

# Migration from OpenGL ES 1.0 to OpenGL ES 2.0

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Filename : Migration from OpenGL ES 1.x to OpenGL ES 2.0 API.1.1f.External.doc  
Version : 1.1f External Issue (Package: POWERVR SDK 2.06.26.0716)  
Issue Date : 11 Aug 2009  
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# 1. Overview

## 1.1. OpenGL ES

OpenGL ES is an API for 2D and 3D graphics designed for use in embedded systems such as mobile phones and appliances. OpenGL ES 1.1 is for use with fixed function hardware and is a subset of desktop OpenGL 1.5 specification. OpenGL ES 2.0 is for programmable hardware and is a subset of the desktop OpenGL 2.0 specification. Full specifications and further information can be found on the Khronos website:

<http://www.khronos.org/opengles/>

<http://www.khronos.org/registry/gles/>

The major difference between OpenGL ES 1.x and OpenGL ES 2.0 is the removal of the fixed pipeline, which is replaced by a shader-based pipeline. The OpenGL ES 2.0 API does not provide any formal functions for setting up lighting, or setting material, or rasterization parameters. Instead, the programmer creates their own 'per vertex' and 'per fragment' programs which will run directly on the graphics hardware. The OpenGL ES Shading Language is used to write these 'shader' programs; it is a subset of the OpenGL Shading Language. Unlike desktop OpenGL 2.0, OpenGL ES 2.0 does not allow use of the fixed function pipeline at all, so applications written for OpenGL ES 1.x are not compatible with OpenGL ES 2.0.

## 1.2. Why use OpenGL ES 2.0?

OpenGL ES 2.0 devices are increasingly becoming more popular. Although drivers for OpenGL ES 1.x are often available for such devices there are a number of good reasons to choose OpenGL ES 2.0 over OpenGL ES 1.x.

As well as allowing all the same types of effects as Open GL ES 1.x, as the programmer has full control of the hardware, Open GL ES 2.0 opens up the possibilities of many more types of effects, including as water effects, bump mapping, refraction, environment mapping, skins, translucency effects, fur/hair shaders and post processing. Many of these shader-based effects are useful for user interfaces, which is particularly important for the embedded market. OpenGL ES 2.0 also allows better quality effects to be attained, for example lighting effects can be calculated per pixel.

With the greater control over the hardware also provides many more opportunities for optimisations, and hence better performance. Often effects that are complicated to implement in OpenGL ES 1.x, perhaps requiring complex changes in state or multiple passes that obfuscate the code, can be implemented more concisely using shaders, giving rise to reduced development costs.

# 2. Initialisation

## 2.1. OpenGL ES and EGL

EGL is an API which provides a mechanism to bind to native windowing systems, so rendering surfaces can be created. There are a few minor differences with the initialisation of EGL between

OpenGL ES 1.x and OpenGL ES 2.0. These include differences in the naming of the header files and library which must be linked.

	OpenGL ES 1.1	OpenGL ES 2.0
Include files:	GLES/egl.h GLES/gl.h	EGL/egl.h GLES2/gl2.h
Libraries:	libGLES_CM or libGLES_CL	libEGL libGLESv2

## 2.2. Example of initialising OpenGL ES 2.0 with EGL

Create EGL variables.

```

EGLDisplay      eglDisplay      = EGL_NO_DISPLAY;
EGLConfig       eglConfig       = 0;
EGLSurface      eglSurface      = EGL_NO_SURFACE;
EGLContext      eglContext      = EGL_NO_CONTEXT;
EGLNativeWindowType eglWindow    = 0;
EGLNativeDisplayType eglNativeDisplay = EGL_DEFAULT_DISPLAY;
EGLint          iErr            = 0;

```

Step 0 – Create a window that we can use for OpenGL ES output. This is done through platform specific functions. If there is no window system eglWindow should remain 0.

```
eglWindow = ... // CreateWindow on Win32, XCreateWindow on X11, etc.
```

Step 1 – Get the display. EGL uses the concept of a “display” which in most environments corresponds to a single physical screen. We can let EGL pick a default display, querying other displays is platform specific.

```

eglNativeDisplay = ... // GetDC on Win32, XOpenDisplay on X11, etc.
eglDisplay = eglGetDisplay(eglNativeDisplay);

```

Step 2 – Initialize EGL. EGL has to be initialized with the display obtained above. We cannot use other EGL functions except eglGetDisplay and eglGetError before eglInitialize has been called. If we're not interested in the EGL version number we can just pass NULL for the second and third parameters.

```

EGLint iMajorVersion, iMinorVersion;
if (!eglInitialize(eglDisplay, &iMajorVersion, &iMinorVersion))
{
    printf("Error: eglInitialize() failed.\n");
    goto cleanup;
}

```

Step 3 – Set OpenGL ES to be the current API. EGL can handle other APIs, such as OpenGL or OpenVG.

```

if (!eglBindAPI(EGL_OPENGL_ES_API))
{
    printf("Error: eglBindAPI () failed.\n");
    goto cleanup;
}

```

Step 4 – Specify the required configuration attributes. An EGL “configuration” describes the pixel format and type of surfaces that can be used for drawing. Here we want a 16 bit RGB surface that is a Window surface, i.e. it will be visible on screen. The list has to contain key/value pairs, terminated with EGL\_NONE. OpenGL ES 2.0 requires EGL\_RENDERABLE\_TYPE set to EGL\_OPENGL\_ES2\_BIT which was not a requirement for OpenGL ES 1.0.

```
EGLint pi32ConfigAttribs[7];
pi32ConfigAttribs[0] = EGL_SURFACE_TYPE;
pi32ConfigAttribs[1] = EGL_WINDOW_BIT;
pi32ConfigAttribs[2] = EGL_RENDERABLE_TYPE;
pi32ConfigAttribs[3] = EGL_OPENGL_ES2_BIT;
pi32ConfigAttribs[4] = EGL_BUFFER_SIZE;
pi32ConfigAttribs[5] = 16;
pi32ConfigAttribs[6] = EGL_NONE;
```

Step 5 – Find a config that matches all requirements. `eglChooseConfig` provides a list of all available configurations that meet or exceed the requirements given as the second argument. In most cases we just want the first config that meets all criteria, so we can limit the number of configs returned to 1.

```
int iConfigs;
if(!eglChooseConfig(eglDisplay, pi32ConfigAttribs, &eglConfig, 1, &iConfigs) ||
    (iConfigs != 1))
{
    printf("Error: eglChooseConfig() failed.\n");
    goto cleanup;
}
```

