OpenGL Extensions and Restrictions for PixelFlow

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Abstract
This document describes the extensions to OpenGL supported by the PixelFlow API, restrictions forced by the architecture, and as-yet unimplemented features.
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READERS OUTSIDE UNC-CH AND HEWLETT-PACKARD PLEASE NOTE: This is an internal working document. The final implementation may differ substantially.

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1 Introduction

This document describes the PxGL graphics API for the UNC/Hewlett-Packard PixelFlow [3] architecture. PxGL is based on the OpenGL [1] API with extensions, restrictions, and unimplemented features1. Only material which differs between PxGL and a conformant OpenGL implementation is covered; readers are expected to be conversant with OpenGL proper.

PixelFlow has enormous flexibility because almost all stages of the graphics pipeline - transformation, rasterization, and shading - are implemented with user-programmable hardware. In order to exploit this capability in the framework of a traditional graphics API, we have extended OpenGL to specify

- When to load and invoke application-defined code (rather than built-in functionality, such as rendering lit, Gouraud-shaded triangles).

- Which stage of the pipeline to invoke it at.

- What parameters to pass when the code is executed.

To optimize performance of OpenGL code on PixelFlow, some architectural details of the machine are exposed to the API. Using these features may relax some OpenGL guarantees or invariants in return for greatly improved performance. They include

- **Primitive and state distribution**, which balances rendering load across the parallel geometry processors while affecting the order in which primitives are composited into the frame buffer.

- **Display list optimization**, which increases performance of upper stages of the pipeline while relaxing knowledge of global state.

While PixelFlow has far more flexibility in most respects than more traditional graphics accelerators, it also has certain constraints not present in those machines. Most notably, the nature of the image-composition architecture forces a frame-oriented paradigm on the API, and implies that there is no valid frame buffer containing pixel colors until after rasterization and shading of all primitives in that frame is complete. PixelFlow also uses a deferred shading model, in which pixel color is not computed until after visibility determination. The consequences of these and other minor architectural and design decisions are that

- Additional, non-standard OpenGL calls are required to delimit the start and end of frame generation.

- Much of the global rendering state (textures, lights, view matrices, and other state which is not associated to individual primitives) must be defined prior to start of frame and may not change within the frame.

- Many API calls are only allowed at specific points in the process of generating a frame.

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1PixelFlow will support a fully conformant OpenGL API, but in general that mode will not be used because of its expected substantial performance cost.
• Most types of blending and stenciling are not supported, and composition order of
primitives is not guaranteed.

• Access to the frame buffer may only take place after end of frame.

Finally, many features of the rich OpenGL API are not implemented in PxGL at this
time, though they may be added later.

1.1 Roadmap
The remainder of this document will address the following areas:

• Frame generation (§2).
• Controlling primitive and state distribution (§3).
• Extending the OpenGL namespace (§4).
• Loading application-defined code (§5).
• Programmable rasterization (§6).
• Programmable shading (§7).
• Programmable lighting (§8).
• User-defined functions (§??).
• Other programmable pipeline stages (§9).
• Transparency and shadows effects (§10).
• Display list optimization (§11).
• Multiple application threads (§12).
• OpenGL variances (§13).
• Unsupported OpenGL features (§14).

1.2 Change Log
This is revision Revision: 1.9 of Source: /tmp/my_net/hydra/pp0/doc/software/opengl/tex/RCS/ppgl.tex,v.
Changes from the next most recent revision are delimited by change bars (or approximations
thereof in the HTML version).

Changes in revision 1.9 (July 22, 1997):

• Changed all uses of glInquireParameterEXT() to
  glGetMaterialParameterNameEXT() or glGetRastParameterNameEXT() as appropriate.
• Note that `glGetLightParameterNameEXT()` and other stage-specific inquiry functions will need to be documented and created.

• Added to section on primitive and state distribution, including `pxDistributionMode()` and `glGenDataEXT()`.

• Added section on user-defined functions.

Changes in revision 1.8 (August 1, 1996):

• Changed references from Division to Hewlett-Packard to reflect PFX sale to HP.

• Added new inquiry calls for rasterizer and shader parameters (though details remain to be documented).

• Rearranged glossary entries in section 7 to group parameter terminology together, at Rich Holloway’s suggestion.

• Added section on transparency and blending effects, including `glTransparencyEXT()`.

Changes in revision 1.7 (March 22, 1996):

• `glShaderEXT()` now allows different shaders on front and back faces of primitives.

• Added discussion to `glSurfaceEXT()` definition of the restriction of a single value for uniform and nonvarying parameters, regardless of whether the front or back face of a primitive is being rasterized.

• Added discussion to `glMaterialIVaryingEXT()` definition of the reason for the apparently-redundant shaderId argument.

• Added `gLinthModelEXT()` to lighting chapter, specifying that user-defined shader parameters are handled in the same way as OpenGL material parameters.

Changes in revision 1.6 (February 12, 1996):

• First version released to outside readers; added disclaimers.

• Removed definitions of hardware-specific terms like composition/geometry network parameters, and changed definitions of varying/nonvarying/uniform parameters to eliminate dependence on those terms.

• Added `face` argument to `glSurfaceEXT()`.

Changes in revision 1.5 (December 17, 1995):

• Added calls for light groups and loadable light functions.

• Removed `glGenShaderEXT()` and folded its functionality into `glNewShaderEXT()`.
• Added sections (though little text yet) for atmospheric and image warping shader stages.

• Changed glSurfaceParamEXT() to glRastParamEXT() to avoid too-close similarity to glSurfaceEXT().

• Updated to reflect separate-namepath model for parameters and separation of instance and current values. In particular, glBindParameterEXT() has been replaced by glSurfaceEXT(), although the name of the latter may change.

• Rewrote interpolator introduction.

Changes in revision 1.4 (November 14, 1995):

• Moved document from IMP EX 2.09 to IMP EX 2.5.

• Added changebars using changebarsty.

Changes in revision 1.3 (November 11, 1995):

• Added flat interpolator for per-primitive constant parameters.

• Added glBindParameterEXT() and glGetParameterEXT().

• glShaderEXT() now takes a face argument. Added GL_FRONT_SHADER_EXT and GL_BACK_SHADER_EXT as targets to glGet().

• Worked on definitions of composition network and geometry network parameters; more work is needed.

2 Frame Generation

The underlying hardware model in OpenGL is that primitives are specified by the application and immediately drawn – vertices are transformed and lit, rasterization and texturing are done, and final pixel colors are copied into the frame buffer, or blended with existing frame buffer contents. Global parameters affecting transformation, rasterization, and shading of primitives, such as the projection matrix, light bindings, blending modes, and so on, may be changed at any time.

This model is not compatible with PixelFlow’s image composition and deferred shading paradigms. In order to achieve good performance on the machine, the API must be frame-oriented; that is, it must specify several stages in the process of generating a frame, and different types of OpenGL operations may occur only during specific stages. The stages and the types of calls that may take place during them are:

• **Frame setup** - establish viewing, lighting, and shading parameters that will apply throughout the frame.

• **Geometry definition** - traverse the database, rasterizing primitives.

• **End of frame** - perform image composition, shade pixels, and read/write directly to the frame buffer.
2.1 Frame Setup

The setup stage begins by calling `glBeginFrameEXT()`. In this stage, parameters which globally affect the scene are defined. This includes defining the projection matrix, loading light functions, creating lights and light groups, changing light source parameters, loading shader functions, creating shaders, changing nonvarying shader parameters, loading rasterizer functions, binding textures, and any other operations that must be known before primitives can be rasterized and shaded (a complete list of OpenGL calls and the stages they may be called for is in section 13). Parameters of the scene such as the viewport size, antialiasing kernel, and background color are also set here; these must be known to define the rendering recipe.

PxFGL currently allows only a single projection matrix to be used during a frame. Many lighting environments may be used, but they must be defined as light groups. Many textures may be used, but they must be defined during frame setup using the texture object calls\(^2\).

