench.c`, makes an IRIS GL object and then temporarily draws that instead of calling `pfDraw()`.

Example 19-1 Drawing an Object Without Calling `pfDraw()`

```
if (SharedFlags->glObject == MAKE_GL_OBJECT)
{
    static have_obj = 0;

    fprintf(stderr, "Making object\n");
    if (have_obj)
        delobj(1);
    makeobj(1); /* OpenGL: glNewList() */
    pfDraw();
    closeobj(); /* OpenGL: glEndList() */
    SharedFlags->glObject = DRAW_GL_OBJECT;
    have_obj = 1;
}
else if (SharedFlags->glObject == DRAW_GL_OBJECT)
    callobj(1); /* OpenGL: glCallList() */
else if (SharedFlags->glObject == PERF_DRAW)
    pfDraw();
```

Graphics and Modeling Techniques to Improve Performances

On machines with fast texture mapping, texture should be used to replace complex geometry. Complex objects, such as trees, signs, and building fronts, can be effectively and efficiently represented by textured images on single polygons in combination with applying `pfAlphaFunc()` to remove parts of the polygon that don't appear in the image.

Using texture to reduce polygonal complexity can often give both an improved picture and improved performance. This is because

- The image texture provides scene complexity, and the texture hardware handles scaling of the image with MIP-map interpolation functions for minification (and, on **RealityEngine** systems, Sharpen and DetailTexture functions for magnification).
- Using just a few textured polygons rather than a complex model containing many individual polygons reduces system load.

In order to represent a tree or other 3D object as a single textured polygon, IRIS Performer can rotate polygons to always face the eyepoint. An object of this type is known as a billboard and is represented by a `pfBillboard` node. As the viewer moves around the object, the textured polygon rotates so that the object appears three-dimensional. For more information on billboards, see “`pfBillboard` Nodes” in Chapter 3.

To determine if the current graphics platform has fast texture mapping, look for a `PFQFTR_FAST` return value from:

```
pfFeature(PFQFTR_TEXTURE, &ret);
```

pfAlphaFunc() with a function `PFAF_EQUAL` and a reference value greater than zero can be used whenever transparency is used to remove pixels of low contribution and avoid their expensive processing phase.

Special Coding Tips

For maximum performance, routines that make extensive use of the IRIS Performer linear algebra routines should use the macros defined in *prmath.h* to allow the compiler to in-line these operations.

Use single- rather than double-precision arithmetic where possible and avoid the use of short-integer data in arithmetic expressions. Append an ‘f’ to all floating point constants used in arithmetic expressions.

BAD In this example, values in both of the expressions involving the floating point variable *x* are promoted to double precision when evaluated:

```
float x;  
if (x < 1.0)  
    x = x + 2.0;
```

GOOD In this example, both of the expressions involving the floating point variable *x* remain in single-precision mode, because there is an 'f' appended to the floating point constants:

```
float x;  
if (x < 1.0f)  
    x = x + 2.0f;
```

Performance Measurement Tools

Performance measurement tools can help you track the progress of your application by gathering statistics on certain operations. IRIS Performer provides run-time profiling of the time spent in parts of the graphics pipeline for a given frame. The **pfDrawChanStats()** function displays application, cull, and draw time in the form of a graph drawn in a channel; see Chapter 18, "Statistics," for more information on that and related functions. There are advanced debugging and tuning tools available from Silicon Graphics that can be of great assistance. WorkShop product in the CASEVision™ tools provides a complete development environment for debugging and tuning of host tasks. The Performance Co-Pilot™ helps you to tune host code in a real-time environment. There is also the WindView™ product from WindRiver that works with IRIX REACT to do full system profiling in a real-time environment. However, progress can be made with the basic tools that are in the IRIX development environment: *prof*, *pixie*, and *glprof*. The IRIS GL debugging utility, *gldebug*, can also be used to aid in performance tuning, as can the OpenGL equivalent, *ogldebug*. This section briefly discusses getting started with these tools.

Note: See the graphics library manuals, available from Silicon Graphics, for complete instructions on using these graphics tools. See the *IRIX System Programming Guide* to learn more about *pixie* and *prof*.

Using *pixie* and *prof* to Measure Performance

You can use the IRIX performance analysis utilities *pixie* and *prof* to tune the application process. Use *pixie* for basic-block counting and use *prof* for *program counter* (PC) sampling. PC sampling gives run-time estimation of where significant amounts of time are spent, whereas basic-block counting will report the number of times a given instruction is executed.

To isolate statistics for the application process, even in single-process models, run the application through *pixie* or *prof* in APP_CULL_DRAW mode to separate out the process of interest. Both *pixie* and *prof* can generate statistics for an individual process.

When using IRIS Performer DSO libraries with *prof* you may want to provide the `-dso` option to *prof* with the full pathname of the library of interest to have IRIS Performer routines included in the analysis. When using *pixie* you will need to have the *pixie* versions of the DSO libraries in your LD_LIBRARY_PATH. Additionally, you will need a *pixie* version of the loader DSO for your database in your LD_LIBRARY_PATH. You may have to *pixie* the loader DSO separately since *pixie* will not find it automatically if your executable was not linked with it. When using *prof* to do PC sampling, link with unshared libraries exclusively and use the `-p` option to *ld*. Then set the environment variable PROFDIR to indicate the directory in which to put profiling data files.

When profiling, run the program for a while so that the initialization will not be significant in the profiling output. When running a program for profiling, run a set number of frames and then use the automatic exit described below.

Using *gldebug* and *ogldebug* to Observe Graphics Calls

You can use the graphics utilities *gldebug* (IRIS GL) and *ogldebug* (OpenGL) to both debug and tune IRIS Performer applications. The application must be run in single-process mode in order to use *gldebug* but *ogldebug* can handling multiprocessed programs.

Use *gldebug* or *ogldebug* to:

- Show which graphics calls are being issued.
- Look for frequent mode changes, or unnecessary mode settings that can be caused if your initialization of the global state doesn't match the majority of the database.
- Look for unnecessary vertex bindings such as unneeded per-vertex colors, or normals for a flat-shaded object.

Follow these steps to examine one frame of the application in a *gldebug* session:

1. Start up profiler of choice:

```
IRIS% gldebug -i ignore -s -F your_prog_name prog_options
OPEN% ogldebug your_prog_name prog_options
```

2. Turn off output and breakpoints from the control panel.
3. Set a breakpoint at **swapbuffers()** or **glXSwapBuffers()**.
4. Click the “Continue” button and go to the frame of interest.
5. Turn on breakpoints.

Execution stops at **swapbuffers()** (or **glXSwapBuffers()**).

6. Turn on all trace output.
7. Click the “Continue” button.

Execution stops at the next **swapbuffers()**, outputting one full scene to *GLdebug.history* (or *progrname.pid.trace* for *ogldebug*).

8. Quit and examine the output.

Note: Since IRIS Performer avoids unnecessary mode settings, recording one frame shows modes that are set during that frame, but it doesn’t reflect modes that were set previously. It’s therefore best to have a program that can come up in the desired location and with the desired modes, then grab the first two frames: one for initialization, and one for continued drawing.

Using *glprof* to Find Performance Bottlenecks

You can use the IRIS GL graphics-profiling utility *glprof* to estimate where there are graphics bottlenecks so that you can tune the database. You don’t have to relink the program or run it in single-process mode to use *glprof*.

Use *glprof* to:

- See if certain views or individual objects are inherently fill- or transform-limited
 - If a scene or object is fill-limited, there can be more complex geometry in the LOD(s).
 - If a scene or object is transform-limited, you need to simplify or add LOD(s), especially for small objects.

- See significant mode changes
- Get additional scene graphics state and fill statistics such as the number of pixels fixed with polygons of different sizes and different modes

Note that since only *glprof* simulates the graphics pipeline, it may not always be entirely accurate in predicting performance.

You can use predraw callbacks on nodes to output *glprof_object* tags that will appear in a *glprof* trace. This method has the disadvantage of turning off sorting, which may increase the number of mode changes and also the balance of bottlenecks in the scene because it may change the drawing order. However, it has the advantage of giving per-object drawing statistics, and it indicates whether a specific object is fill- or transform-limited.

Example 19-2 shows sample code for a traversal that installs and removes the *glprof* object tags taken from *trav.c*. The example demonstrates general-user traversal code, then uses this traversal to install and remove *glprof* callbacks. This code is simplified from that found in */usr/src/Performer/src/lib/libpfutil/trav.c*.