Step 6 – Create a surface to draw to. Use the config picked in the previous step and the native window handle when available to create a window surface. A window surface is one that will be visible on screen inside the native window (or fullscreen if there is no windowing system). Pixmaps and pbuffers are surfaces which only exist in off-screen memory.

```
eglSurface = eglCreateWindowSurface(eglDisplay, eglConfig, eglWindow, NULL);

if((iErr = eglGetError()) != EGL_SUCCESS)
{
    printf("eglCreateWindowSurface failed (%d).\n", iErr);
    goto cleanup;
}
```

Step 7 – Create a context. EGL has to create a context for OpenGL ES. Our OpenGL ES resources like textures will only be valid inside this context (or shared contexts). OpenGL ES 2.0 requires EGL\_CONTEXT\_CLIENT\_VERSION set to 2 which is not required for OpenGL ES 1.0.

```
EGLint pi32ContextAttribs[3];
pi32ContextAttribs[0] = EGL_CONTEXT_CLIENT_VERSION;
pi32ContextAttribs[1] = 2;
pi32ContextAttribs[2] = EGL_NONE;

eglContext = eglCreateContext(eglDisplay, eglConfig, NULL, pi32ContextAttribs);

if((iErr = eglGetError()) != EGL_SUCCESS)
{
    printf("eglCreateContext failed (%d).\n", iErr);
    goto cleanup;
}
```

Step 8 – Bind the context to the current thread and use our window surface for drawing and reading. Contexts are bound to a thread. This means you don't have to worry about other threads and

processes interfering with your OpenGL ES application. We need to specify a surface that will be the target of all subsequent drawing operations, and one that will be the source of read operations. They can be the same surface.

```
eglMakeCurrent(eglDisplay, eglSurface, eglSurface, eglContext);

if((iErr = eglGetError()) != EGL_SUCCESS)
{
    printf("eglMakeCurrent failed (%d).\n", iErr);
    goto cleanup;
}
```

Step 9 – Initialization is done. We can now draw something on the screen with OpenGL ES.

```
// Render loop
{
    glClear(GL_COLOR_BUFFER_BIT);

    // Draw ...

    eglSwapBuffers(eglDisplay, eglSurface);

    if((iErr = eglGetError()) != EGL_SUCCESS)
    {
        printf("eglSwapBuffers failed (%d).\n", iErr);
        goto cleanup;
    }
}
```

Note that on some platforms power management events (device going into stand-by mode) may cause the context to be lost. In this case `eglGetError` will return `EGL_CONTEXT_LOST`. This should usually be handled by recreating all EGL and GL resources.

Step 10 – Terminate OpenGL ES and destroy the window (if present). `eglTerminate` takes care of destroying any context or surface created with this display, so we don't need to call `eglDestroySurface` or `eglDestroyContext` here.

```
cleanup:
    eglMakeCurrent(eglDisplay, EGL_NO_SURFACE, EGL_NO_SURFACE, EGL_NO_CONTEXT) ;
    eglTerminate(eglDisplay);
    // More platform specific cleanup here
```

## 3. Loading Shaders

Shaders can be compiled from source or loaded from pre-compiled binaries. Loading from source is the most common method and it is supported by all platforms.

### 3.1. Loading Shaders from source

Shader source are usually defined as strings in the application source code, or in plain text files which are loaded into memory.

```
// A vertex shader
const char* pszVertShader = "\
    attribute highp vec4    myVertex;\
    uniform mediump mat4    myWVPMatrix;\
    void main(void)\
    {\
        gl_Position = myWVPMatrix * myVertex;\
    }";

// A fragment shader
const char* pszFragShader = "\
    void main (void)\
    {\
        gl_FragColor = vec4(1.0, 1.0, 0.66 ,1.0);\
    }";
```

Define handles for the fragment shader, vertex shader and program object. A program object consists of a fragment shader and a vertex shader.

```
GLuint uiVertShader;
GLuint uiFragShader;
GLuint uiProgramObject;
```

Create the shader objects.

```
uiVertShader = glCreateShader(GL_VERTEX_SHADER);
uiFragShader = glCreateShader(GL_FRAGMENT_SHADER);
```

Load the source code into the shader objects.

```
glShaderSource(uiVertShader, 1, (const char**)&pszVertShader, NULL);
glShaderSource(uiFragShader, 1, (const char**)&pszFragShader, NULL);
```

Compile the shaders.

```
glCompileShader(uiVertShader);
glCompileShader(uiFragShader);
```

Check both the shaders compiled successfully. `glGetShaderiv` and `glGetShaderInfoLog` are used to query the shader object.

```
GLint iShaderCompiled;

glGetShaderiv(uiVertShader, GL_COMPILE_STATUS, &iShaderCompiled);
if (!iShaderCompiled)
{
    // Retrieve the length of the error message
    int i32LogLength, i32CharsWritten;
    glGetShaderiv(uiVertShader, GL_INFO_LOG_LENGTH, &i32LogLength);

    // Allocate enough space for the message and retrieve it
    char* pszLog = new char[i32LogLength];
    glGetShaderInfoLog(uiVertShader, i32LogLength, &i32CharsWritten, pszLog);

    // Display the error
    printf("Failed to compile vertex shader: %s\n", pszLog);

    delete [] pszLog;
    goto cleanup;
}

glGetShaderiv(uiFragShader, GL_COMPILE_STATUS, &iShaderCompiled);
if (!iShaderCompiled)
{
    int i32LogLength, i32CharsWritten;
    glGetShaderiv(uiFragShader, GL_INFO_LOG_LENGTH, &i32LogLength);
    char* pszLog = new char[i32LogLength];
    glGetShaderInfoLog(uiFragShader, i32LogLength, &i32CharsWritten, pszLog);
    printf("Failed to compile fragment shader: %s\n", pszLog);
    delete [] pszLog;
    goto cleanup;
}
```

Create the shader program object and attach the shader object to it.

```
uiProgramObject = glCreateProgram();

glAttachShader(uiProgramObject, uiFragShader);
glAttachShader(uiProgramObject, uiVertShader);
```

Link the program. This creates the actual executable binaries that will be run on the hardware.

```
glLinkProgram(uiProgramObject);
```

Check the program object was linked successfully. This is done similarly to the way the shader objects were checked.

```
GLint iLinked;
glGetProgramiv(uiProgramObject, GL_LINK_STATUS, &iLinked);

if (!iLinked)
{
    int ui32LogLength, ui32CharsWritten;
    glGetProgramiv(uiProgramObject, GL_INFO_LOG_LENGTH, &ui32LogLength);

    char* pszLog = new char[ui32LogLength];
    glGetProgramInfoLog(uiProgramObject, ui32LogLength, &ui32CharsWritten, pszLog);

    printf("Failed to link program: %s\n", pszLog);

    delete [] pszLog;
    goto cleanup;
}
```

The loading and initialisation of the shader is now complete. `glUseProgram` is used to set the program object as part of the current render state, before drawing.



```
glUseProgram(uiProgramObject);
```

After rendering is finished the resources must be cleaned-up.

```
cleanup:
    glDeleteProgram(uiProgramObject);
    glDeleteShader(uiFragShader);
    glDeleteShader(uiVertShader);
```

## 4. OpenGL ES Shading Language Overview

The OpenGL ES Shading Language (GLSL ES) is a language, based on the C programming language, designed to be run on the graphics hardware. The 'per vertex' and 'per fragment' programs in the programmable pipeline are written in this language.