2.2 Geometry Definition

The geometry stage begins by calling `glStartGeometryEXT()`. In this stage, primitives are defined and rasterized different rasterizer bands. Valid calls include operations on the modelling and texture matrices, setting material values and other attributes, changing the current texture, and other changes to global state which affect only transformation and rasterization. Display lists may be compiled and executed, or primitives may be issued in immediate mode.

2.3 End of Frame

The final stage begins when `glEndFrameEXT()` is called. Once it returns, the frame buffer is defined. At this time it may be accessed using functions like `glReadPixels()` or `glCopyTexture()`\(^3\). We expect to support other frame buffer operations such as `glAccum()` at a later date.

2.4 Example

This code fragment draws a frame containing a single red triangle. Lights are assumed to have been defined previously.

```c
.glBeginFrameEXT();
    glMatrixMode(GL_PROJECTION);
    glLoadIdentity();
    glFrustum(-1.0, 1.0, -1.0, 1.0, 1.0, 3.0);
```

\(^2\)The reason for these restrictions is that while performing deferred shading, the viewing, lighting, and texturing environment is assumed to be the same for all samples. If this were not the case, such information would have to be encoded along with each sample, which would enormously increase the amount of pixel memory needed for a sample. By creating named objects representing these environments, we regain this capability, although not at OpenGL’s per-primitive granularity.

\(^3\)Hopefully, for e.g., shadow maps.
3 Controlling Primitive and State Distribution

The PixelFlow architecture achieves scalability by using many parallel rasterizers, each of which is responsible for transforming and rasterizing a portion of the database, and shaders, each of which is responsible for lighting and shading a portion of the pixels in the image. However, primitives are defined in sequential order by the application. So to achieve good rasterization performance, all the primitives defined in the course of a frame must be distributed among the rasterizers.

PyGL has a built-in distribution algorithm, and in most cases, an application does not need to be aware of or make changes in this algorithm. However, in some cases application performance can be increased by modifying how primitives are distributed.

This section describes how primitives are distributed, the implications of the distribution algorithm on graphical state maintenance and performance, and how applications may control distribution.

3.1 Primitive Distribution Algorithm

In the remainder of this section, we assume that a PixelFlow system with \( N \) rasterizer boards is being used, and that \( M \) geometric primitives are to be distributed, where \( M \gg N \).

To be done: call to specify processor groups + comments on ordering implications of distributing primitives, state maintenance, per-vertex state not necessarily affecting global state.

The calls controlling distribution are\(^4\)

\[
\text{GLenum pxDistributionMode(GLenum type, GLenum mode, GLint param)}
\]

\(^4\)The phase headers don’t use GL types for the prototypes, and return void – this inconsistency needs to be resolved.
Changes how GL commands are distributed to rasterizers and shaders. type specifies the type of commands to be affected, and may take on the following values:

- **PIXPRIMITIVE.EXT** - affects sequences of commands delimited by a `glBegin()` ...`glEnd()` block, which are normally rasterizer primitives such as triangles.
- **PIXSTATE.EXT** - affects all other commands not within a block\(^5\).
- **PIXTEXTURE.EXT** - affects textures\(^6\).

mode specifies how that type of command is distributed, and may take on the following values:

- **PIXDEFAULT.EXT** - commands are sent in according a default mapping scheme.
- **PIXBROADCAST.EXT** - commands are sent to all rasterizers that may use them.
- **PIXROUNDROBIN.EXT** - commands are sent to a single rasterizer or shader, but successive commands are sent to different rasterizers or shaders in a simple sequence specified by param, for load balancing purposes.
- **PIXROUNDROBINWEIGHTED.EXT** - commands are sent to a single rasterizer or shader, but successive commands are sent to different rasterizers or shaders in a sequence determined by the cost of the commands, for load balancing purposes\(^7\).
- **PIXSPECIFIEDGPS.EXT** - commands are sent to a set of rasterizers and shaders specified by param\(^8\).

param controls details of the distribution. For **PIXROUNDROBIN.EXT** mode, it is the blocking factor - param commands are sent to each rasterizer or shader before shifting to the next. For **PIXSPECIFIEDGPS.EXT** mode, it is the rasterizer to send commands to. param is currently ignored for the other modes.

**GLINVALID.ENUM** is generated if type or mode are not one of the allowed values.

**GLINVALID.VALUE** is generated if param is less than 1 (for **GLROUNDROBIN.EXT** mode) or an invalid rasterizer or shader ID (for **GLSPECIFIEDGPS.EXT** mode).

**GLenum pxGetDistributionMode(GLenum type, GLenum *mode, GLint *param)**

Returns the distribution mode and param used for the specified type of command. This call may not be placed in a display list.

**GLINVALID.ENUM** is generated if type is not one of the valid command types passed to pxDistributionMode().

\(^5\)Not implemented; may never be implemented
\(^6\)Which commands are "textures", exactly?
\(^7\)How might this be parameterized?
\(^8\)Eventually, param will specify a processor group ID, referring to an arbitrary set of processors established with other pgdl calls. At present, it is just a rasterizer number, with rasterizers numbered starting at 0.
4 Extending the OpenGL Namespace

The C language binding of OpenGL [2] includes several namespaces: functions, types, and enumerants. PxGL extends the function and enumerant namespaces and adds several new namespaces: shader parameters, shader functions, light parameters, light functions, rasterizer parameters, rasterizer functions, and interpolators. Examples of these namespaces are given.

In accordance with the ARB⁹ guidelines for extensions to OpenGL, all additions to the existing namespaces are postfixed by EXT for functions and .EXT for enumerants.

4.1 Functions

The function namespace refers to C calls made by an application, such as glBegin() and glEnable(). About 20 new calls are introduced in PxGL, such as glStartGeometryEXT() and glShaderEXT(). New calls are discussed in detail elsewhere in this document.

4.2 Enumerants

The enumerant namespace refers to compile-time integral constants used to denote options, values, flags, and other parameters to API functions. PxGL adds enumerants for the new calls it introduces, such as GL_ALL_PRIMITIVES.EXT (an allowed parameter to the function glMaterialInterpEXT()). PxGL also allows some existing functions to accept additional enumerant values in the context of extensions, such as passing an enumerant denoting a user-defined sphere rasterizer to glBegin() (which normally accepts only enumerants corresponding to the primitives defined in OpenGL). Finally, some existing functions will generate or return new enumerant values, such as GL_UNSUPPORTED_OPERATION.EXT (which may be generated by calling functions in unsupported modes, and later returned by glGetError()).

4.3 New Namespaces

Application-defined code may be inserted at many stages of the graphics pipeline, primarily for rasterization, surface shading, and lighting. To call this code and pass appropriate values to it, several new namespaces are introduced corresponding to the various types of code and parameters.

Because such code (with the exception of built-in functionality like triangle rasterizers or the OpenGL shading model) is not known at compile time, a way to dynamically define the namespaces is needed. This is accomplished by functions which map from ASCII string names of code and parameters to numeric identifiers¹⁰ which are passed to PxGL calls¹¹.

The new namespaces and the sections in which their uses are discussed are

- Rasterizer functions and parameters, and parameter interpolators (§6).

⁹OpenGL Architecture Review Board.
¹⁰Should generated IDs be GLenum or GLuint? Adding enumerants at runtime is of questionable legality; using integers causes incompatibilities with existing calls like glMaterial().
¹¹It would be possible to pass names everywhere and avoid this mapping, at enormous performance cost.
• Shader functions, instances, and parameters (§7).
• Light functions, instances, and parameters (§8).
• Atmospheric functions and parameters (§9.1).
• Image manipulation functions and parameters (§9.2).

4.3.1 Names of OpenGL Objects

OpenGL parameters such as light and material properties are given string names (§15). There are unique parameter IDs corresponding to the different parameters, such as ambient light color and ambient surface color. This differs from OpenGL, where the same \texttt{pname}, such as \texttt{GL\_AMBIENT}, may be used to refer to both light and material properties. For backwards compatibility, the OpenGL IDs are accepted as aliases of the actual parameter IDs.

Stuff to be done...

• Querying instance/global, interpolator, and default value for shader parameters
• Built-in shader function, shader parameters (also for rasterizers, lights, etc.)
• Specifying transformation of parameters (also for rasterizers, lights, etc.)
• Talk some more about the parameter namespaces and how they relate to OpenGL \texttt{pnames}.