Example 19-2 General Traversal

```
void
InitMyTraverser(MyTraverser *trav)
{
    trav->preFunc = NULL;
    trav->postFunc = NULL;
    trav->mstack = NULL;
    trav->data = NULL;
    trav->node = NULL;
    trav->depth = 0;
}

/* handle return value for pruning or terminating */
#define PFU_DO_RET(_ret) \
    switch (_ret) \
    { \
    case PFTRAV_PRUNE: \
        trav->node = prevNode; \
        if (needPop) \
            pfPopMStack(trav->mstack); \
        return PFTRAV_CONT; \
    case PFTRAV_TERM: \
        trav->node = prevNode; \
        if (needPop) \
```

```

        pfPopMStack(trav->mstack); \
        return PFTRAV_TERM; \
    }

int
MyTraverse(pfNode *node, MyTraverser *trav)
{
    int          i;
    int          numChild = 1;
    int          ret = PFTRAV_CONT, needPop = 0;
    pfNode      *prevNode = trav->node;

    if (node == NULL)
    {
        pfNotify(PFNFY_WARN, PFNFY_USAGE,
                "MyTraverse() Null node");
        return PFTRAV_CONT;
    }
    /*
     * for SCS and DCS push the transform on the stack
     */
    if (pfIsOfType(node, pfGetSCSClassType()) &&
        trav->mstack)
    {
        pfMatrix      mat;

        pfGetSCSMat((pfSCS *)trav->node, mat);

        pfPushMStack(trav->mstack);
        pfPreMultMStack(trav->mstack, mat);
        needPop = 1;
    }

    /* call pre-traversal callback */
    trav->node = (pfNode *)node;
    if (trav->preFunc)
        ret = (*trav->preFunc)(trav);

    PFU_DO_RET(ret);

    /* after preFunc, in case topology changed */
    if (pfIsOfType(node, pfGetGroupClassType()))
    {
        numChild = pfGetNumChildren(node);
        if (pfIsOfType(node, pfGetGroupClassType()))

```

```

        for (i = 0 ; i < numChild ; i++)
        {
            trav->depth++;
            ret = MyTraverse((pfNode*)pfGetChild(group,
                i), trav);
            trav->depth--;
            PFU_DO_RET(ret);
        }
    }

    PFU_DO_RET(ret);

    /* call post traversal callback */
    trav->node = node;
    if (trav->postFunc)
        ret = (*trav->postFunc)(trav);

    PFU_DO_RET(ret);

    if (needPop)
        pfPopMStack(trav->mstack);

    return PFTRAV_CONT;
}

/*****
 * Traversals and callbacks for installing and removing
 * pre-draw callbacks (pfNodeTravFuncs) for generating GL * Prof tags
during drawing
 * WARNING: removes any existing pre or post-draw callbacks
 *****/

/*
 * glprof pre-draw traversal callback
 * issues glprof_object calls
 */
static int
cbGLProf(pfTraverser *trav, void *data)
{
    const pfNode      *node = pfGetTravNode(trav);
    const char        *nn;
    static char        name[80];

    if (node != NULL &&
        (nn = pfGetNodeName(node)))

```

```
{
    /* if it exists, use the node name for the tag */
    strncpy(name, nn, 79);
}
else
{
    /* otherwise, use the node type string for the tag */
    strncpy(name, pfGetTypeString((pfObject *)node), 79);
}
glprof_object(name);
return 0;
}
/*
 * callback for placing glprof callbacks as
 * pre-draw callbacks on nodes
 */
static int
cbPutGLProfTag(MyTraverser *trav)
{
    pfNode *node = trav->node;
    if (node != NULL &&
        ((pfIsOfType(node, pfGetGeodeClassType())
         pfNodeTravFuncs(node, PFTRAV_DRAW, cbGLProf, NULL));
        return PFTRAV_CONT;
}

/*
 * callback to remove the pre-draw glprof tag callbacks
 */
static int
cbRmGLProfTag(MyTraverser *trav)
{
    pfNode *node = trav->node;
    if (node != NULL &&
        (pfIsOfType(node, pfGetGeodeClassType()) ||
         pfIsOfType(node, pfGetGroupClassType())))
        pfNodeTravFuncs(node, PFTRAV_DRAW, NULL, NULL);
    return PFTRAV_CONT;
}

/* glprof object tag traversal */
void
DoGLProfTraversal(pfNode *node, int mode)
{
    MyTraverser trav;
```

```

InitMyTraverser(&trav);

pfNotify(PFNFY_INFO, PFNFY_PRINT,
         "doing travGLProf: mode = %d", mode);

if (mode) /* place glprof tag callbacks */
    trav.preFunc = cbPutGLProfTag;
else     /* remove the callbacks */
    trav.preFunc = cbRmGLProfTag;

MyTraverse(node, &trav);
}

```

Use this traverser in a program with a code fragment like that in Example 19-3.

Example 19-3 Using the Traverser

```

{
    /* mode = 1 - install glprof tag node callbacks
     * mode = 0 - remove glprof tag node callbacks
     */
    DoGLProfTraversal((pfNode *)scene, DBGT_GLPROF, mode);
}

```

Guidelines for Debugging

This section lists some general guidelines to keep in mind when debugging IRIS Performer applications.

Shared Memory

Because **malloc()** doesn't allocate memory until that memory is used, core dumps may occur when arenas don't find enough disk space for paging. The IRIX kernel can be configured to actually allocate space upon calling **malloc()**, but this change is pervasive and has performance ramifications for **fork()** and **exec()**. Reconfiguring the kernel is not recommended, so be aware that unexplained core dumps can result from inadequate disk space.

Be sure to initialize pointers to shared memory and all other nonshared global values before IRIS Performer creates the additional processes in the call to **pfConfig()**. Values put in global variables initialized after **pfConfig()** will only be visible to the process that set them.

For detailed information about other aspects of shared memory, see “Memory Allocation” in Chapter 13.

Use the Simplest Process Model

When debugging an application that uses a multiprocess model, first use a single-process model to verify the basic paths of execution in the program. You don't have to restructure your code; simply select single-process operation by calling **pfMultiprocess(PFMP_APPCULLDRAW)** to force all tasks to initiate execution sequentially on a frame-by-frame basis.

If an application fails to run in multiprocess mode but runs smoothly in single-process mode, you may have a problem with the initialization and use of data that's shared among processes.

If you need to debug one of multiple processes, use

```
IRIS% dbx -p progname
```

while the process is running. This will show the related processes and allow you to choose a process to trace. The application process will always be the process with the lowest process id. In order after that will be the (default) clock process, then the cull process, and then the draw.

Once the program works, experiment with the different multiprocess models to achieve the best overall frame rate for a given machine. Don't specify more processes than CPUs. Use **pfDrawChanStats()** to compare the frame timings of the different stages and frame times for the different process models.

Avoid Floating-Point Exceptions

Arrange error handling for floating-point operations. To see floating-point errors, turn debug messages on and enable floating-point traps. Set **pfNotifyLevel(PFNFY_DEBUG)**.

The goal is to have no NaN (Not a Number), INF (infinite value), or floating-point exceptions resulting from numerical computations.

When the Debugger Won't Give You a Stack Trace

If a NULL or invalid function pointer is called, the program will die with a segmentation fault, bus error, or illegal instruction, and the debugger will often be unable to give a stack trace.

```
(dbx) where
> 0 <Unknown>() [< unknown >, 0x0]
```

When this happens, you can usually still get a single level of trace by looking at the return address register.

```
(dbx) $ra/i
[main:6, 0x400c18] lw ra,28(sp)
```

Once you know this information, you may be able to set a breakpoint to stop just before the bad function pointer and then get a full stack trace from there.

Tracing Members of IRIS Performer Objects

Debuggers like dbx allow you to set a breakpoint or trace on a particular variable or address in memory.

However, this feature does not work well on programs that use atomic shared memory access functions like `test_and_set()` which are implemented using the MIPS instructions `ll` and `sc`. Calling such a function on an address that is on the same memory page (typically 4096 bytes) as the address where a breakpoint is set will result in the program being killed with a SIGTRAP signal.

IRIS Performer uses `test_then_add()` to implement `pfMemory::ref()` and `pfMemory::unref()`, so you will almost always run into this problem if you try to trace a member of an IRIS Performer object (anything derived from `pfMemory`).

You can get around the problem by setting the following environment variable before running the program:

```
% setenv _PF_OLD_REFCOUNTING
```

This tells IRIS Performer to use an alternate (slower) implementation of shared memory reference counting that avoids the ll and sc operations so that breakpoints on variables can be used.

Memory Corruption and Leaks

A number of tools are available for debugging memory corruption errors and memory leaks; no single one is ideal for all purposes. We will briefly describe and compare two useful tools: purify and libdmalloc.

Purify

Purify is a product of PureAtria; see their web site <http://www.pureatria.com> for ordering information.

Purify works by rewriting your program (and all dynamic shared libraries it uses), intercepting malloc and associated functions, and inserting instruction sequences before each load and store instruction that immediately catch illegal memory accesses (e.g. uninitialized memory reads, out-of-bounds memory reads or writes, freed memory reads or writes, and multiple frees) and also keeps track of memory leaks. When an error is encountered, a stack trace is given for the error, as well as a stack trace from when the memory in question was originally allocated. When used in conjunction with a debugger like dbx, you can set a breakpoint to stop when purify encounters an error so that you can examine the program state.

Purify is immensely useful for tracking down memory problems. Its main drawbacks are that it is very slow (to compile and run programs) and it currently doesn't know about the functions amalloc/afree/arealloc, which are very important in IRIS Performer applications (pfMalloc and associated functions are implemented in terms of them).

You can trick purify into telling you about some shared arena memory access errors by telling the run-time linker to use malloc in place of amalloc; however, this cannot work if there are forked processes sharing the arena, so to use this trick you must run in single-process (PFMP_APPCULLDRAW) mode. To do this, compile the following into a DSO called pureamalloc.so:

```
malloc(int n) {return malloc(n);}
afree(void*p) {free(p);}
arealloc(void*p, int n) {return realloc(p, n);}
```

and tell the runtime linker to point to it:

```
% setenv _RLDN32_LIST `pwd`/pureamalloc.so:DEFAULT
```

(this assumes you are using the N32 ABI; see the rld man page for the equivalents for the O32 and 64 ABIs). Then run “perfly -m0” or any other program in PFMP_APPCULLDRAW mode.

For more information on Purify, visit PureAtria’s web site: <http://www.pureatria.com>.

Libdmalloc

Libdmalloc is a library that was developed internally at Silicon Graphics. It is officially unsupported but you can get it through IRIS Performer’s ftp site.