GLSL ES is based on the OpenGL Shading Language (GLSL). Programs are often directly compatible between the two languages with the exception the precision qualifiers are a requirement for GLSL ES fragment shaders.

The full specification of GLSL ES can be found on the Khronos website:

<http://www.khronos.org/registry/gles/>

### 4.1. Types

#### 4.1.1. List of Types

In addition to the basic types one would expect in C, like float, and int, GLSL also has matrix and vector types built into the base language.

Type	Description
<b>float</b>	Floating-point number
<b>int</b>	Integer number
<b>bool</b>	Boolean (true or false)
<b>void</b>	(May be used as a function return type)
<b>mat2</b>	2 x 2 floating-point matrix
<b>mat3</b>	3 x 3 floating-point matrix
<b>mat4</b>	4 x 4 floating-point matrix
<b>vec2</b>	2 component floating-point vector
<b>vec3</b>	3 component floating-point vector
<b>vec4</b>	4 component floating-point vector
<b>ivec2</b>	2 component integer vector
<b>ivec3</b>	3 component integer vector
<b>ivec4</b>	4 component integer vector

Type	Description
<b>bvec2</b>	2 component boolean vector
<b>bvec3</b>	3 component boolean vector
<b>bvec4</b>	4 component boolean vector
<b>sampler2D</b>	Handle for a 2D texture
<b>samplerCube</b>	Handle for a Cube map texture (6 x 2D textures)

`const` may be used to indicate values are set at compile time and will not change throughout the program.

There is no automatic conversion between types, thus it is important to distinguish float literals from integer literals.

Square brackets (e.g. `[]`) are used to indicate an array. During initialisation the integer number between the square brackets is the size of array. When an array is used this number indicates the item to use within the array.

Samplers are handles to textures. There are a number of built in functions (discussed below) which can be used to access their values.

#### 4.1.2. Precision Qualifiers

Precision qualifiers are used to indicate the minimum accuracy required for a floating-point or integer variable. These qualifiers are used as the variable is declared. Less memory will be allocated to lower precision values, which often leads to faster performance at runtime.

Precision	Size	Typical uses
<code>highp</code>	32-bit	Vertex position calculations, world, view, projection matrices. Texture and lighting calculations.
<code>mediump</code>	16-bit	Texture coordinate varyings.
<code>lowp</code>	10-bit	Colours – it can represent all colour values for a colour channel. Normals from a normal map texture.

#### 4.1.3. Examples

The `=` operator is used to assign values to the variables defined.

```
mediump float myFloat = 3.0;

highp vec3 myVector = vec3(1.0, 2.0, 3.0);

mediump mat2 myMatrix = mat2(1.0, 2.0, 3.0, 4.0);

const int maxValue = 5;

bool myBool = false;

mediump int myArray[5];
```

## 4.2. Language Syntax

### 4.2.1. Operators

Operator	Description
( )	Parenthetical grouping, function call, constructor
[ ]	Array subscript
.	Field selector
,	Sequence
+	Addition
-	Subtraction
*	Multiplication
/	Division
=	Assignment
++	Increment
--	Decrement
+=	Add and assign
-=	Subtract and assign
*=	Multiply and assign
/=	Divide and assign
<	Less than
>	Greater than
<=	Less than or equal to
>=	Greater than or equal to
==	Equal
!=	Not equal
&&	Logical and
^^	Logical exclusive or
	Logical inclusive or
!	Not
? :	Selection

### 4.2.2. Control flow

#### Loops

Definition	Example
<pre>for(init ; condition ; expression) {     statements }</pre>	<pre>for(int i = 0, i &lt; 10; ++i) {     ... }</pre>

Definition	Example
<pre><b>while</b>(condition) {     statements }</pre>	<pre>int i = 0; <b>while</b>(i &lt; 10) {     ...     ++i; }</pre>
<pre><b>do</b> {     statements } <b>while</b>(condition)</pre>	<pre>int i = 0; <b>do</b> {     ...     ++i; } <b>while</b>(i &lt; 10)</pre>

## Conditionals

Definition	Example
<pre><b>if</b>(bool-expression) {     true-statements }</pre>	<pre><b>if</b>(a == 1) {     ... }</pre>
<pre><b>if</b>(bool-expression) {     true-statements } <b>else</b> {     false-statements }</pre>	<pre><b>if</b>(a &gt; 5) {     ... } <b>else</b> {     ... }</pre>

## Jumps

Definition	Example
<p><b>continue</b></p> <p>Used in loops. Skips the remainder of the body of the inner most loop.</p>	<pre>for(int i = 0, i &lt; 10; ++i) {     int a = 0;     ...     if(a &gt; 5)         <b>continue</b>; }</pre>

Definition	Example
<b>break</b>  Used in loops. Exit the inner-most loop.	<pre>for(int i = 0, i &lt; 10; ++i) {     int a = 0;     ...     if(a &gt; 5)         break; }</pre>
<b>discard</b>  Only used in the fragment shader. Abandons the operation on the current fragment.	<pre>void main (void) {     mediump vec4 color;     mediump float intensity;     ...     if (intensity &lt; 0.1)         discard;     gl_FragColor = color; }</pre>
<b>return</b> <b>return</b> expression  Exit from the current function.	<pre>mediump float intensity (void) {     mediump float value = 0.0;     ...     if (value &lt; 0.1)         return 0.0;     ...     return value; }</pre>

### 4.2.3. Functions

Functions are defined and used similarly to the C programming language. A function is a body of code that can be called from other parts of the program. It can have one return type and any number of input arguments. Each shader program must have a main function, which is the function automatically called by the application when the shader program is run. (See Vertex Shader and Fragment Shader below). A function must be defined, or declared, before it may be used.

```
return_type functionName(type0 arg0, type1 arg1, ...)
{
    // ...
    return return_value;
}
```

## 4.3. Vertex shader

A vertex shader is the program that runs for each vertex in the primitive being rendered. It must write to the variable `gl_Position` with a value for the position of the current vertex.