5 Loading Application-Defined Code

Adding application-defined code written in the PixelFlow shading language [5] to the PxGL graphics pipeline is done at runtime\textsuperscript{12}.

The application identifies such code using string \texttt{names} that symbolically refer to different modules; the API hides details of how the names are mapped into object files which are loaded into the hardware\textsuperscript{13}. For example, a light function using the Torrance-Sparrow model might be named \texttt{torrance}; a sphere rasterizer function might be named \texttt{sphere}; and a marble shader function might be named \texttt{marble}.

Application-defined code may be loaded using this call:

\texttt{Glenum glLoadExtensionCodeEXT(Glenum stage \textsuperscript{14}, const GLubyte *name)}

\textsuperscript{12} The mechanism used involves compiling code in the shading language into shared object files that are loaded on demand.

\textsuperscript{13} Although we can expect that the name will either be a Unix filename component, or a key to look up a filename.

\textsuperscript{14} Do we want to load code for different stages with a single interface? We distinguish between stages with \texttt{glGetMaterialParameterNameEXT()} and \texttt{glGetRastParameterNameEXT()} for example.
Loads application-defined code for the specified pipeline stage identified by name. Returns an enumerated id which is passed to other calls controlling when the code is to be used.

May be called with a built-in function or called again for application-defined code that’s already been loaded. No action is taken, but the same valid id is returned. stage may take on the following values:

GL_LIGHT_FUNCTION_EXT - load a light function. id is passed to glNewLightEXT().
GL RASTERIZER_FUNCTION_EXT - load a rasterizer function. id is passed to glBegin().
GL_SHADER_FUNCTION_EXT - load a shading function. id is passed to glNewShaderEXT().
GL_ATMOSPHERIC_FUNCTION_EXT - load an atmospheric function. id is passed to GL_INVALID_ENUM is generated if stage is not one of the allowed values, and 0 is returned.
GL_INVALID_VALUE is generated if name does not exist, and 0 is returned.
GL_INVALID_OPERATION is generated if called between glStartGeometryEXT() and glEndFrameEXT(), and 0 is returned.

Code loaded with glLoadExtensionCodeEXT() usually has associated parameters; rastenizers may also have associated interpolators. Loading code may have the side effect of extending those namespaces. At present, there is a single namespace for parameters even though they are accessed by different calls depending on the stage in which those parameters are used. Thus, we require user-defined namespace scoping to distinguish both the stage and the specific object within that stage which the parameter applies to; for example, rast sphere radius and shader polkadot radius.

To map parameter names into identifiers, use the calls glGetMaterialParameterNameEXT() or glGetRastParameterNameEXT().

6 Programmable Rasterization

The programmable rasterization model used in PxGL extends the glBegin() / glEnd() mechanism used to define built-in primitive types such as triangles and lines. These new terms are introduced:

15Yes, to what?
16And again, to what?
17We should recommend namespace conventions.
**Interpolator** - A method for combining parameter values specified at one or more discrete locations on a primitive being rasterized to generate values for that parameter at all other locations on the primitive where it is not specified. The most common interpolators are named **constant** (corresponding to flat shading on a primitive), **flat** (corresponding to **glShadeModel(GL_FLAT)**), e.g., flat shading on individual polygons within a primitive), and and **linear** (corresponding to **glShadeModel(GL_SMOOTH)**), e.g., Gouraud shading on polygons within a primitive). Other interpolator types may be defined for user-specified rasterizer functions.

Since interpolation considered as a mathematical process is tightly bound to the geometrical definition of a surface, most interpolators are only defined for specific types of primitives. Interpolators have string names and corresponding enumerated parameter IDs, referred to as **interpname** and **interp id** in code examples.

**Rasterizer Function** - A function which takes as input a set of rasterizer parameters and generates screen-space samples at which the function is visible. A rasterizer function represents a type of geometric primitive; its parameters determine a specific instance of that geometry. In abstract terms, the function creates geometry, transforms it according to the current model-view and projection matrices, and samples it. At visible samples, shader parameters defined for the current shader are computed using a specified parameter interpolator and copied into the sample buffer.

**Rasterizer Parameter** - A parameter to a rasterizer function. Some examples include vertices of polygons, sphere radii, or control points of parametric patches.

**Sequence Point** - Specifies the binding time for a group of rasterizer and shader parameters. A rasterizer function may require one or more sequence points to define a specific instance of its geometry. In many cases, including all the OpenGL primitive types, the rasterizer parameters bound at the sequence point will simply be vertices of a surface. Other examples include center and radii of spheres, twist vectors of Hermite patches, or coefficients of general quadric surfaces\(^\text{18}\).

### 6.1 Loading and Using Rasterizer Functions

To use an application-defined rasterizer function, the following steps must be taken:

- Load the rasterizer function and obtain its ID with **glLoadExtensionCodeEXT()**
- Obtain parameter IDs of rasterizer parameters using **glGetRastParamNameEXT()**.
- Call **glBegin()** with the rasterizer ID to start delimiting sequence points of a rasterizer function.
- Specify rasterizer parameters using **glRastParamEXT()** and bind them using **glSequencePointEXT()**.

\(^{18}\)Rasterizer writers will have to document which parameters are per-block and which are per-sequence-point.
• Call `glEnd()` to finish delimiting sequence points of the function and call the rasterizer function.

6.1.1 Example
In the following example, a rasterizer function named `spheres` is loaded. The function has two parameters, the center and radius of the sphere; each sequence point defines a separate sphere. Two unit-radius spheres which touch at the origin and are centered at (1,0,0) and (-1,0,0) are drawn.

    // Load the rasterizer and obtain its ID
    GLenum spherefuncid =
        glLoadExtensionCodeEXT(GL_RASTERIZER_FUNCTION_EXT, "spheres");

    // Obtain IDs for named parameters
    GLenum centerid = glGetRastParameterNameParameterEXT("rast_sphere_center");
    GLenum radiusid = glGetRastParameterNameParameterEXT("rast_sphere_radius");

    glBeginFrameEXT();
    glStartGeometryEXT();

    GLfloat vertminus[3] = { -1, 0, 0 };  
    GLfloat vertplus[3] = { 1, 0, 0 };  

    // Draw the two spheres
    glRastParamfEXT(radiusid, 1.0);
    glBegin(spherefuncid);
        glRastParamfvEXT(centerid, &vertminus);
        glSequencePointEXT();
        glRastParamfvEXT(centerid, &vertplus);
        glSequencePointEXT();
    glEnd();

    Example - Using rasterizer functions

6.2 Rasterizer API Definitions
There is currently an naming inconsistency where some calls use `RastParam` and others use `RastParameter`. This should be resolved, probably in favor of the latter.

void glGetRastParamEXT(GLenum paramid, TYPE *params)

    Returns the value of the specified parameter in `params`.

    `GL_INVALID_ENUM` is generated if `paramid` is not a valid rasterizer parameter.
GLenum glGetUniformLocation(GLchar *name_string)

Returns the parameter ID corresponding to the string name.

GL_INVALID_OPERATION is generated if string is not a parameter of any rasterizer, and 0 is returned.

GLchar * glGetRastParameterStringEXT(GLenum pname)

Returns the string name corresponding to the specified parameter ID.

GL_INVALID_ENUM is generated if pname is not a valid parameter ID, and NULL is returned.

void glSequencePointEXT()

Binds parameters of the rasterizer and shader functions in use.

GL_INVALID_OPERATION is generated when glSequencePointEXT() is called other than between glBegin() and glEnd().

void glRastParamEXT(GLenum paramid, TYPE params)

glRastParam assigns values to rasterizer parameters. paramid specifies which parameter will be modified. params specifies what value or values will be assigned to the parameter.

GL_INVALID_VALUE is generated if paramid is not a defined rasterizer parameter ID.