Libdmalloc is implemented as a dynamic shared object (DSO) that you can link in to your program at runtime. It intercepts all calls to malloc, free, and associated functions, and checks for memory corruption of the particular piece of memory being accessed. It also attempts to purposely break programs that make bad assumptions: it initializes newly malloced (or amalloced) memory with a fill pattern to break programs that depend on it being 0’s, and similarly fills freed memory with a fill pattern to break programs that look at freed memory. Finally, the entire malloc arena and any shared arenas are checked for corruption during exit() and execve(). Error messages are printed to stderr whenever an error is detected (which is typically later than the error actually occurred, unlike purify’s immediate detection). Libdmalloc doesn’t know about UMRs (uninitialized memory reads) or stack variables, unlike purify.

Libdmalloc’s advantages are that it knows about amalloc/afree/arealloc, and it has virtually no overhead, so you can leave it on all the time (it will check for errors in every program you run). If it uncovers a reproducible bug in an area that purify knows about too, then you can use purify to trace the exact location of the problem— purify is much better at that than libdmalloc.

When using libdmalloc, you can easily toggle verbose tracing of all calls to malloc/free/realloc and amalloc/afree/arealloc by sending the processes a signal at runtime— there should be none of these calls per-frame in the main pipeline of a tuned IRIS Performer application.

For more information, install `libdmalloc` from the IRIS Performer ftp site and read the file `/usr/share/src/dmalloc/README` and, for IRIS Performer-specific suggestions, `/usr/share/src/dmalloc/SOURCEME.dmalloc.performer`.

Notes on Tuning for RealityEngine Graphics

This section contains some specific notes on performance tuning with RealityEngine graphics.

Multisampling

Multisampling provides full-scene antialiasing with performance sufficient for a real-time visual simulation application. However, it isn't free and it adds to the cost of some other fill operations. With RealityEngine graphics, most other modes are free until you add multisampling— multisampling requires some fill operations to be performed on every subpixel. This is most noticeable with z-buffering and stenciling operations, but also applies to `blendfunction()` and `glBlendFunc()`. Texturing is an example of a fill operation that can be free on a RealityEngine and isn't affected by the use of multisampling.

The multisampling hardware reduces the cost of subpixel operations by optimizing for pixels that are fully opaque. Pixels that have several primitives contributing to their result are thus more expensive to evaluate and are called *complex pixels*. Scenes usually end up having a very low ratio of complex pixels.

Multisampling offers an additional performance optimization that helps balance its cost: a virtually free screen clear. Technically, it doesn't really clear the screen but rather allow you to set the z values in the framebuffer to be undefined. Therefore, use of this clear requires that every pixel on the screen be rendered every frame. This clear is invoked with a `pfEarthSky` using the `PFES_TAG` option to `pfESkyMode()`. Refer to the `pfEarthSky(3pf)` reference page for more detailed information.

Transparency

There are two ways of achieving transparency on a RealityEngine: blending, and screen-door transparency with multisampling.

Blended transparency, using the IRIS GL **blendfunction()** routine (or the OpenGL **glBlendFunc()** equivalent), can be used with or without multisampling. Blending doesn't increase the number of complex pixels, but is expensive for complex pixels.

To reduce the number of pixels with very low alpha, one can use a **pfAlphaFunc()** that ignores pixels of low alpha, such as alpha less than 3 or 4. This will slightly improve fill performance and probably not have a noticeable effect on scene quality. Many scenes can use values as high as 60 or 70 without suffering degradation in image quality. In fact, for a scene with very little actual transparency, this can reduce the fuzzy edges on textures that simulate geometry (such as trees and fences) that arise from MIP-mapping.

Screen-door transparency gives order-independent transparent effects and is used for achieving the fade-LOD effect. It's a common misperception that screen-door transparency on RealityEngine gives you n levels of transparency for n multisamples. In fact, n samples gives you $4n$ levels of transparency, because RealityEngine uses 2-pixel by 2-pixel dithering. However, screen-door transparency causes a dramatic increase in the number of complex pixels in a scene, which can affect fill performance.

Texturing

Texturing is free on a RealityEngine if you use a 16-bit texel internal texture format. There are 16-bit texel formats for each number of components. These formats are used by default by IRIS Performer but can be set on a **pfTexture** with **pfTexFormat()**. Using a 32-bit texel format will yield half the fill rate of the 16-bit texel formats.

Do not use huge ranges of texture coordinates on individual triangles. This can incur both an image quality degradation and a severe performance degradation. Keep the maximum texture coordinate range for a given component on a single triangle under

$$1 \ll (13 - \log_2(\text{TexCSize}))$$

where *TexCSize* is the size in the dimension of that component.

The use of Detail Texture and Sharpen can greatly improve image quality. Minimize the number of different detail and sharpen splines (or just use the internal default splines). Applying the same detail texture to many base textures can incur a noticeable cost when base textures are changed. Detail textures are intended to be derived from a high-resolution image that corresponds to that of the base texture.

Other Tips

Two final notes on RealityEngine performance:

- Changing the width of antialiased lines and points is expensive.
- **pfMtlColorMode()** (which calls the IRIS GL function **lmcolor()** or the OpenGL function **glColorMaterial()**) has a huge performance benefit.

“Programming with C++”

This chapter discusses the differences in programming using the C and C++ programming interfaces.

Programming with C++

This chapter provides an overview of some of the differences between programming IRIS Performer using the C++ Application Programming Interface (C++ API) rather than the C-language Application Programming Interface (C API) which is described in the earlier chapters of this guide.

Overview

Although this guide uses the C API throughout, the C++ API is in every way equal and in some cases superior in functionality and performance to the C API.

Every function available in the C API is available in the C++ API. All of the C API routines tightly associated with a class have a corresponding member function in the C++ API, for example, **pfGetDCSMat()** becomes **pfDCS::getMat()**. Routines not closely associated with a class are the same in both APIs. Examples include high-level global functions such as **pfMultiprocess()** and **pfFrame()** and low-level graphics functions such as **pfAntialias()**.

Most of the routines associated with a class can be divided into three categories: setting an attribute, getting attribute and acting on the object. In the C API, sets were usually expressed as **pf<Class><Attribute>**, gets as **pfGet<Class><Attribute>** and simple actions as **pf<Action><Class>**, where **<Class>** is the abbreviation for the full name of the class. In some cases where there was no room for confusion or this usage was awkward, the routine names were shortened, for example, **pfAddChild()**.

The principal difference in the naming of member functions in the C++ API and the corresponding routine name in the C-language API is in the naming of member functions where the “pf” prefix and the **<Class>** identifier are dropped. In addition, the word “set” or “get” is prefixed when attribute values are being set or retrieved. Hence, value setting functions are usually have names of the form **pfClass::set<Attribute>**, value getting functions are named **pfClass::get<Attribute>**, and actions appear as **pfClass::<Action>**.

Table 20-1 Corresponding Routines in the C and C++ API

C Routine	C++ Member Function	Description
pfMtlColor()	pfMaterial::setColor()	Set material color
pfGetMtlColor()	pfMaterial::getColor()	Get material color
pfApplyMtl()	pfMaterial::apply()	Apply the material

Note: Member function whose names begin with “pf_”, “pr_” or “nb_” are internal functions and should not be used by applications. These functions may have unpredictable side effects and also should not be overridden by application subclasses.

Class Taxonomy

There are three main types of C++ classes in IRIS Performer. The following description is based on this categorization of the main types: *public structs*, *libpr classes*, and *libpf classes*. A fourth distinct class is pfType, the class used to represent the type of *libpr* and *libpf classes*.

Public Structs

These classes are public structs with exposed data members. They include pfVec2, pfVec3, pfVec4, pfMatrix, pfQuat, pfSeg, pfSphere, pfBox, pfCylinder and pfSegSet.

libpr Classes

These classes derive from pfMemory. When multiprocessing, all processes share the same copy of the object’s data members.

libpf Classes

These classes derive from pfUpdatable and when multiprocessing, each APP, CULL and ISECT process has a unique copy of the object’s data members.

pfType Class

As with the C API, information about the class hierarchy is maintained with pfType objects.

Programming Basics

Header Files

The C++ include files for *libpf* and *libpr* are in */usr/include/Performer/pf* and */usr/include/Performer/pr*, respectively. An application using a class should include the corresponding header file.

Table 20-2 Header Files for *libpf* Scene Graph Node Classes

<i>libpf</i> Class	Include File
pfASD	<Performer/pf/pfASD.h>
pfBillboard	<Performer/pf/pfBillboard.h>
pfDCS	<Performer/pf/pfDCS.h>
pfFCS	<Performer/pf/pfFCS.h>
pfGeode	<Performer/pf/pfGeode.h>
pfGroup	<Performer/pf/pfGroup.h>
pfLOD	<Performer/pf/pfLOD.h>
pfLayer	<Performer/pf/pfLayer.h>
pfLightPoint	<Performer/pf/pfLightPoint.h>
pfLightSource	<Performer/pf/pfLightSource.h>
pfNode	<Performer/pf/pfNode.h>
pfPartition	<Performer/pf/pfPartition.h>
pfSCS	<Performer/pf/pfSCS.h>
pfScene	<Performer/pf/pfScene.h>

Table 20-2 (continued) Header Files for *libpf* Scene Graph Node Classes

<i>libpf</i> Class	Include File
pfSequence	<Performer/pf/pfSequence.h>
pfSwitch	<Performer/pf/pfSwitch.h>
pfText	<Performer/pf/pfText.h>

Table 20-3 Header Files for Other *libpf* Classes

<i>libpf</i> Class	Include File
pfBuffer	<Performer/pf/pfBuffer.h>
pfChannel	<Performer/pf/pfChannel.h>
pfEarthSky	<Performer/pf/pfEarthSky.h>
pfLODState	<Performer/pf/pfLODState.h>
pfMPClipTexture	<Performer/pf/pfMPClipTexture.h>
pfPipe	<Performer/pf/pfPipe.h>
pfPipeWindow	<Performer/pf/pfPipeWindow.h>
pfPipeVideoChannel	<Performer/pf/pfPipeVideoChannel.h>
pfTraverser pfPath	<Performer/pf/pfTraverser.h>