A typical vertex shader may take in the vertex data (input as an attribute) and transforms it by the world-view-projection matrix (input as a uniform) and uses these values to calculate the position of the vertex. It is also often used to calculate values which are passed to the fragment shader such as lighting intensity.

```
attribute highp vec3 inVertex;
attribute highp vec3 inNormal;
attribute highp vec2 inTexCoord;

uniform highp mat4 WorldViewProjection;
uniform highp mat3 WorldViewIT;
uniform mediump vec3 LightDir;

varying mediump float LightIntensity;
varying mediump vec2 TexCoord;

void main(void)
{
    gl_Position = WorldViewProjection * vec4(inVertex, 1.0);

    mediump vec3 normal = normalize(WorldViewIT * inNormal);
    LightIntensity = max(0.0, dot(normal, LightDir));

    TexCoord = inTexCoord.st;
}
```

## 4.4. Fragment shader

A fragment shader is the program that runs for each fragment (pixel). It must write to the variable `gl_FragColor` with a value for the colour of that pixel. The 4th component of the `gl_FragColor` is the alpha value this should be set to 1.0 if the object is required to be opaque.

A typical fragment shader may take in texture coordinates and lighting values from the vertex shader and also texture sampler and calculate the colour of the fragment based on the texture and lighting values. As a fragment shader runs once for each fragment high quality effects (per-pixel) may be calculated, however, this is much more expensive than running such calculations in the vertex shader.

```
uniform sampler2d sTexture;

varying mediump float LightIntensity;
varying mediump vec2 TexCoord;

void main()
{
    lowp vec3 texColour = texture2D(sTexture, TexCoord).rgb;
    gl_FragColor = vec4(texColour * LightIntensity, 1.0);
}
```

## 4.5. Built in functions

### Angle and Trigonometry Functions

### Angle and Trigonometry Functions

<code>radians(angle)</code>	Converts degrees to radians
<code>degrees(angle)</code>	Converts radians to degrees
<code>sin(angle)</code>	Returns sine function, takes an angle in radians
<code>cos(angle)</code>	Returns cosine function, takes an angle in radians
<code>tan(angle)</code>	Returns tangent function, takes an angle in radians
<code>asin(x)</code>	Returns arc sine function, returns an angle in radians
<code>acos(x)</code>	Returns arc cosine function, returns an angle in radians
<code>atan(x)</code>	Returns arc tangent function, returns an angle in radians

### Exponential Functions

<code>pow(x, y)</code>	Returns x raised to the power of y
<code>exp(x)</code>	Returns e raised to the power of x
<code>log(x)</code>	Returns natural logarithm of x
<code>exp2(x)</code>	Returns 2 raised to the power of x
<code>log2(x)</code>	Returns base 2 logarithm of x
<code>sqrt(x)</code>	Returns square root of x
<code>inversesqrt(x)</code>	Returns 1 over the square root of x

### Common Functions

<code>abs(x)</code>	Return the absolute value of x (i.e. $-x$ if $x < 0$ )
<code>sign(x)</code>	Returns 1.0 if $x > 0$ , 0.0 if $x = 0$ , -1.0 if $x < 0$
<code>floor(x)</code>	Returns the nearest integer less than or equal to x
<code>ceil(x)</code>	Returns the nearest integer greater than or equal to x
<code>fract(x)</code>	Returns $x - \text{floor}(x)$
<code>mod(x)</code>	Returns modulus of x
<code>min(x, y)</code>	Returns lower value of x and y
<code>max(x, y)</code>	Returns greater value of x and y
<code>clamp(x, minVal, maxVal)</code>	Returns $\text{min}(\text{max}(x, \text{minVal}), \text{maxVal})$
<code>mix(x, y, a)</code>	Returns linear blend of x and y
<code>step(edge, x)</code>	Returns 0.0 if $x < \text{edge}$ , else it returns 1.0
<code>smoothstep(edge0, edge1, x)</code>	Returns 0.0 if $x \leq \text{edge0}$ and 1.0 if $x \geq \text{edge1}$ , otherwise the smooth Hermite interpolation between 0 and 1.

### Geometric (Vector) Functions

<code>length(x)</code>	Returns length of vector x
<code>distance(x, y)</code>	Return distance between point x and point y
<code>dot(x, y)</code>	Returns the dot product of x and y
<code>cross(x, y)</code>	Returns the cross product of x and y
<code>normalize(x)</code>	Returns a vector in the same direction as x with length of 1
<code>faceforward(x, y, z)</code>	If $\text{dot}(z, y) < 0$ return x, else return $-x$
<code>reflect(x, y)</code>	Returns the reflection direction for incident vector x and surface normal y.

### Matrix Functions

### Matrix Functions

<code>matrixCompMult(x, y)</code>	Returns component-wise multiplication of matrices x and y
-----------------------------------	---

### Vector Relational Functions

<code>lessThan(x, y)</code>	Returns component-wise compare (as bvec) of $\text{vec } x < y$
<code>lessThanEqual(x, y)</code>	Returns component-wise compare (as bvec) of $\text{vec } x \leq y$
<code>greaterThan(x, y)</code>	Returns component-wise compare (as bvec) of $\text{vec } x > y$
<code>greaterThanEqual(x, y)</code>	Returns component-wise compare (as bvec) of $\text{vec } x \geq y$
<code>equal(x, y)</code>	Returns component-wise compare (as bvec) of $\text{vec } x == y$
<code>notEqual(x, y)</code>	Returns component-wise compare (as bvec) of $\text{vec } x \neq y$
<code>any(x)</code>	Returns true if any component of bvec x is true
<code>all(x)</code>	Returns true if all components of bvec x are true
<code>not(x)</code>	Returns component-wise logical complement of bvec x

### Texture Lookup Functions

<code>texture2D(x, y)</code> <code>texture2DProj(x, y)</code> <code>texture2DLod(x, y, z)</code> <code>texture2DProjLod(x, y, z)</code>	Use texture coordinate y to a texture lookup in the 2D texture bound to sampler x.
<code>textureCube(x, y)</code> <code>textureCubeLod(x, y, z)</code>	Use texture coordinate y to a texture lookup in the cube map texture bound to sampler x.