6.3 glVertex() and Sequence Points

Vertices defining built-in primitive types are rasterizer parameters. The following two code sequences have identical effects:

```c
glVertex3f(x, y, z);
```

Defining a vertex using glVertex()

```c
GLenum vertid = glGetRastParameterNameEXT("gl_vertex");
GLfloat point[4] = { x, y, z, 1.0 };
...
glRastParamfvEXT(vertid, &point);
glSequencePointEXT();
```

Defining a vertex using rasterizer extensions

6.4 Vertex Array Extensions for Rasterizers and Shaders

These will be needed, but can’t be finalized until the GL 1.1 specification is out.
6.5 Interpolators

Every rasterizer function has one or more interpolators associated with its geometry, which take shader parameters specified at control points and generate parameter values at all samples. All rasterizers may use the constant interpolator, which copies a single value into all samples. Rasterizers defined by OpenGL all support the flat interpolator, which copies a separate constant value into each successive primitive (triangle, line segment, quadrilateral, etc.) in a group, and the linear interpolator, which fits a linear function (possibly perspective-corrected) to the first two or three vertices of a primitive.

There is also an implicit interpolator, which ignores parameter values specified at sequence points. Its exact function varies depending on the rasterizer and parameter type. For built-in rasterizers, the implicit interpolator can only be applied to texture coordinates, implementing the functionality of glTexGen().

Other types of rasterizers may use these interpolators, if they make sense, or define new interpolators corresponding to their geometry\(^{19}\). For example, a triangle with 3 additional sequence points at the midpoints of its edges might define a quadratic interpolator, to allow smoother shading between triangles. A parametric patch might define an interpolator which applies the same weights to shader parameters as to control points. A sphere or general quadratic surface rasterizer might interpret the implicit interpolator to generate texture coordinates and normals based on the intrinsic geometry of the surface.

6.6 Interpolator API Definitions

void glGetMaterialInterpEXT(GLenum paramid, GLenum primtype, GLenum *interpID)

- Returns the interpolator used for rasterizing the specified shader parameter for the specified primitive type.
- GL_INVALID_ENUM is generated if paramid is not a valid shader parameter or if primtype is not a valid primitive type.

void glMaterialInterpEXT(GLenum paramid, GLenum primtype, GLenum interpID)

- Sets the interpolator to be used for rasterizing the specified shader parameter for the specified primitive type. A primitive type is required because most interpolators are defined only for specific types of geometry.
- interpID is usually an interpolator ID for a specific primitive. Five interpolators are built into P3GL:
- GL_CONSTANT_INTERPOLATOR_EXT copies the parameter value current when...

\(^{19}\)We don't have a way to get IDs for interpolators loaded as part of rasterizers, yet - something like a glGetInterpolatorNameEXT() call is needed.

\(^{20}\)Do we want to implement it for surface normals, too?
glBegin() is called into all samples rasterized for that primitive or group of primitives. It is guaranteed to be implemented for all primitive types and all parameter types.

GL_FLAT_INTERPOLATOR_EXT copies the parameter value current when the last vertex or sequence point defining a primitive is called into all samples rasterized for that primitive. Unlike the constant interpolator, a group of primitives defined in a glBegin() / glEnd() block may have a different value specified for each primitive. This corresponds to glShadeModelEXT(GL_FLAT).

GL_LINEAR_INTERPOLATOR_EXT is implemented for all built-in primitive types and parameters, and corresponds to glShadeModel(GL_SMOOTH)\(^{21}\).

GL_DEFAULT_INTERPOLATOR_EXT is a way to specify the most "natural" type of interpolator for a primitive: linear for a polygon, implicit for a sphere, bicubic for a patch, and so on.

primtype is either a valid primitive type or the special value GL_ALL_PRIMITIVES_EXT. In the latter case, only GL_CONSTANT_INTERPOLATOR_EXT, GL_FLAT_INTERPOLATOR_EXT, or GL_DEFAULT_INTERPOLATOR_EXT may be specified.

GL_INVALID_ENUM is generated if paramid is not a valid shader parameter, if primtype is neither a valid primitive type nor GL_ALL_PRIMITIVES_EXT, or if interpid is not a valid interpolator.

GL_INVALID_OPERATION is generated if interpid is not defined for the specified paramid and primtype.

To be added: glGenDataEXT() and glDeleteDataEXT().

7 Programmable Shading

The programmable shading model used in PxGL is based on the RenderMan [4] shading language, but use of some terms differ and these new terms are introduced:

Shader Function - A function, either built-in to PxGL or loaded at runtime, which takes as input a set of shader parameters and generates as output a color. A shader function is conceptually applied to each sample of a primitive which was rasterized with a corresponding shader applied\(^{22}\). Shader functions have string names and corresponding enumerated IDs, referred to as shaderfunc and shaderfuncid in code examples.

Shader - An instance of a shader function which binds a subset of the function’s parameters to be nonvarying for all samples to which the shader is applied. This is done primarily to increase rasterization and shading speed and to reduce traffic on the PixelFlow image composition network. Shaders have enumerated IDs, referred to as shaderid in code examples.

\(^{21}\)Note that in PxGL, interpolation is applied to shading parameters before lighting, rather than to color after lighting, as in OpenGL. This allows true Phong shading, avoiding the artifacts caused by OpenGL’s Gouraud interpolation of Phong-lit vertices.

\(^{22}\)Deferred shading means that in practice, only samples which affect visibility are actually shaded.
**Shader Parameter** - An input argument to a shader function. These fall into three types depending on how they arrive at the shading hardware: *uniform*, *nonvarying*, and *varying* parameters. Shader parameters have string names and corresponding enumerated IDs, referred to as *paramName* and *paramId* in code examples.

**Nonvarying Parameter** - A shader parameter whose value is the same for all samples rasterized using that shader. A non-*uniform* parameter of a shader function may be chosen to be either nonvarying or *varying* on a per-shader basis using `glMaterialVaryingEXT()`.

**Uniform Parameter** - A shader parameter whose value is the same for all samples rasterized using that shader. Uniform parameters cannot be made *varying*.

**Varying Parameter** - A shader parameter whose value may be different in each sample rasterized using that shader.

### 7.1 Creating Shaders

To create a shader, the following steps must be taken:

- Load a shader function and obtain its ID with `glLoadExtensionCodeEXT()`.
- Create the new shader and obtain a shader ID using `glNewShaderEXT()`.
- Obtain parameter IDs of shader parameters using `glGetMaterialParameterNameEXT()`.
- Specify which shader parameters are varying using `glMaterialVaryingEXT()` (all parameters not otherwise specified are assumed to be uniform).
- Instantiate the shader with `glEndShaderEXT()`.

After creating the shader, nonvarying parameter values may be set using `glSurfaceEXT()`. These parameter values can be changed at any time before start of geometry.

#### 7.1.1 Example

This code fragment loads a hypothetical shader function named `phong_shader`. The shader function has two parameters, named `gl_shader_color` (intrinsic color) and

---

23 OpenGL uses *prime* to refer to material parameters such as emission color, which are shader parameters of the built-in OpenGL shading model. This discrepancy should be resolved; Rich suggests an explanation of parameter names vs. parameter IDs.

24 The distinction between uniform parameters and nonvarying parameters is subtle from the user's point of view, and these definitions need work: both are sent to the shader GFs over the geometry network, but uniform parameters are held on the GF during shading code execution, while nonvarying parameters are copied into pixel memory. The distinction is primarily an efficiency measure to reduce composition network bandwidth requirements.
gl_shader_normal (surface normal)\textsuperscript{25}. Two shaders are created. The first, phongshader, allows both color and normal to vary. The second, redshader, has a nonvarying intrinsic color of red.

\begin{verbatim}
// Load the named shader and obtain its ID
GLenum phongfuncid =
    glLoadExtensionCodeEXT(GL_SHADER_FUNCTION_EXT, "phong_shader");

// Obtain IDs for named parameters
GLenum colorid = glGetUniformLocationEXT("gl_shader_color");
GLenum normalid = glGetUniformLocationEXT("gl_shader_normal");

// Create a shader with ID 'phongshader', allowing both parameters to vary
GLuint phongshader = glNewShaderEXT(phongfuncid);
    glMaterialVaryingEXT(phongshader, colorid);
    glMaterialVaryingEXT(phongshader, normalid);
    glEndShaderEXT();

// Create 'redshader', allowing only normals to vary and
// binding the nonvarying color to red.
GLfloat red[3] = { 1, 0, 0 };
GLuint redshader = glNewShaderEXT(phongfuncid);
    glMaterialVaryingEXT(redshader, normalid);
    glEndShaderEXT();
    glSurfacefvEXT(redshader, colorid, &red);
\end{verbatim}

Example - Creating shaders

\subsection{7.2 Using Shaders}

To use a shader once it has been created, the following steps must be taken:

- Select the shader using \texttt{glShaderEXT()}.
- Specify the interpolation method to be used for \textit{varying} shader parameters using \texttt{glMaterialInterpEXT()}.
- Define a primitive, setting values of varying shader parameters using \texttt{glMaterial()}.