Table 20-4 Header Files for *libpr* Graphics Classes

<i>libpr</i> Class	Include File
pfColortable	<Performer/pr/pfColortable.h>
pfClipTexture	<Performer/pr/pfClipTexture.h>
pfDispList	<Performer/pr/pfDispList.h>
pfFog	<Performer/pr/pfFog.h>
pfFont	<Performer/pr/pfFont.h>
pfGeoSet pfHit	<Performer/pr/pfGeoSet.h>

Table 20-4 (continued) Header Files for *libpr* Graphics Classes

<i>libpr</i> Class	Include File
pfGeoState	<Performer/pr/pfGeoState.h>
pfHighlight	<Performer/pr/pfHighlight.h>
pfLPointState	<Performer/pr/pfLPointState.h>
pfLight pfLightModel	<Performer/pr/pfLight.h>
pfMaterial	<Performer/pr/pfMaterial.h>
pfSprite	<Performer/pr/pfSprite.h>
pfState	<Performer/pr/pfState.h>
pfString	<Performer/pr/pfString.h>
pfTexture pfTexGen pfTexEnv	<Performer/pr/pfTexture.h>

Table 20-5 Header Files for Other *libpr* Classes

<i>libpr</i> Class	Include File
pfCycleBuffer pfCycleMemory	<Performer/pr/pfCycleBuffer.h>
pfDataPool	<Performer/pr/pfDataPool.h>
pfEngine	<Performer/pr/pfEngine.h>
pfFile	<Performer/pr/pfFile.h>
pfFlux	<Performer/pr/pfFlux.h>
pfSphere pfBox pfCylinder pfPolytope pfFrustum pfSeg pfSegSet	<Performer/pr/pfGeoMath.h>

Table 20-5 (continued) Header Files for Other *libpr* Classes

<i>libpr</i> Class	Include File
pfVec2	<Performer/pr/pfLinMath.h>
pfVec3	
pfVec4	
pfMatrix	
pfQuat	
pfMatStack	
pfList	<Performer/pr/pfList.h>
pfMemory	<Performer/pr/pfMemory.h>
pfObject	<Performer/pr/pfObject.h>
pfQueue	<Performer/pr/pfQueue.h>
pfStats	<Performer/pr/pfStats.h>
pfType	<Performer/pr/pfType.h>
pfWindow	<Performer/pr/pfWindow.h>
pfVideoChannel	<Performer/pr/pfVideoChannel.h>

There are additional C++ object classes in the utility libraries. Header files for those classes are similarly named with their own library name for the directory and prefix for the header file name. *Libpui* C++ has a full C++ API and its header files are named like the example, <Performer/pfui/pfTrackball.h>. *Libpfutil* has some C++ classes and the header files are named as <Performer/pfu/pfuProcessManager.h>.

Creating and Deleting IRIS Performer Objects

The IRIS Performer base classes all provide **operator new** and **operator delete**. All *libpr* and *libpf* objects, except *pfObject*, *pfMemory*, and their derivatives, must be explicitly created with **operator new** and deleted with **operator delete**. Objects of these classes cannot be created statically, on the stack or in arrays.

All objects of classes derived from *pfObject* or *pfMemory* are reference counted and must be deleted using **pfDelete()**, rather than the delete operator. **pfDelete()** checks the reference count of the object and when multiprocessing, delays the actual deletion until other processes are done with the object. To decrement the reference count and delete with a single call use **pfUnrefDelete()**.

Note: Public structs such as `pfVec3`, `pfSphere`, etc. may be deleted either with `pfDelete()` or the delete operator.

The default new operator creates objects in the current shared memory arena, if one exists. *libpr* objects and public structures have an additional new operator that takes an arena argument. This new operator allows allocation from the heap (indicated by an arena of NULL) or from a shared memory arena created by the application with `IRIX acreate()`.

Example 20-1 Legal Creation of Objects in C++

```
// legal creation of libpf objects
pfDCS    *dcs = new pfDCS;           // only way

// legal creation of libpr objects
pfGeoSet *gs = new pfGeoSet;        // from default arena
pfGeoSet *gs = new(NULL) pfGeoSet;  // from heap

// legal creation of public structs
pfVec3 *vert = new pfVec3;          // from default arena
pfVec3 *verts = new pfVec3[10];     // array from default
static pfVec3 vert(0.0f, 0.0f, 0.0f); // static
```

Example 20-2 Illegal Creation of Objects in C++

```
// illegal creation of libpf objects
pfDCS    *dcs = new(NULL) pfDCS;    // not in shared mem
pfDCS    *dcs = new pfDCS[10];      // array

// illegal creation of libpr objects
pfGeoSet *gs = new pfGeoSet[10];    // array

// illegal creation of public structs
pfVec3 *vert = new(NULL) pfVec3[10]; // array, non-default new
```

Caution: This last item in Example 20-2 is illegal because C++ does not provide a mechanism to delete arrays of objects allocated with a new operator defined to take additional arguments, for example, `operator new(size_t s, void *arena)`. Attempting to delete an array of objects allocated in this manner can cause unpredictable and fatal results such as the invocation of the destructor a large number of times on pointers inside and outside of the original allocation.

Invoking Methods on IRIS Performer Objects

Since *libpr* and *libpf* objects are allocated, they can only be maintained by reference.

Passing Vectors and Matrices to Other Libraries

Passing arrays of floats is very common in graphics programming. Calls to IRIS GL or OpenGL often require an array of floats or a matrix. In the C API, the data types such as `pfMatrix` are arrays and so can be passed straight through to OpenGL routines, for example,

```
pfMatrix ident;  
pfMakeIdentMat(ident);  
glLoadMatrix(ident);
```

In the C++ API, the data field of the `pfMatrix` must be passed instead, for example,

```
pfMatrix ident;  
ident.makeIdent();  
glLoadMatrix(ident.mat);
```

Porting from C API to C++ API

When compiled with C++, IRIS Performer supports three usages of the API:

1. Pure C++ API. This is the default style of usage.
2. Pure C API. This can be achieved by defining the token `PF_CPLUSPLUS_API` to be 0, for example, by adding the line:

```
#define PF_CPLUSPLUS_API 0
```

in source files before they include any IRIS Performer header files. In this mode all data types are the same as when compiling with C.

3. C++ API and C API. This mode can be enabled by defining the token `PF_C_API` to be 1, for example, by adding the line

```
#define PF_C_API 1
```

in source files before they include any IRIS Performer header files. In this mode, both C++ and C functions are available and data types are C++. See the section below concerning passing certain data types.

Typedefed Arrays vs. Structs

In the C API, the `pfVec2`, `pfVec3`, `pfVec4`, `pfMatrix` and `pfQuat` data types are all typedefed arrays. In the C++ API, they are all structs. When converting C code to use the C++ API or when compiling CAPI code with both APIs enabled, be sure to change routines in your code that pass objects of these types. In the C++ API, you almost always want to pass arguments of these types by reference rather than by value.

For example, the C API routine

```
void MyVectorAdd(pfVec2 dst, pfVec2 v1, pfVec2 v2)
{
    dst[0] = v1[0] + v2[0];
    dst[1] = v1[1] + v2[1];
}
```

should be rewritten for the C++ API to pass by reference

```
void MyVectorAdd(pfVec2& dst, pfVec2& v1, pfVec2& v2)
{
    dst[0] = v1[0] + v2[0];
    dst[1] = v1[1] + v2[1];
}
```

or

```
void MyVectorAdd(pfVec2* dst, pfVec2* v1, pfVec2* v2)
{
    dst->vec[0] = v1->vec[0] + v2->vec[0];
    dst->vec[1] = v1->vec[1] + v2->vec[1];
}
```

Without this change, time will be wasted copying `v1` and `v2` by value and the result will not be returned to the routine calling `MyVectorAdd()`.

Interface Between C and C++ API Code

The same difference in passing conventions applies if you are calling a C function from code that uses the C++ API. Functions passing typedefed arrays with the C API must have a different prototype for use with the C++ API. Macros for use in C prototypes bilingual can be found in `/usr/include/Performer/prmath.h`.

```
#if PF_CPLUSPLUS_API
#define PFVEC2 pfVec2&
#define PFVEC3 pfVec3&
#define PFVEC4 pfVec4&
#define PFQUAT pfQuat&
#define PFMATRIX pfMatrix&
#else
#define PFVEC2 pfVec2
#define PFVEC3 pfVec3
#define PFVEC4 pfVec4
#define PFQUAT pfQuat
#define PFMATRIX pfMatrix
#endif /* PF_CPLUSPLUS_API */
```

These macros are used in the C API prototypes for IRIS Performer that pass typedefed arrays, for example,

```
extern float pfDotVec2(const PFVEC2 v1, const PFVEC2 v2);
```

But they are not necessary or appropriate for when passing pointers to typedefed arrays in C, for example,

```
extern void pfFontCharSpacing(pfFont *font, int ascii,
                             pfVec3 *spacing);
```

because a pointer to a struct is passed in the same manner as a pointer to an array.

Subclassing pfObjects

With the C API, the main mechanism for extending the functionality of the classes provided in IRIS Performer is the specification of the user data pointer on pfObjects with **pfUserData()** and the specification of callbacks on pfNodes with **pfNodeTravFuncs()** and **pfNodeTravData()**. The C++ API also supports these mechanisms, but also provides the additional capacity to subclass new data types from the classes defined in IRIS Performer. Subclassing allows additional member data fields and functions to be added to IRIS Performer classes. At it's simplest, subclassing merely provides a way of adding additional data fields that is more elegant than hanging new data structures off of a pfObject's user data pointer. But in some uses, subclassing also allows significantly more control over the functional behavior of the new object because virtual functions can be overloaded to bypass, replace or augment the processing handled by the parent class from IRIS Performer.