## 4.6. Uniforms (per primitive data)

Uniforms are used to pass per primitive data from the application to the shaders. They are used for things like the world-view-projection matrix, light direction, or material properties, which will be the same over the whole primitive being rendered.

Extract of application code setting some uniform values:

```
GLfloat pWVP[16] = ... // get world-view-projection matrix
GLfloat pWVIT[9] = ... // get world-view inverse transform matrix
GLfloat pLightDir[3] = ... // get light direction

GLint i32Location;

i32Location = glGetUniformLocation(uiProgramObject, "WorldViewProjection");
glUniformMatrix4fv(i32Location, 1, GL_FALSE, pWVP);

i32Location = glGetUniformLocation(uiProgramObject, "WorldViewIT");
glUniformMatrix3fv(i32Location, 1, GL_FALSE, pWVIT);

i32Location = glGetUniformLocation(uiProgramObject, "LightDir");
glUniform3fv(i32Location, 1, GL_FALSE, pLightDir);
```

Extract of vertex shader using uniforms:



```
uniform highp mat4 WorldViewProjection;
uniform highp mat3 WorldViewIT;
uniform mediump vec3 LightDir;

void main(void)
{
    gl_Position = WorldViewProjection * vec4(inVertex, 1.0);

    mediump vec3 normal = normalize(WorldViewIT * inNormal);
    LightIntensity = max(0.0, dot(normal, LightDir));
}
```

When submitting data in bone batch, such as a skinning effect, the uniforms for the bone matrix array will usually be updated per batch, whereas other uniforms such as light direction can remain unchanged.

## 4.7. Attributes (per vertex data)

Attributes are used to pass per vertex data from the application to the shaders. They are used for things like the vertex data, normals, texture co-ordinates, which will be different for each vertex.

Extract of application code setting some attribute values:

```
#define VERTEX_ARRAY 0
#define NORMAL_ARRAY 1
#define TEXCOORD_ARRAY 2

glBindAttribLocation(uiProgramObject, VERTEX_ARRAY, "inVertex");
glBindAttribLocation(uiProgramObject, NORMAL_ARRAY, "inNormal");
glBindAttribLocation(uiProgramObject, TEXCOORD_ARRAY, "inTexCoord");

GLsizei stride = ... // get data tride
GLuint vertexOffset = ... // get vertices offset
GLuint normalOffset = ... // get normals offset
GLuint texcoordOffset = ... // get texture coords offset

glEnableVertexAttribArray(VERTEX_ARRAY);
glVertexAttribPointer(VERTEX_ARRAY, 3, GL_FLOAT, GL_FALSE, stride, (void*)vertexOffset);

glEnableVertexAttribArray(NORMAL_ARRAY);
glVertexAttribPointer(NORMAL_ARRAY, 3, GL_FLOAT, GL_FALSE, stride, (void*)normalOffset);

glEnableVertexAttribArray(TEXCOORD_ARRAY);
glVertexAttribPointer(TEXCOORD_ARRAY, 2, GL_FLOAT, GL_FALSE, stride, (void*)texcoordOffset);
```

Extract of vertex shader using attribute values:

```
attribute highp vec3 inVertex;
attribute highp vec3 inNormal;
attribute highp vec2 inTexCoord;

void main(void)
{
    gl_Position = WorldViewProjection * vec4(inVertex, 1.0);

    mediump vec3 normal = normalize(WorldViewIT * inNormal);
    LightIntensity = max(0.0, dot(normal, LightDir));

    TexCoord = inTexCoord.st;
}
```

## 4.8. Varyings (passing data from vertex shader to fragment shader)

Varyings are used to pass data from the vertex shader to the fragment shader. They are used for things like passing texture co-ordinates, or lighting values calculated per vertex.

Extract of vertex shader using varyings:

```
varying mediump float LightIntensity;
varying mediump vec2 TexCoord;

void main(void)
{
    gl_Position = WorldViewProjection * vec4(inVertex, 1.0);

    mediump vec3 normal = normalize(WorldViewIT * inNormal);
    LightIntensity = max(0.0, dot(normal, LightDir));

    TexCoord = inTexCoord.st;
}
```

Extract of fragment shader using varyings:

```
varying mediump float LightIntensity;
varying mediump vec2 TexCoord;

void main()
{
    lowp vec4 texColour = texture2D(sTexture, TexCoord);
    gl_FragColor = texColour * LightIntensity;
}
```

## 5. Drawing a Triangle

The example below shows how to draw a simple triangle using OpenGL ES2.

*Note: Please see the HelloTriangle training course in the POWERVR OpenGL ES 1 and OpenGL ES 2 SDKs for a full example with source code. Available to download from the POWERVR Insider website: <http://www.powervrinsider.com>*

```

GLuint ui32Vbo = 0; // Vertex buffer object handle

// Initialise EGL

// Initialise 3D

// Matrix used for projection model view (PMVMatrix)
float pfIdentity[] = { 1.0f, 0.0f, 0.0f, 0.0f,
                      0.0f, 1.0f, 0.0f, 0.0f,
                      0.0f, 0.0f, 1.0f, 0.0f,
                      0.0f, 0.0f, 0.0f, 1.0f };

// Fragment and vertex shaders code
const char* pszFragShader = "\
    void main (void)\
    {\
        gl_FragColor = vec4(1.0, 1.0, 0.66 ,1.0);\
    }";

const char* pszVertShader = "\
    attribute highp vec4    myVertex;\
    uniform mediump mat4    myPMVMatrix;\
    void main(void)\
    {\
        gl_Position = myPMVMatrix * myVertex;\
    }";

GLuint uiFragShader, uiVertShader; // Used to hold the fragment and vertex shader handles
GLuint uiProgramObject;           // Used to hold the program handle (made out of
the two previous shaders

// Create the fragment shader object
uiFragShader = glCreateShader(GL_FRAGMENT_SHADER);

// Load the source code into it
glShaderSource(uiFragShader, 1, (const char**)&pszFragShader, NULL);

// Compile the source code
glCompileShader(uiFragShader);

// Check if compilation succeeded
GLint bShaderCompiled;
glGetShaderiv(uiFragShader, GL_COMPILE_STATUS, &bShaderCompiled);

if (!bShaderCompiled)
{
    // An error happened, first retrieve the length of the log message
    int i32InfoLogLength, i32CharsWritten;
    glGetShaderiv(uiFragShader, GL_INFO_LOG_LENGTH, &i32InfoLogLength);

    // Allocate enough space for the message and retrieve it
    char* pszInfoLog = new char[i32InfoLogLength];
    glGetShaderInfoLog(uiFragShader, i32InfoLogLength, &i32CharsWritten, pszInfoLog);

    // Displays the error
    printf("Failed to compile fragment shader: %s\n", pszInfoLog);
    delete [] pszInfoLog;
    goto cleanup;
}

// Loads the vertex shader in the same way
uiVertShader = glCreateShader(GL_VERTEX_SHADER);
glShaderSource(uiVertShader, 1, (const char**)&pszVertShader, NULL);
glCompileShader(uiVertShader);
glGetShaderiv(uiVertShader, GL_COMPILE_STATUS, &bShaderCompiled);

if (!bShaderCompiled)
{
    int i32InfoLogLength, i32CharsWritten;
    glGetShaderiv(uiVertShader, GL_INFO_LOG_LENGTH, &i32InfoLogLength);
    char* pszInfoLog = new char[i32InfoLogLength];
    glGetShaderInfoLog(uiVertShader, i32InfoLogLength, &i32CharsWritten, pszInfoLog);
    printf("Failed to compile vertex shader: %s\n", pszInfoLog);
    delete [] pszInfoLog;
    goto cleanup;
}