\subsubsection{7.2.1 Example}

This continues the previous example, defining three triangles. The first uses \texttt{redshader} to draw a red phong-lit triangle with linearly interpolated normals. The second uses \texttt{phongshader} to draw a vertex-colored triangle using linear interpolation of the vertex colors. The third uses \texttt{phongshader} to draw a green triangle using constant interpolation.

\textsuperscript{25}Note that these parameters are also parameters of the built-in OpenGL shader; they are used by the loadable shader so the example can make shortcut calls like \texttt{glNormal()} and \texttt{glColor()} to specify shader parameters, rather than \texttt{glMaterial()}.  

21
// Select the red-colored shader
glShaderEXT(GL_FRONT_AND_BACK, redshader);

// Choose a linear interpolator for normals and draw a red
// phong-shaded triangle.
glMaterialInterpEXT(normalid, GL_TRIANGLES, GL_LINEAR_INTERPOLATOR_EXT);

glBegin(GL_TRIANGLES);
    for (i = 0; i < 3; i++) {
        glNormal3fv(normal[i]);
        glVertex3fv(vertex[i]);
    }
 glEnd();

// Select the phong shader, use linear interpolation for color,
// and draw a vertex-colored phong-shaded triangle
glShaderEXT(GL_FRONT_AND_BACK, phongshader);

glMaterialInterpEXT(colorid, GL_TRIANGLES, GL_LINEAR_INTERPOLATOR_EXT);

glBegin(GL_TRIANGLES);
    for (i = 0; i < 3; i++) {
        glColor3fv(color[i]);
        glNormal3fv(normal[i]);
        glVertex3fv(vertex[i]);
    }
 glEnd();

// Change to constant interpolation for color, and draw a green
// phong-shaded triangle.
glMaterialInterpEXT(colorid, GL_TRIANGLES, GL_CONSTANT_INTERPOLATOR_EXT);

GLfloat green[3] = { 0, 1, 0};
gColor3fv(green);

glBegin(GL_TRIANGLES);
    for (i = 0; i < 3; i++) {
        glNormal3fv(normal[i]);
        glVertex3fv(vertex[i]);
    }
 glEnd();

Example - Using shaders

There is a subtle difference between the first and third triangles: the first uses a shader
where color is nonvarying, so that all primitives rendered using that shader will be red. The
third triangle uses a shader where color is varying, but the constant interpolator causes the
color to be fixed on that particular triangle\textsuperscript{26}.

### 7.3 Shading API Definitions

void glDeleteShaderEXT(GLuint shaderid)

Removes the definition of the specified shader; shaderid is unused after this call.

GL\_INVALID\_VALUE is generated if shaderid is not a defined shader ID.

GL\_INVALID\_OPERATION is generated if called between glStartGeometryEXT() and glEndFrameEXT().

void glEndShaderEXT()

Instantiates a shader created by glNewShaderEXT(). All shader parameters which are not explicitly specified in previous calls to glMaterialVaryingEXT() are made nonvarying; values of these parameters are set with glSurfaceEXT().

GL\_INVALID\_OPERATION is generated if called between glStartGeometryEXT() and glEndFrameEXT(), or when not preceded by a corresponding glNewShaderEXT().

void glGet(GLenum pname, TYPE *params)

glGet() is extended to accept parameters GL\_FRONT\_SHADER\_EXT and GL\_BACK\_SHADER\_EXT, which return the current front and back face shaders as specified via glShaderEXT().

void glGetMaterial(GLenum face, GLenum paramid, TYPE *params)

glGetMaterial() is extended so that paramid can refer to shader parameters defined by dynamically loaded shaders.

GL\_INVALID\_ENUM is generated if paramid is not a valid shader parameter.

GLenum glGetMaterialParameterNameEXT(GLchar *name_string)

Returns the parameter ID corresponding to the string name_string.

GL\_INVALID\_NAME\_STRING\_EXT is generated if name_string is not a parameter of any shader, and 0 is returned.

void glGetMaterialParametersEXT(GLuint shaderid, GLenum *pnames)

Returns a list of parameter IDs used by the specified shader. pnames must have room for at least the number of IDs specified by glGetNumMaterialParametersEXT().

GL\_INVALID\_VALUE is generated if shaderid is not a defined shader ID.

\textsuperscript{26}The purpose of the constant interpolator is to reduce work done during rasterization; it’s appropriate when performing (for example) flat shading. The same visual effect could also be achieved by using the linear interpolator and specifying the same color at each vertex, but rasterization speed would be lower.
GLchar * glGetMaterialParameterStringEXT(GLenum pname)

Returns the string name corresponding to the specified parameter ID.
GL_INVALID_ENUM is generated if pname is not a valid parameter ID, and NULL is returned.

GLuint glGetNumMaterialParametersEXT(GLuint shaderid)

Returns the number of material parameters accepted by the specified shader. Used in conjunction with glGetMaterialParametersEXT().
GL_INVALID_VALUE is generated if shaderid is not a defined shader ID.

void glGetSurfaceEXT(GLuint shaderid, GLenum face, GLenum paramId, TYPE *params)

Retrieves the value of a nonvarying parameter of the specified shader. Bound values are set by glSurfaceEXT().
GL_INVALID_ENUM is generated if face is not GL_FRONT or GL_BACK, or if paramId is not a bound parameter of shaderid.
GL_INVALID_VALUE is generated if shaderid is not a defined shader ID.

GLboolean glIsMaterialParameterEXT(GLuint shaderid, GLenum pname)

Returns TRUE if pname is a parameter of the specified shader, FALSE otherwise.
GL_INVALID_VALUE is generated if shaderid is not a defined shader ID, and FALSE is returned.
GL_INVALID_ENUM is generated if pname is not a valid parameter ID, and FALSE is returned.

GLboolean glIsMaterialUniformEXT(GLuint shaderid, GLenum pname)

Returns TRUE if pname is a uniform parameter of the specified shader, FALSE otherwise.
GL_INVALID_VALUE is generated if shaderid is not a defined shader ID, and FALSE is returned.
GL_INVALID_ENUM is generated if pname is not a valid parameter ID, and FALSE is returned.

GLboolean glIsShaderEXT(GLuint shaderid)

Returns TRUE if shaderid is used for an existing shader, FALSE otherwise.

void glMaterial(GLenum face, GLenum paramId, TYPE params)

glMaterial() is extended so that paramId can refer to shader parameters defined by dynamically loaded shader functions.
GL_INVALID_ENUM is generated if paramId is not a shader parameter either of the built-in OpenGL shading function or of a shader function previously loaded.
void glMaterialVaryingEXT(GLuint shaderid, GLenum paramid)

    Specifies that a parameter is varying for this shader. All parameters of a shader are
    uniform or nonvarying unless specified as varying by the time glEndShaderEXT()
    is called\(^\text{27}\).

    \(\text{GL\_INVALID\_ENUM}\) is generated if \textit{paramid} is not a valid shader parameter or a un-
    iform parameter.

    \(\text{GL\_INVALID\_VALUE}\) is generated if \textit{shaderid} is not a defined shader ID.

    \(\text{GL\_INVALID\_OPERATION}\) is generated if called other than between
    glNewShaderEXT() and glEndShaderEXT().