Initialization and Type Definition

The new object should provide two static functions, a constructor that initializes the instances `pfType*` and a static data member for the type system as shown in the following table;

Table 20-6 Data and Functions Provided by User Subclasses

Class Data or Function	Function
static void <code>init()</code>	Initialize the new class
static <code>pfType*</code> <code>getClassType()</code>	Returns the <code>pfType*</code> of the new class
static <code>pfType*</code> <code>classType</code>	Stores the <code>pfType*</code> of the new class
constructor	Sets the <code>pfType*</code> for each instance

The `init()` member function should initialize any data structures that are related to the class as a whole, as opposed to any particular instance. The most important of these is the entry of the class into the type system. For example, the Rotor class defined in the Open Inventor loader (see *Rotor.h* and *Rotor.C* in `/usr/share/Performer/src/lib/libpfdp/libpfiv`) is a subclass of `pfDCS`. It's initialization function merely enters the class into the type system.

Example 20-3 Class Definition for a Subclass of `pfDCS`

```
public Rotor : public pfDCS
{
    static void init();
    static pfType* getClassType(){ return classType; };
    static pfType* classType;
}

pfType *Rotor::classType = NULL;

Rotor::Rotor()
{
    setType(classType); // set the type of this instance
    ...
}

void
Rotor::init()
```

```
{
    if (classType == NULL)
    {
        pfDCS::init();
        classType =
            new pfType(pfDCS::getClassType(), "Rotor");
    }
}
```

As described in the section below, the initialization function, `Rotor::init()` should be called before `pfConfig()`.

Defining Virtual Functions

Below is the example of the Rotor class which specifies the traversal function for the *libpf* application traversal. When overloading a traversal function, it is usually desirable to invoke the parent class function, in this case, `pfDCS::app()`. It is not currently possible to overload *libpf*'s intersection or culling traversals. See "libpf Objects and Multiprocessing" on page 639.

Example 20-4 Overloading the *libpf* Application Traversal

```
int
Rotor::app(pfTraverser *trav)
{
    if (enable)
    {
        pfMatrix mat;
        double now = pfGetFrameTimeStamp();

        // use delta and renorm for large times
        prevAngle += (now - prevTime)*360.0f*frequency;
        if (prevAngle > 360.0f)
            prevAngle -= 360.0f;
        mat.makeRot(prevAngle, axis[0], axis[1], axis[2]);
        setMat(mat);
        prevTime = now;
    }

    return pfDCS::app(trav);
}

int
```

```
Rotor::needsApp(void)
{
    return TRUE;
}
```

The same behavior could also be implemented in either the C or C++ IRIS Performer API using a callback function specified with **pfNodeTravFuncs()**.

Note: Classes of pfNodes that need to be visited during the application traversal even in the absence of any application callbacks should define the virtual function **needsApp()** to return TRUE.

Accessing Parent Class Data Members

Accesses to parent class data is made through the functions on the parent class. Data members on built-in classes should never be accessed directly.

Multiprocessing and Shared Memory

Initializing Shared Memory

In general to assure safe multiprocess operation with any DSOs providing C++ virtual functions or defining new pfTypes. Initialization should be carried out in the following sequence:

1. Call **pfInit()**. This initializes the type system and for *libpf* applications sets up shared memory.
2. Call the init function for utility libraries that you are using if you use their C++ API. This includes **pfuInit()** for *libpfutil* and **pfInit()** for *libpfui*.
3. Initialize any application-supplied classes:
 - a) Load any application-specific C++ DSOs
 - b) Call **pfdInitConverter()** to initialize and load any converter DSOs and allow those DSOs to initialize any potential C++ classes.
 - c) Enter any user-supplied pfTypes into the type system, for example, call

```
Rotor::init()
```

4. Call **pfConfig()**. This forks off other processes as specified by **pfMultiprocess()**. New **pfTypes** created after this point cannot be used in any forked processes.
5. Create *libpf* and *libpr* objects.

Note: Pure *libpr* applications that do their own multiprocessing outside of IRIS Performer with **fork()** should explicitly create shared memory with **pfInitArenas()** before calling **pfInit()**. Otherwise, the type system will not be visible in the address space of other processes.

More on Shared Memory and the Type System

Advanced

IRIS Performer objects or other objects that use **pfTypes** can only be shared between *related processes*. Related processes are those created with **fork()** or **sproc()** from the main process after **pfInit()** in a *libpf* application, for example, processes created by **pfConfig()**.

New **pfTypes** should be added before **pfConfig()** forks off other processes so that the static data member containing the class type is visible in all processes, otherwise **pf<Class>::getClassType()** will return NULL in other processes. This effectively precludes the creation of subclasses of IRIS Performer objects after **pfConfig()**.

Advanced

Virtual Address Spaces and Virtual Functions

When using virtual functions, it's very important that the object code reside at the same address in all processes. Normally, this is not an issue since the object code for all IRIS Performer classes is loaded (whether statically linked or loaded as dynamic shared objects, DSOs) before **pfConfig()** is called to fork off processes. For user-defined C++ classes with virtual functions, it's important that the object code reside at the same virtual address space in all processes that access them. For this reason, the DSOs for any user-defined classes should be loaded before **pfConfig()** regardless of whether they use the **pfType** system or not.

Data Members and Shared Memory

Non-static Member Data

The default operator **new** for objects derived from **pfObject** causes all instances to be created in shared memory, so that objects will be visible to other related processes that need to see them.

Static Member Data

Classes having static data members that may change value and need to be visible from all processes, should allocate shared memory for the data (for example, `pfMalloc` or `new pfMemory`) and set the static data member to point to this memory before `pfConfig()` as shown in the following example.

Example 20-5 Changeable Static Data Member

```
class Rotor : public pfDCS
{
    static int* instanceCount;
}
Rotor::instanceCount = NULL;

void Rotor::init()
{
    ...
    instanceCount = new(sizeof(int)) pfMemory;
    *instanceCount = 0;
}
Rotor::Rotor()
{
    ...
    (*instanceCount)++; // increment the creation counter
}
```

A static data member whose value is set before `pfConfig()` and never changes thereafter does not need to be allocated from shared memory. The `classType` member of `Rotor` is an example of this since the class should be initialized, i.e. `Rotor::init()` called, before `pfConfig()`.

libpf Objects and Multiprocessing

Advanced

The multiprocessing behavior of *libpf* objects (i.e. those deriving from `pfNode` or `pfUpdatable`) differs from that of *libpr* objects. Both are typically created in shared memory, but with a *libpr* object, all processes share the same data members, while *libpf* objects have a built in multiprocessing data mechanism that provides different copies in the APP, CULL and ISECT stages of the IRIS Performer pipeline. The term *multibuffering* refers to the maintenance and frame-accurate updating of these data.

Advanced

With a user-defined subclass of a *libpf* class, the original data elements of the *libpf* parent class are still multibuffered. However, the parallel multibuffer copies maintained in the other processes are instances of the parent class rather than the subclass. This is not normally visible to the application, since even for callbacks in the CULL and ISECT processes, the application always works from the pointer to the copy used in the APP process, in part so that objects can be identified by comparison of pointers. However, this difference would be visible if the virtual traversal functions for culling or intersection were overloaded. These virtual functions should not be overloaded by the subclass since they will not have any effect when the CULL or ISECT stages are in separate processes. Node callbacks specified with `pfNodeTravFuncs()` should be used instead.

If you require multibuffering of your subclassed data members, use a `pfCycleBuffer` or a `pfFlux` to hold this data.

Subclassing will be vastly simplified and more flexible in a future release.

Performance Hints

Constructor Overhead

It's quite natural to frequently construct and destroy arrays of public structs such as `pfVec3` on the stack. Beware, even though the constructors for these classes are empty, it still requires a function call for each element of the array. The same applies to classes that contain arrays of structs, for example, `pfSegSet` contains an array of `pfSegs`.

Math Operators

Assignment operators, for example, `+=`, are significantly faster than their corresponding binary operators, for example, `+` because the latter involves constructing a temporary object for the return value.