```

```

}

// Create the shader program
uiProgramObject = glCreateProgram();

// Attach the fragment and vertex shaders to it
glAttachShader(uiProgramObject, uiFragShader);
glAttachShader(uiProgramObject, uiVertShader);

// Bind the custom vertex attribute "myVertex" to location VERTEX_ARRAY
glBindAttribLocation(uiProgramObject, VERTEX_ARRAY, "myVertex");

// Link the program
glLinkProgram(uiProgramObject);

// Check if linking succeeded in the same way we checked for compilation success
GLint bLinked;
glGetProgramiv(uiProgramObject, GL_LINK_STATUS, &bLinked);

if (!bLinked)
{
    int ui32InfoLogLength, ui32CharsWritten;
    glGetProgramiv(uiProgramObject, GL_INFO_LOG_LENGTH, &ui32InfoLogLength);
    char* pszInfoLog = new char[ui32InfoLogLength];
    glGetProgramInfoLog(uiProgramObject, ui32InfoLogLength, &ui32CharsWritten,
    pszInfoLog);
    printf("Failed to link program: %s\n", pszInfoLog);
    delete [] pszInfoLog;
    goto cleanup;
}

// Actually use the created program
glUseProgram(uiProgramObject);

// Sets the clear color.
// The colours are passed per channel (red,green,blue,alpha) as float values from 0.0 to 1.0
glClearColor(0.6f, 0.8f, 1.0f, 1.0f); // clear blue

// We're going to draw a triangle to the screen so create a vertex buffer object for our
triangle
{
    // Interleaved vertex data
    GLfloat afVertices[] = {
        -0.4f, -0.4f, 0.0f, // Position
        0.4f, -0.4f, 0.0f,
        0.0f, 0.4f, 0.0f };

    // Generate the vertex buffer object (VBO)
    glGenBuffers(1, &ui32Vbo);

    // Bind the VBO so we can fill it with data
    glBindBuffer(GL_ARRAY_BUFFER, ui32Vbo);

    // Set the buffer's data
    unsigned int uiSize = 3 * (sizeof(GLfloat) * 3);
    // Calc afVertices size (3 vertices * stride (3 GLfloats per vertex))

    glBufferData(GL_ARRAY_BUFFER, uiSize, afVertices, GL_STATIC_DRAW);
}

// Draw frames with OpenGL ES 2
for(int i = 0; i < 800; ++i)
{
    // Clears the color buffer.
    glClear(GL_COLOR_BUFFER_BIT);
    if (!TestEGLLError("glClear"))
    {
        goto cleanup;
    }

    /*
        Bind the projection model view matrix (PMVMatrix) to
        the associated uniform variable in the shader
    */
}

```

```

// First gets the location of that variable in the shader using its name
int i32Location = glGetUniformLocation(uiProgramObject, "myPMVMatrix");

// Then passes the matrix to that variable
glUniformMatrix4fv( i32Location, 1, GL_FALSE, pfIdentity);

/*
    Enable the custom vertex attribute at index VERTEX_ARRAY.
    We previously binded that index to the variable in our shader "vec4 MyVertex;"
*/
glEnableVertexAttribArray(VERTEX_ARRAY);

// Sets the vertex data to this attribute index
glVertexAttribPointer(VERTEX_ARRAY, 3, GL_FLOAT, GL_FALSE, 0, 0);

/*
    Draws a non-indexed triangle array from the pointers previously given.
    This function allows the use of other primitive types : triangle strips, lines,
...
    For indexed geometry, use the function glDrawElements() with an index list.
*/
glDrawArrays(GL_TRIANGLES, 0, 3);
if (!TestEGLError("glDrawArrays"))
{
    goto cleanup;
}

/*
    Swap Buffers.
    Brings to the native display the current render surface.
*/
eglSwapBuffers(eglDisplay, eglSurface);

if (!TestEGLError("eglSwapBuffers"))
{
    goto cleanup;
}

glDisableVertexAttribArray(VERTEX_ARRAY);
}

cleanup:
// Frees the OpenGL handles for the program and the 2 shaders
glDeleteProgram(uiProgramObject);
glDeleteShader(uiFragShader);
glDeleteShader(uiVertShader);

// Delete the VBO as it is no longer needed
glDeleteBuffers(1, &ui32Vbo);

// Destroy EGL

```

## 6. Transformation Shaders

In OpenGL ES 1.x the vertices and normals are transformed and projected by the fixed pipeline. In OpenGL ES 2.0 the user has to supply the shaders to perform the transformation of vertices position and normal.

The transformation matrices are the same in OpenGL ES 1.x and OpenGL ES 2.0 although in the second case the user needs to put them into Uniforms so these can be accessible from the vertex shader.

The simple case is where the World, View and Projection matrices are multiplied in a single 'transformation matrix'. The vertex shader only needs to calculate the dot product between this matrix and the vertex position:

```
attribute highp vec4    myVertex;
uniform mediump mat3    myModelViewIT;

void main(void)
{
    gl_Position = myMVPMatrix * myVertex;
}
```

Normals are transformed in the same way (see example below).

For more complex lighting models or other effect the 'transformation' matrices might require to be processed separately.

## 7. Lighting

OpenGL ES2 does not use `glLight` and `glMaterial`, like OpenGL ES1, instead, lighting and material properties must be calculated in the shader. Pass light direction, position, material properties to the shaders (accessed as uniforms).

### 7.1. Directional Light

Here is an example of how to do a basic direction lighting effect in both OpenGL ES1 and OpenGL ES2.