GLuint glNewShaderEXT(GLenum shaderfuncid)

    Creates and returns a shader ID for a new instance of the specified shader function.

    \(\text{GL\_INVALID\_ENUM}\) is generated if \textit{shaderfuncid} does not refer to a valid shader func-
    tion, and 0 is returned.

    \(\text{GL\_INVALID\_OPERATION}\) is generated if called between glStartGeometryEXT()
    and glEndFrameEXT(), and 0 is returned.

void glShaderEXT(GLenum face, GLuint shaderid)

    Sets the shader to be used for shading the specified face of primitives defined fol-
    lowing the call. \textit{face} may be \textit{GL\_FRONT}, \textit{GL\_BACK}, or \textit{GL\_FRONT\_AND\_BACK}.

    \(\text{GL\_INVALID\_ENUM}\) is generated if \textit{face} is not one of the allowed values.

    \(\text{GL\_INVALID\_VALUE}\) is generated if \textit{shaderid} is not a defined shader ID.

void glSurfaceEXT(GLuint shaderid, GLenum paramid, TYPE params)

    Sets the value of nonvarying parameters of a shader instance. The values of
    varying parameters are set with glMaterial().

    Nonvarying parameters cannot be specified separately for front and back faces; there
    is a single value used regardless of whether the front or back face of a primitive is
    rasterized. This can be addressed by using different shaders on front and back faces.

    A nonvarying parameter has an initial value defined by the shader using that pa-
    rameter. The value is set when the shader is loaded.

    \(\text{GL\_INVALID\_ENUM}\) is generated if \textit{paramid} does not refer to a nonvarying parameter
    of the specified shader.

    \(\text{GL\_INVALID\_VALUE}\) is generated if \textit{shaderid} is not a defined shader ID.

    \(\text{GL\_INVALID\_OPERATION}\) is generated if called between glStartGeometryEXT()
    and glEndFrameEXT().

\(^{27}\)While \textit{shaderid} appears redundant, keeping the parameter allows the possibility of changing a parameter
between varying and nonvarying on the fly, in a possible future implementation.
7.4 To Be Done

- Parameter Transformation (normals, texture matrix).
- Parameter Generation (glTexCoord(), sphere normals).
- Implicit Parameters (texture scale factors, texture ID, normals).
- glFrontAndBack vs. uniform parameters and optimized lists.

8 Programmable Lighting

The programmable lighting model used in PnGL introduces these new terms:

Light Function - A function which takes as input a set of light source parameters and a set of shader parameters at a sample, and generates an illumination at that sample which is used by a shader function to compute color of the sample.

Light Group - A subset of all existing light instances, used to illuminate specified primitives during shading. Only one light group may be active at any time.

8.1 Creating Lights

To create a light, the following steps must be taken:

- Load a light function and obtain its ID with glLoadExtensionCodeEXT()
- Create the new light and obtain a light ID using glNewLightEXT().
- Obtain parameter IDs of light source parameters using glGetLightParameterName28EXT().
- Call glLight() to specify light source parameters.

8.1.1 Example

I don’t have a good example of a user-defined light function. This example just creates a new instance of the built-in OpenGL light function, which is named gl_light_function. The light is made a red, diffuse, infinite light in direction -Z.

```c
    glBeginFrameEXT();

    // Get the light function ID for the built-in light model
    // by "loading" it.
    GLenum lightfuncid = glLoadExtensionCodeEXT(GL_LIGHT_FUNCTION_EXT, "gl_light_function");

    // Create a new instance of the OpenGL light function
```

28This call needs to be added.
GLenum lightid = glNewLightEXT(lightfuncid);

    // Get IDs of light source parameters. We do not really
    // need to do this for the built-in light function; GL_POSITION
    // and GL_DIFFUSE could be used instead.
    GLenum positionid = glGetLightParameterNameEXT("gl_light_position");
    GLenum diffusoid = glGetLightParameterNameEXT("gl_light_direction");

    GLfloat position[4] = { 0.0, 0.0, -1.0, 0.0 };
    GLfloat diffusecolor[4] = { 1.0, 0.0, 0.0, 1.0 };

    glLightfv(lightid, positionid, &position);
    glLightfv(lightid, diffusoid, &diffusecolor);

Example - Creating a light

8.2 Using Lights

There is no limit on the number of lights which may be created (above and beyond the
built-in OpenGL lights). Lights are placed in light groups, which are arbitrary subsets of
the defined lights with enumerated IDs; the current light group may be changed at any time
and that set of lights is applied when shading primitives. Initially a single light group,
GL_DEFAULT_LIGHT_GROUP_EXT, exists and is the current light group.

To change the lighting environment, the following steps must be taken:

- Optionally create a new light group.
- Place desired lights in the light group.
- Specify the current light group.
- Render primitives with the specified light group illuminating them.

8.2.1 Example

This continues the previous example, placing the new light in a new light group, selecting
that as the current light group, and drawing a triangle.

    // Create a new light group
    GLuint groupid = glNewLightGroupEXT();

    // Add the new light to this group
    glEnableLightGroupEXT(groupid, lightid);

    glStartGeometryEXT();

    gLightGroupEXT(groupid);

    // Primitives drawn now are lit by the new light
8.3 Light API Definitions

void glDeleteLightEXT(GLenum lightid)

Removes the definition of the specified light; lightid is unused after this call.

GL_INVALID_VALUE is generated if lightid is not a defined shader ID.

GL_INVALID_OPERATION is generated if called between glBeginGeometryEXT() and glEndFrameEXT().

void glDeleteLightGroupEXT(GLuint groupid)

Removes the definition of the specified light group; groupid is unused after this call.

GL_INVALID_VALUE is generated if groupid is not a defined light group.

GL_INVALID_OPERATION is generated if called between glBeginGeometryEXT() and glEndFrameEXT().

void glDisable(GLenum cap)

void glEnable(GLenum cap)

glDisable() and glEnable() are extended to operate on light groups. When cap is GL_LIGHT#, the specified built-in light is removed from or added to the current light group.\textsuperscript{20}

void glDisableLightGroupEXT(GLuint groupid, GLenum lightid)

void glEnableLightGroupEXT(GLuint groupid, GLenum lightid)

Removes or adds the specified light to the specified light group.

GL_INVALID_VALUE is generated if groupid is not a valid light group ID or lightid is not a valid light ID.

GL_INVALID_OPERATION is generated if called between glBeginGeometryEXT() and glEndFrameEXT().

void glGet(GLenum pname, TYPE *param)

glGet() is extended to accept parameter GL_LIGHTGROUP_EXT, which returns the current light group as specified via glBeginGeometryEXT().

void glGetLight(GLenum lightid, GLenum paramid, TYPE *param)

glGetLight() is extended so that paramid can refer to light source parameters defined by dynamically loaded light functions.

GL_INVALID_ENUM is generated if lightid is not a valid light or if paramid is not a light source parameter of the light

\textsuperscript{20}GL_LIGHTING could be implemented as a flag on the entire light group; at present it has no effect.
void glGetLightFunctionEXT(GLenum lightid, GLenum *lightfuncid)

Returns in lightfuncid the light function used by the specified light.
GL_INVALID_ENUM is generated if lightid is not a valid light.

GLboolean glIsLightEXT(GLenum lightid)

Returns TRUE if lightid is used for an existing light, FALSE otherwise.

GLboolean glIsLightGroupEXT(GLuint groupid)

Returns TRUE if groupid is used for an existing light group, FALSE otherwise.

void glLight(GLenum lightid, GLenum paramid, TYPE param)

glLight() is extended so that paramid can refer to light source parameters defined
by dynamically loaded light functions.
GL_INVALID_ENUM is generated if paramid is not a light source parameter either of
the built-in OpenGL light function or of a light function previously loaded.
GL_INVALID_OPERATION is generated if called between glBeginExt() and glEndFrameEXT().

void glLightGroupEXT(GLuint groupid)

Sets the light group to be used for lighting primitives specified following the call.
GL_INVALID_VALUE is generated if groupid is not a defined light group ID.

void glLightModelEXT(GLenum pname, TYPE param)

glLightModel() is extended so that when two-sided lighting is enabled via
GL_LIGHT_MODEL_TWO_SIDE, it includes all varying parameters of the shader being
used for a primitive. This allows texture coordinates, texture IDs, and user-defined
shader parameters to differ on front and back faces of a primitive.