Glossary

alias

An alternate extension for a file type as processed by the **pfdLoadFile()** utility. For example, VRML “.wrl” files are in a sense an alias for Open Inventor “.iv” files since the Open Inventor loader can read VRML files as well. Once the alias is established, files with alternate extensions will be loaded by the designated loader.

application buffer

The main (and usually only) buffer of *libpf* data structures such as the nodes in the scene graph. Alternate buffers may be created and data can be constructed in these new buffers from parallel processes to support high- performance asynchronous database paging during real-time simulation.

arena

An area (allocation area) from which shared memory is allocated. Usually the arena is the default one created by **pfninit()** or **pfninitArenas()**, but some objects (e.g. those in *libpr*) may be created in any arena returned by **acreate()**. IRIS Performer calls that accept an arena pointer as an argument can also accept the NULL pointer, indicating that the memory should be allocated from the heap. See also *heap*.

asynchronous database paging

An advanced method of scene-graph creation, asynchronous database paging allows desired data to be read from a disk or network connection and IRIS Performer internal data structures to be built for this data using one or more processes running on separate CPUs rather than performing these tasks in the application process. Once the data structures are created in these database processes, they must be explicitly merged into the application buffer.

attribute binding

The binding of an attribute specifies how often an attribute is specified and the scope of each specification. For example given a collection of triangles for rendering, a color can be specified with each vertex of each triangle, with each triangle or once for the entire collection of triangles.

base geometry

The object with the lowest visual priority in a pfLayer node's list of children. This would be the runway, for example, in a runway and stripes airport database example. See also *layer geometry*.

bezel

The beveled border region surrounding any item, but most notably, around the edge of a CRT monitor.

billboard

Geometry that rotates to follow the eyepoint. This is often simply a single texture mapped quadrilateral used to represent an object that has roughly cylindrical or spherical symmetry, such as a tree or a puff of smoke, respectively. IRIS Performer supports billboards that can rotate about an axis for cylindrical objects or a point for spherical objects.

binning

The action of the sort phase of libpf's cull traversal that segregates drawable geometry into major sections (such as opaque and transparent) before the per-bin sorting based in the contents of associated pfGeoStates, so that state changes can be reduced by drawing groups of similar geometry sequentially while still drawing semitransparent objects in the desired order within the frame.

bins

The unique collections into which the cull traversal segregates drawable geometry. The number of bins is defined by calls to **pfChanBinSort()** and **pfChanBinOrder()**. Typical bins are those for opaque and transparent geometry, where opaque objects are rendered first for superior image quality when using blended transparency.

blur margin

There is a parameter, called blur margin which helps determine when DTR should sharpen.

bounding volume

A convex region that encompasses a geometric object or a collection of such objects. IRIS Performer pfGeoSets have axis-aligned bounding boxes which are rectangular boxes whose faces are along the X, Y, or Z axes. Each IRIS Performer pfGeode has a bounding sphere that contains the bounding box of each pfGeoSet in the pfGeode. Performer group nodes have hierarchical bounding spheres that contain (bound) the geometry in their

descendent nodes. The purpose of bounding volumes is to allow a quick test of a region for being off-screen or out of range of intersection search vectors.

buffer scope

All IRIS Performer nodes are created in a `pfBuffer`, either the primary application buffer or in an alternate returned by `pfNewBuffer()`. Only one `pfBuffer` is considered “current,” and this buffer can be selected using `pfSelectBuffer()`. All new nodes are created in the current `pfBuffer` and will be visible *only* in the current buffer until that `pfBuffer` is merged into the application buffer using `pfMergeBuffer()`. A process cannot access nodes that do not have scope in its current buffer except through the special “buffer” commands: `pfBufferAddChild()`, `pfBufferRemoveChild()`, and `pfBufferClone()`. Thus they are said to have buffer scope.

channel

A visual channel specifies how a geometric scene should be rendered to the display device. This includes the viewport area on the screen as well as the location, orientation and field of view associated with the viewer or camera.

channel group

A set of channels that share attributes such as the eyepoint or callbacks. When a shared attribute is set on any member of the group, all members get the new value. Channel groups are most commonly used for adjacent displays making up a panorama.

channel share mask

A bit mask indicating the attributes that are shared by all channels in a *channel group*. Typical shared attributes are field of view, view specification, near and far clipping distances, the scene to be drawn, stress parameters, level of detail parameters, the earth/sky model, and swapbuffer timing.

children

IRIS Performer’s hierarchical scene graph of `pfNodes` has internal nodes derived from the `pfGroup` class, and each node attached below a `pfGroup` type node is known as a child of that node. The complete list of child nodes are collectively termed the children of that node.

class hierarchy

The provenance through which IRIS Performer classes are defined. This class hierarchy defines the data elements and member functions of these data types through the notion of class inheritance as described below.

class inheritance

Class inheritance describes the process of defining one object as a special version of another. For example, a pfSwitch node is a special version of a pfGroup node in that it has control information about which children are active for drawing or intersection. In all other respects, a pfSwitch has the same capabilities as a pfGroup, and the Performer API supports this notion directly in both the C and C++ API by allowing a pfSwitch node to be used wherever a pfGroup is called for in a function argument. This same flexibility is supported for all derived types.

clipped

Geometry is said to be clipped when some or all of its geometric extent crosses one or more clipping planes and the portion of the geometry beyond the clipping plane is mathematically trimmed and discarded.

clipping planes

The normal clipping planes are those that define the viewing frustum. These are the left, right, top, bottom, near, and far clipping planes. All rendered geometry is clipped to the intersection of the half-spaces defined by these planes and only the portion inside all six is displayed by the graphics hardware.

clip texture

(aka ClipMap) virtualizes MIPmapped textures using hardware and software support so that only the texels in the region close to the viewer (known as the clipped region) need to be loaded in texture memory.

cloned instancing

The style of instancing that creates a (possibly partial) copy of a node hierarchy rather than simply making a reference to the parent node. This allows pfDCS nodes and other internal nodes to be changed in the copy without changing those in the original. Also see *shared instancing*.

cloning

Making a copy of a data structure recursively copying down to some specified level. In IRIS Performer **pfCopy()** creates a shallow copy. **pfClone()** creates a deeper copy that creates new copies of internal nodes, but not of leaf nodes. This means that the pfDCS, pfSwitch, and other internal nodes in the cloned hierarchy are separate from those in the original.

compiled mode

IRIS Performer pfGeoSets are designed for rapid immediate-mode rendering and in most situations outperform IRIS GL and OpenGL display list usage. In those cases where GL display lists are desired, pfGeoSets may be placed in compiled mode, whereby a GL display list will be created the first time the pfGeoSet is rendered and this display list will be used for subsequent renderings until the pfGeoSet compiled mode flag is explicitly reset. Once a pfGeoSet is compiled, any changes to its data arrays by the pfMorph node or other means will not be effective until the compiled-mode flag is cleared.

complex pixels

Pixels for which several different geometric primitives contribute to the pixel's assigned color value. Such pixels are rare in typical scenes, and only exist at edges of polygons unless multisample blending is in use. When this blending mode is used, then all pixels rendered as neither fully opaque nor fully transparent are complex pixels.

cost tables

Performer contains texture download cost tables, which DTR uses to estimate the time it will take to carry out those texture subloads.

critically damped

A closed-loop control system notion where the feedback transfer function is just right: not so slow that the system goes out of range before correction is applied and not so fast that overcorrection causes rapid swings or variation. This should be the goal of any user specified stress management function.

cull

See *culling*.

cull volume visualization

The visual display of the culling volume, usually the same as the viewing frustum, to which the scene is culled before rendering. Normally the projected culling volume fills the display area. By rendering with a larger field of view or from a eye point that differs from the origin of the frustum, the tightness of culling can be determined for database tuning. The culling volume itself is often drawn in wireframe.

culling

Discarding database objects that are not visible. Usually this refers to discarding objects located outside the current *viewing frustum*. This is done by comparing the bounding volume of these database objects with the six planes that bound the frustum. Objects completely outside may be safely discarded. See also *occlusion culling*.

data fusion

IRIS Performer's ability to read data in a variety of different database formats and convert it into the internal IRIS Performer scene database format. Further, the ability of these different formats to provide special run-time behavior via callback functions or node subclassing and to have these different data formats all active in their native modes simultaneously

database paging

Loading databases from disk or network into memory for traversal during real-time simulation. Database paging is implicit in large area simulations due to the huge database sizes inherent in any high-resolution earth database. A frequent component of database paging is texture paging, in which new textures are downloaded to the graphics system at the same time new geometry is loaded from disk.

debug libraries

IRIS Performer libraries compiled with debugging symbols left in are known as debug libraries. These libraries provide greater and more accurate stack trace information when examining core dumps, such as during application development.

decal geometry

Objects that appear "above" other objects in pLayer geometry. In a runways and stripes example, the stripes would be the decal geometry. There can be multiple layers of decals with successively higher visual priorities. See *layer geometry*.

depth complexity

The "pixel rendering load" of a frame which is defined as the total number of pixels written divided by the number of pixels in the image. For example, an image of two full-screen polygons would have a depth complexity of 2. It is often observed that different types of simulation images have predictable depth complexities, with values ranging from a low of 2.5 for high altitude flight simulation to 4 or more for ground-based simulations. These figures can serve as a guide when configuring hardware and estimating frame rates for visual simulation systems. IRIS Performer fill statistics provide detailed accounting and real-time visualization of depth complexity, as seen in *perfly*.

displace decaling

An implementation method for decal geometry that uses a Z-displacement to render coplanar geometry. The actual displacement used is a combination of a fixed offset and a range-based scaled offset which are combined to produce the effective offset.

display list

A list into which graphics commands are placed for efficient traversal. Both IRIS Performer and the underlying graphics libraries (OpenGL or IRIS GL) have their own display list structures.

draw mask

A bit-mask specified for both pfNodes and pfChannels which together selects a subset of the scene graph for rendering. The node and channel draw masks are logically AND-ed together during the CULL traversal which prunes the node if the result is zero. Draw masks may be used to “categorize” the scene graph where each bit represents a particular characteristic. Each node contains these masks, binary values whose bits serve as flags to indicate if the node and its children are considered drawable, intersectable, pickable, and so on. Most of these bits are available for application use.

drop

Refers to frame processing. When in locked or fixed phase and a processing stage takes too long, the frame is dropped and not rendered. Dropped frames are a sure sign of system overload.

DSO

See *dynamic shared object*.

dynamic

Something that is updated automatically when one of its attributes or children in a scene graph changes. Often refers to the update of hierarchical bounding volumes in the scene graph.

dynamic shared object

A Library which is not copied into the final application executable file but is instead loaded dynamically (that is, when the application is launched). Since DSOs are shared, only one copy of a given DSO is loaded into memory at a time, no matter how many applications are using it. DSOs also provide the dynamic binding mechanism used by the IRIS Performer database loaders.

Euler angles

A set of three angles used to represent a rotation.