#### 7.1.1. OpenGL ES 1

```
glEnable(GL_LIGHTING);
glEnable(GL_LIGHT0);

/*
    Specifies the light direction.
    If the 4th component is 0, it's a parallel light (the case here).
    If the 4th component is not 0, it's a point light.
*/
float aLightDirection[] = {0.0f, 0.0f, 1.0f, 0.0f};

/*
    Assigns the light direction to the light number 0.
    This function allows you to set also the ambient, diffuse,
    specular, emission colors of the light as well as attenuation parameters.
    We keep the other parameters to their default value in this demo.
*/
glLightfv(GL_LIGHT0, GL_POSITION, aLightDirection);

glMaterial4f(GL_FRONT_AND_BACK, GL_AMBIENT, 1.0f, 1.0f, 1.0f, 1.0f);
glMaterial4f(GL_FRONT_AND_BACK, GL_DIFFUSE, 1.0f, 1.0f, 1.0f, 1.0f);

glEnableClientState(GL_NORMAL_ARRAY);
glNormalPointer(GL_FLOAT, stride, (void*)(offset));

//DRAW
```

#### 7.1.2. OpenGL ES 2

In addition to the vertex data and world-view-projection matrix discussed above; the light direction, model-view inverse transpose matrix, and vertex normals are passed to the shader. The vertex shader uses these values to calculate the intensity of the lighting at each vertex (`varDot`). It uses a

simple dot-product of the light direction in view space and vertex normal in view space. The model-view inverse transpose matrix must be used to convert the normals rather than the model-view matrix as any scaling would change the direction of the normal. The fragment shader multiplies the base colour by this light intensity value to produce the colour of the fragment.

```
// Bind the Model View Inverse Transpose matrix to the shader.
i32Location = glGetUniformLocation(m_uiProgramObject, "myModelViewIT");
glUniformMatrix3fv( i32Location, 1, GL_FALSE, aModelViewIT);

// Bind the Light Direction vector to the shader
i32Location = glGetUniformLocation(m_uiProgramObject, "myLightDirection");
glUniform3f(i32Location, 0, 0, 1);

// Pass the normals data
glEnableVertexAttribArray(NORMAL_ARRAY);
glVertexAttribPointer(NORMAL_ARRAY, 3, GL_FLOAT, GL_FALSE, stride, (void*)(offset));

//DRAW
```

#### Vertex Shader:

```
attribute highp vec4 myVertex;
attribute mediump vec3 myNormal;

uniform mediump mat4   myPMVMatrix;
uniform mediump mat3   myModelViewIT;
uniform mediump vec3   myLightDirection;

varying mediump float  varDot;

void main(void)
{
    gl_Position = myPMVMatrix * myVertex;

    mediump vec3 transNormal = myModelViewIT * myNormal;
    varDot = max(dot(transNormal, myLightDirection), 0.0 );
}
```

#### Fragment Shader:

```
varying mediump float  varDot;

void main (void)
{
    vec3 baseColour = vec3(1.0, 1.0, 1.0);
    gl_FragColor = vec4(baseColour * varDot, 1.0);
}
```

## 8. Texturing

### 8.1. Basic Texturing

Here is an example of how to do a basic texturing effect in both OpenGL ES1 and OpenGL ES2. In OpenGL ES 2 the texture lookup must be performed explicitly in the shader.

#### 8.1.1. OpenGL ES 1

```
// Load the texture and set filtering parameters

glEnable(GL_TEXTURE_2D);

glEnableClientState(GL_TEXTURE_COORD_ARRAY);
glTexCoordPointer(2, VERTTYPEENUM, stride, (void*)(offset));

//DRAW
```

### 8.1.2. OpenGL ES 2

The handle to the texture and vertex texture co-ordinates are passed to the shader. The vertex shader passes the texture coordinates straight through to the fragment shader. The fragment shader uses these texture co-ordinates to lookup the colour from the texture, this colour is used as the fragment colour.

```
// Load the texture and set filtering parameters

// Sets the sampler2D variable to the first texture unit
glUniform1i(glGetUniformLocation(uiProgramObject, "sampler2d"), 0);

// Pass the texture co-ordinate data
glEnableVertexAttribArray(TEXCOORD_ARRAY);
glVertexAttribPointer(TEXCOORD_ARRAY, 2, GL_FLOAT, GL_FALSE, stride, (void*)(offset));

//DRAW
```

Vertex Shader:

```
attribute highp vec4 myVertex;
attribute mediump vec2 myUV;

uniform mediump mat4 myPMVMatrix;

varying mediump vec2 varCoord;

void main (void)
{
    gl_Position = myPMVMatrix * myVertex;

    varCoord = myUV.st;
}
```

Fragment Shader:

```
uniform sampler2D sampler2d;

varying mediump vec2 varCoord;

void main (void)
{
    gl_FragColor = texture2D(sampler2d, varCoord);
}
```

## 8.2. Fast Texture and Lighting Example

This is an example of a very fast texture and lighting effect, it uses a crude method for calculating the lighting per vertex. The shaders take the light direction (in model space) and a bias and scale for the material from the application.



The vertex shader calculates diffuse and specular lighting values for the red, green, and blue channels. Diffuse lighting is calculated as the dot product of the normal and the light direction. Unlike the previous example, no transformation by the world-view inverse transpose is required here. The specular lighting is calculated from the diffuse lighting value offset by the `MaterialBias` and scaled by the `MaterialScale` value.

The fragment shader takes the texture co-ordinates and looks up the corresponding colour from the texture. This colour value is multiplied by diffuse lighting values and the specular lighting is added to it to give the red, green and blue values for the fragment colour.