GLenum glNewLightEXT(GLenum lightfuncid)

Creates and returns a light ID for a new instance of the specified light function.
GL_INVALID_ENUM is generated if lightfuncid does not refer to a valid light function,
and 0 is returned.
GL_INVALID_OPERATION is generated if called between glBeginExt() and glEndFrameEXT(), and 0 is returned.

GLuint glNewLightGroupEXT()

Creates a new light group and returns the group ID. Initially no lights are in the
group; lights may be added with glEnableLightGroupEXT().
GL_INVALID_OPERATION is generated if called between glBeginExt() and glEndFrameEXT().
9 Programming Other Pipeline Stages - to be written

9.1 Atmospheric

Talk about glFog() here.

9.2 Warping

To be defined.

10 Transparency and Other Blending Effects

Because PixelFlow is an image composition architecture, in which there is not a single frame buffer during rasterization, the effects possible via blending in OpenGL must be done via alternate methods.

Further discussion about blending across frame boundaries and such will go here later.

10.1 Transparency

Transparent primitives may be handled in one of two ways. The first is screen-door transparency. This supports a limited number of levels of transparency, depending on the number of samples/pixel being rasterized, but is the most general method. The second method is a multipass algorithm which extracts all transparent primitives and renders them properly in sorted order using multiple rendering passes to resolve visibility (Appar paper citation goes here). Unlike alpha blending in OpenGL, neither approach relies on the database being traversed in any particular order.

To use transparent primitives, several steps must be taken:

- Enable transparency on a per-frame basis using glTransparencyEXT().
- Enable transparency on a per-primitive basis using glEnable().
- Specify transparent primitives by defining colors with non-unitary alpha components.

The new calls are:

void glTransparencyEXT(GLenum mode)

Specifies the method by which transparent primitives are rendered. Must be called during the frame setup stage (section 2.1).

mode may take on the following values:

GL_TRANSPARENCY_NONE_EXT - transparency is not handled. All primitives are treated as opaque regardless of alpha values.

GL_TRANSPARENCY_SCREEN_DOOR_EXT - transparency is done by turning on a fraction of the samples in each pixel corresponding to the alpha value of
that fragment. This is usually the fastest and lowest quality mode.

GL_TRANSPARENCY_MULTIPASS_EXT - transparency is done by multipass rendering of potentially transparent primitives. This is usually the slowest and highest quality mode.

GL_INVALID_OPERATION is generated if called between glStartGeometryEXT() and glEndFrameEXT().

void glDisable(GLenum cap)
void glEnable(GLenum cap)

glDisable() and glEnable() are extended to support potentially transparent primitives. When cap is GL_TRANSPARENCY_EXT and is enabled, primitives may be handled using the transparency mode determined by glTransparencyEXT(). When disabled, primitives are treated as opaque regardless of their alpha values.

For maximum performance, GL_TRANSPARENCY_EXT should be enabled only when potentially transparent primitives are being rasterized.

10.1.1 Determining Transparency

Determining whether or not primitives are transparent at rasterization time is difficult in a deferred-shading architecture, since user-defined shaders need not have an input parameter analogous to the alpha value used by OpenGL. At present, transparency is only handled for primitives using the built-in OpenGL shader\textsuperscript{30}.

11 Display List Optimization - to be written

- How to specify optimization; types of optimizations.
- Inheriting state from environment for constant-interpolated params, binding at glBegin().
- Interaction with glShadeModelEXT().

12 Multiple Application Threads - to be written

Discuss multiple AP contexts, ordering issues, frame synchronization points, global namespaces for lights, shaders, and rasterizers, local (perhaps) namespaces for display lists.

13 OpenGL Variances - to be written

Tables of (enumerant, relevant calls) and (call, valid frame stages) will go here.

\textsuperscript{30} Is this true? We've gone around on possible approaches to shaders generating transparent samples before, but there has been no resolution yet. What does the current implementation do?
• Depth buffer always enabled.
• Depth function always GL_LESS.
• Transparency specially handled (see section 10.1).
• And lots more...

14 Unsupported OpenGL Features - to be written
Lee's lengthy document should be referenced here.

15 Function, Enumerant, and Name Tables
Parameters of the built-in light, shader, and rasterizer functions have all been assigned string names which map to enumerated IDs. Existing OpenGL enumerants (such as GL_AMBIENT or GL_LIGHT0) are recognized as aliases for the actual IDs. String names of built-in parameters, and the corresponding OpenGL enumerants, are listed below.

15.1 Light Function and Parameter Names
There is a single built-in light function corresponding to the OpenGL lighting model, named gl_light_function. Table 1 lists parameters of this function, which correspond to OpenGL light source parameters.

<table>
<thead>
<tr>
<th>String Name</th>
<th>OpenGL ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>gl_light_ambient</td>
<td>GL_AMBIENT</td>
</tr>
<tr>
<td>gl_light_diffuse</td>
<td>GL_DIFFUSE</td>
</tr>
<tr>
<td>gl_light_specular</td>
<td>GL_SPECULAR</td>
</tr>
<tr>
<td>gl_light_position</td>
<td>GL_POSITION</td>
</tr>
<tr>
<td>gl_light_spot_direction</td>
<td>GL_SPOT_DIRECTION</td>
</tr>
<tr>
<td>gl_light_spot_exponent</td>
<td>GL_SPOT_EXPONENT</td>
</tr>
<tr>
<td>gl_light_spot_cutoff</td>
<td>GL_SPOT_CUTOFF</td>
</tr>
<tr>
<td>gl_light_constant_attenuation</td>
<td>GL_CONSTANT_ATTENUATION</td>
</tr>
<tr>
<td>gl_light_linear_attenuation</td>
<td>GL_LINEAR_ATTENUATION</td>
</tr>
<tr>
<td>gl_light_quadratic_attenuation</td>
<td>GL_QUADRATIC_ATTENUATION</td>
</tr>
</tbody>
</table>

Table 1: Built-in light source parameter names
15.2 Rasterizer Function and Parameter Names

Table 2 lists the built-in rasterizer function names and the corresponding OpenGL IDs.

<table>
<thead>
<tr>
<th>String Name</th>
<th>OpenGL ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>gl_rasterizer_points</td>
<td>GL_POINTS</td>
</tr>
<tr>
<td>gl_rasterizer_lines</td>
<td>GL_LINES</td>
</tr>
<tr>
<td>gl_rasterizer_line_strip</td>
<td>GL_LINE_STRIP</td>
</tr>
<tr>
<td>gl_rasterizer_line_loop</td>
<td>GL_LINE_LOOP</td>
</tr>
<tr>
<td>gl_rasterizer_triangles</td>
<td>GL_TRIANGLES</td>
</tr>
<tr>
<td>gl_rasterizer_triangle_strip</td>
<td>GL_TRIANGLE_STRIP</td>
</tr>
<tr>
<td>gl_rasterizer_triangle_fan</td>
<td>GL_TRIANGLE_FAN</td>
</tr>
<tr>
<td>gl_rasterizer_quads</td>
<td>GL_QUADS</td>
</tr>
<tr>
<td>gl_rasterizer_quad_strip</td>
<td>GL_QUAD_STRIP</td>
</tr>
<tr>
<td>gl_rasterizer_polygon</td>
<td>GL_POLYGON</td>
</tr>
</tbody>
</table>

Table 2: Built-in rasterizer functions

There is a single parameter of built-in rasterizers, named gl_vertex. Vertices are normally specified using glVertex() rather than glRastParamEXT() (§6.3).

15.3 Shader Function and Parameter Names

There is a single built-in shader function corresponding to the OpenGL shading model, called gl_shader_function. Table 3 lists parameters of this function and the corresponding OpenGL material parameter names.

15.4 Atmospheric Function and Parameter Names

There is a single built-in atmospheric function corresponding to the OpenGL fog model, called gl_fog_function. Table 4 lists parameters of this function and the corresponding OpenGL fog parameter names.