See *heading*, *pitch* and *roll*.

fade count

The application sets a fade count, which controls the number of frames over which a new DTR level is faded in.

fixed frame rate

Rendering images at a consistent chosen frame rate. Fixed frame rates are a central theme of visual simulation and are supported in IRIS Performer via the PFPHASE_LOCK and PFPHASE_FLOAT modes. Maintaining a fixed frame rate in databases of varying complexity is difficult and is the task of IRIS Performer stress processing, which changes LOD scales based in measured system load.

flatten

Flattening consists of taking multiple instances of a single object and converting them into separate objects (deinstancing) and then applying any static transformations defined by pfSCS nodes to the copied geometry; this action improves performance at a cost in memory space.

flimmering

The visual artifact associated with improperly drawing coplanar Z-buffered geometry. The term is derived from the German verb *flimmern*, which has synonyms flutter, flicker, sparkle, twinkle, and vibrate (as in, *die Augen flimmern mir*, my eyes are swimming.) One way to understand flimmering is to consider the screen space interpolation of Z-depth values, wherein a discrete difference of depth must be interpolated across a discrete number of pixels (or sub-pixels). When two polygons that would be coplanar in an infinite precision real-number context are considered in this discrete interpolation space, it is clear that the interpolated depth values will differ when the delta-Z to delta-pixels ratios are relatively prime. The image that results is essentially a Moirè pattern showing the modular relationship of the differences in the least significant bits of interpolated depth between the polygons. The *libpr pfDecal()* function and *libpf pfLayer()* node exist to handle the drawing of coplanar geometry without flimmering.

floating phase

The style of frame overload management where the next frame after an overloaded frame is allowed to start at any vertical retrace boundary rather than being forced to wait for a specific boundary as in the LOCKED phase.

frame

The term frame is used to mean “image” in most IRIS Performer contexts. The image being rendered by the hardware is drawn into a “frame buffer” which is simply an image memory. This image, when delivered via video signals to a monitor or projector, exists as one or two video fields. In the one-field case, also known as non-interlaced, each row of the image is read from the frame buffer and generated as video in sequential order. In the interlaced method, the first field of display comprises alternate lines, one field for the odd lines and one field for the even lines. In this mode a frame consists of two fields, as the norm for NTSC broadcast video. Also, the frame is the unit of work in Performer; the main loop in any Performer application consists of calls to **pfFrame()**.

frame accurate

In a pipelined multiprocessing model, at any particular time the different stages of the pipeline is working on different frames. Data in the pipeline is called frame accurate when a change made to the data in a particular frame is not visible in downstream stages of the pipeline until those stages begin processing that frame. Processing of libpf objects are frame accurate because multiple copies of data are retained for the different pipeline stages.

free-running

The unconstrained phase relationship of image generation where frame rendering is initiated as soon as the previous frame is complete without consideration of a minimum or maximum frame rate.

frustum

A truncated pyramid—two parallel rectangular faces, one smaller than the other, and four trapezoidal faces that connect the edges of one rectangular face with the corresponding edges of the other rectangular face. Note that it is pronounced as it is spelled and contains only one “r” despite common misuse. Also, the plural of frustum is frusta, which does not contain an “s”.

gaze vector

The +Y axis from the eyepoint—informally, the direction the eye is facing.

graph

A network of nodes connected by arcs. An IRIS Performer scene graph is so termed due to its having this form. In particular, a Performer scene graph must be an acyclic graph. See also *scene graph*.

graphics context

The set of modes and other attributes maintained by IRIS GL or OpenGL in both system software and the hardware graphics pipeline that defines how subsequent geometry is to be rendered. It is this information which must be saved and restored when drawing occurs in multiple windows on a single graphics pipeline.

graphics state elements

Individual libpr state components, such as material color, line stipple pattern, point size, current texture definition, and the other elements that comprise the graphics context.

heading

In the context of X-axis to the right, Y-axis forward, and Z-axis up, then heading is rotation about the Z-axis. This is the disturbing rotation that pivots your car clockwise or counterclockwise during a skid. Heading is also known as *yaw*, but IRIS Performer uses the term heading to keep the H, P, and R abbreviations distinct from X, Y, and Z. Also see *Euler angles*.

heap

The process heap is the normal area from which memory is allocated by **malloc()** when more memory is required, **sbrk()** is automatically called to increase the process virtual memory. Also see *arena*.

identity matrix

A square matrix with ones down the main diagonal and zeroes everywhere else. This matrix is the multiplicative identity in matrix multiplication.

immediate mode rendering

Immediate mode rendering operations are those which immediately issue rendering commands and transfer data directly to the graphics hardware rather than compiling commands and data into data structures such as display lists. See *compiled mode*.

instancing

An object in the scene is called instanced if there is more than one path through the scene graph that reaches it. Instancing is most commonly used to place the same model in more than one location by instancing it under more than one pfDCS transformation node.

intersection pipeline

Like the rendering pipeline, IRIS Performer supports a two-stage multiprocessing pipeline between the APP and ISECT processes. See also *rendering pipeline*.

latency

The amount of time between an input and the response to that input. For example rendering latency is usually defined as the time from which the eyepoint is set until the display devices scans out the last pixel of the first field corresponding to that eye point.

latency-critical

Operations which must be performed during the current frame and which will reliably finish quickly. An example of this would be reading the current position of a head-tracking device from shared memory.

layer geometry

Objects that appear “above” other objects in pfLayer geometry. In a runways and stripes example, the stripes would be the decal geometry. There can be multiple layers of decals with successively higher visual priorities. See also *base geometry*.

level of detail

The idea of representing a single object, such as a house, with several different geometric models (a cube, a simple house, and a detailed house, for example) that are designed for display at different distances. The models and ranges are designed such that the viewer is unaware of the substitutions being made. This is possible because distant objects appear smaller and thus can be rendered with less detail. The IRIS Performer pfLOD node and the associated pfLODState implement this scheme.

libpf

One of IRIS Performer’s two core libraries. *libpf* manages multiprocessing and scene graph traversals. Built on top of *libpr*: Multiple copies of *libpf* objects are automatically maintained so that the APP, CULL and ISECT stages of the processing pipeline do not collide

libpfdu

IRIS Performer’s database utilities library. Layered on top of *libpf* and *libpr*. Includes functions for building and optimizing geometry before putting it into a scene graph.

libpfutil

IRIS Performer’s general utility library which is distributed in source form for both usage and information.

libpr

One of IRIS Performer's two core libraries. *libpr* manages graphics state and rendering, while also providing a number of math and shared memory utility functions. Provides the foundation for *libpf*. All processes share the same copy of *libpr* objects.

libpr classes

The low-level structured data types of *libpr*. These objects—with the exception of *pfCycleBuffers*—lack the special multibuffered multiprocess data exclusion support that *libpf* objects provide.

light point

A point of light such as a star or a runway light. Accurate display of light points requires that they attenuate and fog differently than other geometry (see *punch through*). In flight simulation, light points often have additional parameters concerning angular distributions of illumination.

load

The processing burden of rendering a frame. This includes both processing performed on the host CPU and in the graphics subsystem. It is the maximum of these times (sum in single process mode) that is used to compute the system stress level for adjusting *pfLODState* values.

locked phase

A style of frame overload processing where drawing may only begin on specific vertical retraces, namely those that are an integer multiple of the basic frame rate.

morph attribute

One of the collections of arrays of floating point data used in the *pfMorph* node's linear combination processing. This process multiplies each element of each source array by a changeable weight value for that source array and sums the result of these products to produce the destination array.

morphing

The mathematical manipulation of *pfGeoSet* data (positions, normals, colors, texture coordinates) to cause a shape-shifting behavior. This is very useful for animated characters, continuous terrain level of detail, for smooth object level of detail, and for a number of advanced applications. In IRIS Performer, morphing is provided by the *pfMorph* node.

multiple inheritance

Deriving a class from more than one other class. This is in contrast to single inheritance in which a type hierarchy is a tree. IRIS Performer does not use multiple inheritance.

multithreaded

In the context of IRIS Performer culling, multithreading is an option for increased parallelism when multiple pfChannels exist in a single IRIS Performer rendering pipeline. In this case, multiple cull processes are created to work on culling the channels of a pfPipe in parallel. For example, a single IRIS Performer pipeline stage (such as the CULL) is multithreaded when configured as multiple, concurrent processes. These “threads” are not arranged in pipeline fashion but work in parallel on the same frame.

mutual exclusion

Controlling access to a data structure so that two or more threads in a multiprocessing application cannot simultaneously access a data structure. Mutual exclusion is often required to prevent a partially updated data structure from being accessed while it is in an invalid state.

node

An IRIS Performer libpf data object used to represent the structure of a visual scene. Nodes are either leaf nodes that contain geometry via libpr, or are internal nodes derived from pfGroup that control and define part of the scene hierarchy.

nonblocking file access

A method of obtaining data from a file without having to wait for any other processes to finish using the file. Such accesses involve a two-step transaction in which the application first indicates the task to be performed and is given a handle. This handle can later be used to inquire about the status of the file action: is it in progress, has it completed, or has there been an error.

non-degrading priorities

Process priorities are used by the operating system to decide when and for how long processes should run. A non-degrading priority specifies that the process scheduling should not take into account how long the process has been running when deciding whether to let another process run. The use of non-degrading priorities is important for real-time performance.

occlusion culling

The discarding of objects which are not visible because they are occluded by other closer objects in the scene, e.g. a city behind a mountain. See also *culling*.

opera lighting

The generic term for a powerful carbon-arc lamp producing an intense light such as that invented by John H. Kliegl and Anton T. Kliegl for use in public staged events and cinematographic undertakings that is often mounted within a dual-gimballed exoskeletal framework to afford the lamp sufficient freedom of orientation that the projected beam can be made to track and highlight performers as they move across a stage. The temperature of the thermal plasma that develops between the carbon electrodes of such arc lamps can be determined by spectroscopic investigation of its dissociated condition, and has been found to be between 20,000°C and 50,000°C. The term can also refer to a stage-lighting technique that projects an image of a background scene onto the stage or screen. Accurate visual simulation of both of these light types (as well as common vehicle headlights, airplane landing lights, and searchlights) is provided by the projected texture capability of the pfLightSource node.

overload

A condition where the time taken to process a frame is longer than the desired frame rate allows. This causes the goal of a fixed-frame rate to be unattainable, and thus is an undesired situation.

overrun

A synonym for overload in the context of fixed frame rate rendering.

pair-wise morphing

The geometric blending of two topologically equivalent objects. Usually this is done by specifying weights for each object, e.g. 90% of object A plus 10% of object B. Each vertex in the resulting object is a linear interpolation between the vertices in the original object. See *morphing*.

parent

The IRIS Performer node directly above a given node is known as the parent node.

passthrough data

Data which is passed down the steps in the rendering pipeline until it reaches a callback. Such data provides the mechanism whereby an application can communicate information between the app, cull, and draw stages in a pipelined manner without code changes in single-CPU and multiprocessing applications.

path

A series of nodes from a scene graph's root down to a specific node defines a path to that node. When there are multiple paths to a node (and thus the scene graph is really a graph rather than a tree) this path can be important when interpreting an intersection or picking request. For example, if a car model uses instancing for the tires, just knowing that a tire is picked is not sufficient for further processing.

perfly

The application distributed with IRIS Performer that serves as a demonstration program installed in `/usr/sbin` as well as a programming example found in `/usr/share/Performer/src/sample/apps/C` and `/usr/share/Performer/src/sample/apps/C++` for the C and C++ versions, respectively.

phase

An application's synchronization mode—defining how the system behaves if the processing and drawing time for a given frame extends past the time allotted for a frame. See also *locked phase* and *floating phase*.

pipe

Used to refer to both an IRIS Performer software rendering pipeline and to a graphics hardware rendering pipeline, such as a RealityEngine. See *rendering pipeline*.

pitch

In the context of X-axis to the right, Y-axis forward, and Z-axis up, then pitch is rotation about the X-axis. This is the rotation that would raise or lower the nose of an aircraft. Also see *Euler angles*.

popping

The term for the highly noticeable instantaneous switch from one level of detail to the next when morph or blend transitions are not used. This problem is distracting and should be eliminated in high-quality simulation applications.

process callbacks

The mechanism through which a developer takes control of processing activities in the various IRIS Performer traversals and major processing stages: the application traversal, the cull traversal, the draw traversal, and the intersection traversal all provide a mechanism for registered process callbacks. These are user functions that are invoked at the beginning of the indicated processing stage, and in the process handling the traversal.

projective texturing

A texture technique that allows texture images to be projected onto polygons in the same manner as a slide or movie projector would exhibit keystone distortion when images are cast non-obliquely onto a wall or screen. This effect is perfect for projected headlights and similar lighting effects.

prune

To eliminate a node from further consideration during *culling*.

punch through

Decreasing the rate at which intensely luminous objects such as light points are attenuated as a function of distance. Normal fogging is inappropriate for such objects because up close they are actually much brighter than can be rendered given the dynamic range of the frame buffer and raster display devices.

reference counting

The counter within each pfObject and pfMemory object that keeps track of how many other data structures are referencing the particular instance. The primary purpose is to indicate when an object may be safely deleted because it is no longer referenced.

rendering pipeline

An IRIS Performer rendering pipeline, represented in an application by a pfPipe. Typically a rendering pipeline has three stages APP, CULL and DRA.W. These stages may be handled in separate processes or combined into one or two processes.

right-hand rule

Derived from a simple visual example for the direction of positive rotation about an axis, the right-hand rule states that the curled fingers of the right hand indicate the direction of positive rotation when the right hand is placed about the desired axis with the thumb pointing in the positive direction. The positive angle is the one that rotates the primary axes toward each other. For example, a positive rotation (counter clockwise) about the X-axis takes the positive Y-axis into the position previously occupied by the positive Z-axis.

roll

In the context of X-axis to the right, Y-axis forward, and Z-axis up, then roll is rotation about the Y-axis. This is the rotation that would raise and lower the wings of an aircraft, leading to a turn. Also see *Euler angles*.

scene

A collection of geometry to be rendered into a pfChannel.

scene complexity

The complexity of the scene for rendering purposes, in particular the amount of geometry, transformations, and graphics state changes in the scene.

scene graph

A hierarchical assembly of IRIS Performer nodes linked by explicit attachment arcs that constitutes a virtual world definition for traversal and subsequent display.

search path

A list of directory names given to IRIS Performer to specify where to look for data files which aren't specified as full path names.

sense

An indication of whether a positive angle is interpreted as representing a clockwise or counterclockwise rotation with respect to an axis. All CCW rotations in IRIS Performer are specified by positive (+) angles and negative angles represent CW rotations.

shadow map

A special texture map created by rendering a scene from the view of a light source and then recording the depth at each pixel. This Z-map is then used with projective texturing in a second pass to implement cast shadows. The entire process is automated by the IRIS Performer pfLightSource node.

share groups

The attributes that a slave share mask can track are divided into groups called share groups.

share mask

The share mask associates master and/or slave cliptextures.

shared instancing

The simplest form of instancing whereby two or more parent nodes share the same node as a child. In this situation, any change made to the child will be seen in each instance of that node. Also see *cloned instancing*.

shininess

The coefficient of specular reflectivity assigned to a pfMaterial that governs the appearance of highlights on geometry to which it is bound.

siblings

The name given to nodes that have the same parent in a scene graph.

skip

Refers to frame processing. See *drop*.

sorting

The grouping together of geometry with similar graphics state for more efficient rendering with fewer graphics state changes. IRIS Performer sorts during scene graph traversal.

spacing

The relative motion required to move the starting point for subsequent pfFont rendering after drawing a particular character pfGeoSet in a pfFont. This motion is a pfVec3 to allow arbitrary escapement for character sets that use vertical rather than horizontal text layouts. Note that for vertically oriented fonts, the origin should be such that motion by the spacing value crosses the character: in other words, the origin should be on the left for left-to-right fonts and at the top for top-to-bottom fonts, on the bottom for bottom-to-top fonts, and on the right for right-to-left fonts.

spatial organization

The grouping together of geometric objects that are spatially close to each other in the scene graph. For optimal culling performance, the scene should be organized spatially.

sprite

A transformation that rotates a piece of geometry, usually textured, so that it always faces the eye point.

stage

This is a section of the IRIS Performer software rendering pipeline and is one of application, culling, or drawing. Sometimes used to refer to either of the two non-pipeline tasks of intersection and asynchronous database processing.

state

State refers to attributes used to render an object that are managed during traversal. State commonly falls into two areas, traversal state that affects which portions of the scene graph are traversed and graphics state that affects how something is rendered. Graphics state includes the current transformation, the graphics modes managed by pfGeoStates and other state such as stenciling.

stencil decaling

An implementation method for pfLayer nodes that uses an extra bit per pixel in the frame buffer to record the Z-buffer pass or fail status of the base geometry. This bit is then used as a visibility determination (rather than the Z-buffer test) for each of the layers, which are rendered in bottom (lowest visual priority) to top (highest visual priority) order. Z-buffer updating is disabled during the stencil rendering operation, and is restored when the pfLayer node has been completely rendered. Stencil-bit processing is the highest quality mode of pfLayer operation.

stress

IRIS Performer stress processing is the closed-loop feedback mechanism that monitors cull and draw times to determine how pfLODState range scale factors should be adjusted to compensate for system load in order to maintain a chosen frame rate.

subgraph

A connected subset of a scene graph; usually, the set consisting of all descendents of a particular node.

texel

Short for “texture element”—a pixel of a texture.

texture mapping

Displaying a texture as though it were the surface of a given polygon.

tile

A section of a spatially subdivided database or a rectangular subregion of a larger texture image.

transformation

Homogeneous 4x4 matrices that define 3D transformations—some combination of scaling, rotation, and translation.

transition distance

The distance at which one level-of-detail model is switched for another. When fading or morphing between levels-of-detail, the distance at which 50% of each model is rendered. See *level of detail*.

traversals

One of IRIS Performer's pre-order visitations of a hierarchical scene graph. Traversals for application, culling, and intersection processing are internal to libpf and user-written traversals are supported by the pfuTraverser tools.

traversing

See *traversals*.

trigger routine

A routine that initiates a traversal or the invocation of a callback in another process. **pfCull()** triggers the cull traversal. **pfFrame()** triggers processing for the current frame.

up vector

The +Z axis of the eyepoint, defining the display's "up" direction. Must be perpendicular to the *gaze vector*.

view volume visualization

The display of the viewing frustum for a particular channel; usually done by rendering a wireframe version of the frustum with a different eye point or field-of-view. See *cull volume visualization*.

viewing frustum

The *frustum* containing the portion of the scene database visible from the current eyepoint.

viewpoint

The location of the camera or eye used to render the scene.

viewport

The portion of the framebuffer used for rendering. Each pfChannel has a viewport in the framebuffer of its corresponding pfPipeWindow.

visual

An construct that the X Window System uses to identify framebuffer configurations.

widget

A manipulable or decorative element of a graphical user interface. Much of the programming for GUI elements is associated with defining the reaction of widgets to user mouse and keyboard events.

window manager

A special X window system client which handles icons, window placement, and window borders and titles.

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