15.5 Interpolator Names

Table 5 lists the built-in interpolator functions which may be used with the built-in rasterizer functions. The constant and implicit interpolators may also be used with any application-defined rasterizer function.
<table>
<thead>
<tr>
<th>String Name</th>
<th>OpenGL ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>gl_shader.ambient</td>
<td>GL_AMBIENT</td>
</tr>
<tr>
<td>gl_shader.diffuse</td>
<td>GL_DIFFUSE</td>
</tr>
<tr>
<td>gl_shader.color</td>
<td>Use glColor()</td>
</tr>
<tr>
<td>gl_shader.specular</td>
<td>GL_SPECULAR</td>
</tr>
<tr>
<td>gl_shader.emission</td>
<td>GL_EMISSION</td>
</tr>
<tr>
<td>gl_shader.shininess</td>
<td>GL_SHININESS</td>
</tr>
<tr>
<td>gl_shader.textureid</td>
<td>Use texture object calls</td>
</tr>
<tr>
<td>gl_shader.normal</td>
<td>Use glNormal()</td>
</tr>
<tr>
<td>gl_shader.u, gl_shader.v</td>
<td>Use glTexCoord()</td>
</tr>
<tr>
<td>gl_shader_du, gl_shader_dv</td>
<td>Implicitly generated</td>
</tr>
</tbody>
</table>

Table 3: Built-in material parameters

<table>
<thead>
<tr>
<th>String Name</th>
<th>OpenGL ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>gl_fog.mode</td>
<td>GL_FOG_MODE</td>
</tr>
<tr>
<td>gl_fog.density</td>
<td>GL_FOG_DENSITY</td>
</tr>
<tr>
<td>gl_fog.start</td>
<td>GL_FOG_START</td>
</tr>
<tr>
<td>gl_fog.end</td>
<td>GL_FOG_END</td>
</tr>
<tr>
<td>gl_fog.color</td>
<td>GL_FOG_COLOR</td>
</tr>
</tbody>
</table>

Table 4: Built-in atmospheric parameters

<table>
<thead>
<tr>
<th>String Name</th>
<th>OpenGL ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>gl_interpolator.implicit</td>
<td>GL_IMPLICIT_INTERPOLATOR_EXT</td>
</tr>
<tr>
<td>gl_interpolator.constant</td>
<td>GL_CONSTANT_INTERPOLATOR_EXT</td>
</tr>
<tr>
<td>gl_interpolator.flat</td>
<td>GL_FLAT_INTERPOLATOR_EXT</td>
</tr>
<tr>
<td>gl_interpolator.linear</td>
<td>GL_LINEAR_INTERPOLATOR_EXT</td>
</tr>
<tr>
<td>gl_interpolator.default</td>
<td>GL_DEFAULT_INTERPOLATOR_EXT</td>
</tr>
</tbody>
</table>

Table 5: Built-in interpolator names
15.6 Defined Constants

Table 6 lists manifest constants in P3GL which are not in OpenGL, along with the corresponding commands these constants are used in.

<table>
<thead>
<tr>
<th>Constant</th>
<th>Associated Commands</th>
</tr>
</thead>
<tbody>
<tr>
<td>GL_ALL_PRIMITIVES_EXT</td>
<td>glMaterialInterpEXT()</td>
</tr>
<tr>
<td>GL_BACK_SHADER_EXT,</td>
<td></td>
</tr>
<tr>
<td>GL_FRONT_SHADER_EXT,</td>
<td></td>
</tr>
<tr>
<td>GL_LIGHT_GROUP_EXT</td>
<td></td>
</tr>
<tr>
<td>GL_DEFAULT_LIGHT_GROUP_EXT</td>
<td>gLightGroupEXT()</td>
</tr>
<tr>
<td>GL_CONSTANT_INTERPOLATOR_EXT,</td>
<td></td>
</tr>
<tr>
<td>GL_DEFAULT_INTERPOLATOR_EXT,</td>
<td></td>
</tr>
<tr>
<td>GL_FLAT_INTERPOLATOR_EXT,</td>
<td></td>
</tr>
<tr>
<td>GL_IMPLICIT_INTERPOLATOR_EXT,</td>
<td></td>
</tr>
<tr>
<td>GL_LINEAR_INTERPOLATOR_EXT</td>
<td></td>
</tr>
<tr>
<td>GL_ATMOSPHERIC_FUNCTION_EXT,</td>
<td>gLoadExtensionCodeEXT()</td>
</tr>
<tr>
<td>GL_LIGHT_FUNCTION_EXT,</td>
<td></td>
</tr>
<tr>
<td>GL_RASTERIZER_FUNCTION_EXT,</td>
<td></td>
</tr>
<tr>
<td>GL_SHADER_FUNCTION_EXT,</td>
<td></td>
</tr>
<tr>
<td>GL_WARPING_FUNCTION_EXT</td>
<td></td>
</tr>
<tr>
<td>GL_TRANSPARENCY_EXT</td>
<td>glEnable()</td>
</tr>
<tr>
<td>GL_TRANSPARENCY_NONE_EXT,</td>
<td></td>
</tr>
<tr>
<td>GL_TRANSPARENCY_SCREEN.DOOR_EXT,</td>
<td>gTransparencyEXT()</td>
</tr>
<tr>
<td>GL_TRANSPARENCY_MULTIPASS_EXT</td>
<td></td>
</tr>
<tr>
<td>GL_UNSUPPORTED_OPERATION_EXT</td>
<td>many</td>
</tr>
</tbody>
</table>

Table 6: Defined constants

16 Glossary

**Interpolator** - A method for combining parameter values specified at one or more discrete locations on a primitive being rasterized to generate values for that parameter at all other locations on the primitive where it is not specified.

**Light Function** - A function which takes as input a set of light source parameters and a set of shader parameters at a sample, and generates an illumination at that sample which is used by a shader function to compute color of the sample.

**Light Group** - A subset of all existing light instances, used to illuminate specified primitives during shading. Only one light group may be active at any time.
Nonvarying Parameter - A shader parameter whose value is the same for all samples rasterized using that shader.

Rasterizer Function - A function which takes as input a set of rasterizer parameters and generates screen-space samples at which the function is visible.

Rasterizer Parameter - A parameter to a rasterizer function.

Sequence Point - Specifies the binding time for a group of rasterizer and shader parameters.

Shader Function - A function, either built-in to PxGL or loaded at runtime, which takes as input a set of shader parameters and generates as output a color.

Shader Parameter - An input argument to a shader function.

Shader - An instance of a shader function which binds a subset of the function’s parameters to be nonvarying for all samples to which the shader is applied.

Uniform Parameter - A shader parameter whose value is the same for all samples rasterized using that shader.

Varying Parameter - A shader parameter whose value may be different in each sample rasterized using that shader.

Rasterizer Boards - Hybrid MIMD/SIMD parallel processors which transform subsets of the primitives making up an image, rasterizing shader parameters into local sample buffers. These buffers are later combined using the image composition network as directed by the rendering recipe.

Rendering Recipe - A list of instructions describing how to combine rasterized screen regions containing shading parameters using the image composition network, shade the resulting visible samples, and combine shaded samples into the frame buffer. The rendering recipe is normally defined by state such as viewport size and number of supersamples used for antialiasing.

Sample Buffer - Buffers on rasterizer boards which contain samples of locally-visible surfaces and shading parameters for those samples.

17 Credits

The PixelFlow API has developed by discussion among the following people:\footnote{I think this covers everyone who had significant input, but please correct me - JPL.}

Dan Aliaga, Jon Cohen, Lawrence Kestenoot, Anselmo Lastra, Jon Leech, Jonathan McAllister, Steve Molnar, Marc Olano, Greg Pruett, Yulan Wang, and Rob Wheeler (UNC), and Rich Holloway, Roman Kuchkuda, and Lee Westover (HP)
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glGetSurfaceEXT 24
glGet 23
glGet 28
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glIsLightGroupEXT 29
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glLightGroupEXT 29
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glLight 29
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