#### Vertex Shader:

```
attribute highp vec4 inVertex;
attribute highp vec3 inNormal;
attribute highp vec2 inTexCoord;

uniform highp mat4 MVPMatrix;
uniform highp vec3 LightDirection;
uniform highp float MaterialBias;
uniform highp float MaterialScale;

varying lowp vec3 DiffuseLight;
varying lowp vec3 SpecularLight;
varying mediump vec2 TexCoord;

void main()
{
    gl_Position = MVPMatrix * inVertex;

    DiffuseLight = vec3(max(dot(inNormal, LightDirection), 0.0));
    SpecularLight = vec3(max((DiffuseLight.x - MaterialBias) * MaterialScale, 0.0));

    TexCoord = inTexCoord;
}
```

#### Fragment Shader:

```
uniform sampler2D sTexture;

varying lowp vec3 DiffuseLight;
varying lowp vec3 SpecularLight;
varying mediump vec2 TexCoord;

void main()
{
    lowp vec3 texColor = texture2D(sTexture, TexCoord).rgb;
    lowp vec3 color = (texColor * DiffuseLight) + SpecularLight;
    gl_FragColor = vec4(color, 1.0);
}
```

## Appendix A. Specifications Overview

### A.1. Functions

OpenGL ES 1	OpenGL ES 2
glActiveTexture	glActiveTexture
glAlphaFunc	
glAlphaFuncx	
	glAttachShader
glBindBuffer	glBindAttribLocation
	glBindBuffer
	glBindFramebuffer
	glBindRenderbuffer
glBindTexture	glBindTexture
	glBlendColor
	glBlendEquation
	glBlendEquationSeparate
glBlendFunc	glBlendFunc
	glBlendFuncSeparate
glBufferData	glBufferData
glBufferSubData	glBufferSubData
	glCheckFramebufferStatus
glClear	glClear
glClearColor	glClearColor
glClearColorx	
glClearDepthf	glClearDepthf
glClearDepthx	
glClearStencil	glClearStencil
glClientActiveTexture	
glClipPlanef	
glClipPlanex	
glColor4f	
glColor4ub	
glColor4x	
glColorMask	glColorMask
glColorPointer	
glCompressedTexImage2D	glCompileShader
glCompressedTexSubImage2D	glCompressedTexImage2D
glCopyTexImage2D	glCompressedTexSubImage2D
glCopyTexSubImage2D	glCopyTexImage2D
	glCopyTexSubImage2D
	glCreateProgram
	glCreateShader
glCullFace	glCullFace
glDeleteBuffers	glDeleteBuffers
	glDeleteFramebuffers
	glDeleteProgram
	glDeleteRenderbuffers
	glDeleteShader
glDeleteTextures	glDeleteTextures
glDepthFunc	glDepthFunc
glDepthMask	glDepthMask
glDepthRangef	glDepthRangef

OpenGL ES 1	OpenGL ES 2
glDepthRangex	
glDisable	glDetachShader
glDisableClientState	glDisable
glDrawArrays	glDisableVertexAttribArray
glDrawElements	glDrawArrays
glEnable	glDrawElements
glEnableClientState	glEnable
glFinish	glEnableVertexAttribArray
glFlush	glFinish
glFogf	glFlush
glFogfv	
glFogx	
glFogxv	
glFrontFace	glFramebufferRenderbuffer
glFrustumf	glFramebufferTexture2D
glFrustumx	glFrontFace
glGenBuffers	glGenBuffers
	glGenerateMipmap
	glGenFramebuffers
	glGenRenderbuffers
glGenTextures	glGenTextures
	glGetActiveAttrib
	glGetActiveUniform
	glGetAttachedShaders
	glGetAttribLocation
glGetBooleanv	glGetBooleanv
glGetBufferParameteriv	glGetBufferParameteriv
glGetClipPlanef	
glGetClipPlanex	
glGetError	glGetError
glGetFixedv	
glGetFloatv	glGetFloatv
glGetIntegerv	glGetFramebufferAttachmentParameteriv
glGetLightfv	glGetIntegerv
glGetLightxv	
glGetMaterialfv	
glGetMaterialxv	
glGetPointerv	
	glGetProgramiv
	glGetProgramInfoLog
	glGetRenderbufferParameteriv
	glGetShaderiv
	glGetShaderInfoLog
	glGetShaderPrecisionFormat
	glGetShaderSource
glGetString	glGetString
glGetTexEnvfv	
glGetTexEnviv	
glGetTexEnvxv	

OpenGL ES 1	OpenGL ES 2
glGetTexParameterfv glGetTexParameteriv glGetTexParameterxv  glHint glIsBuffer glIsEnabled  glIsTexture glLightModelf glLightModelfv glLightModelx glLightModelxv glLightf glLightfv glLightx glLightxv glLineWidth glLineWidthx  glLoadIdentity glLoadMatrixf glLoadMatrixx glLogicOp glMaterialf glMaterialfv glMaterialx glMaterialxv glMatrixMode glMultMatrixf glMultMatrixx glMultiTexCoord4f glMultiTexCoord4x glNormal3f glNormal3x glNormalPointer glOrthof glOrthox glPixelStorei glPointParameterf glPointParameterfv glPointParameterx glPointParameterxv glPointSize glPointSizex glPolygonOffset glPolygonOffsetx	glGetTexParameterfv glGetTexParameteriv  glGetUniformfv glGetUniformiv glGetUniformLocation glGetVertexAttribfv glGetVertexAttribiv glGetVertexAttribPointerv glHint glIsBuffer glIsEnabled glIsFramebuffer glIsProgram glIsRenderbuffer glIsShader glIsTexture  glLineWidth  glLinkProgram     glPixelStorei   glPolygonOffset

OpenGL ES 1	OpenGL ES 2
glPopMatrix glPushMatrix glReadPixels  glRotatef glRotatex glSampleCoverage glSampleCoveragex glScalef glScalex glScissor glShadeModel  glStencilFunc  glStencilMask  glStencilOp  glTexCoordPointer glTexEnvf glTexEnvfv glTexEnvi glTexEnviv glTexEnvx glTexEnvxv glTexImage2D glTexParameterf glTexParameterfv glTexParameteri glTexParameteriv glTexParameterx glTexParameterxv glTexSubImage2D glTranslatef glTranslatex	glReadPixels glReleaseShaderCompiler glRenderbufferStorage  glSampleCoverage  glScissor  glShaderBinary glShaderSource glStencilFunc glStencilFuncSeparate glStencilMask glStencilMaskSeparate glStencilOp glStencilOpSeparate  glTexImage2D glTexParameterf glTexParameterfv glTexParameteri glTexParameteriv  glTexSubImage2D  glUniform1f glUniform1fv glUniform1i glUniform1iv glUniform2f glUniform2fv glUniform2i glUniform2iv glUniform3f glUniform3fv glUniform3i glUniform3iv glUniform4f glUniform4fv glUniform4i glUniform4iv glUniformMatrix2fv

OpenGL ES 1	OpenGL ES 2
glVertexPointer glViewport	glUniformMatrix3fv glUniformMatrix4fv glUseProgram glValidateProgram glVertexAttrib1f glVertexAttrib1fv glVertexAttrib2f glVertexAttrib2fv glVertexAttrib3f glVertexAttrib3fv glVertexAttrib4f glVertexAttrib4fv glVertexAttribPointer  glViewport

## A.2. Definitions

OpenGL ES 1	OpenGL ES 2
/* OpenGL ES core versions */ GL_VERSION_ES_CM_1_0 GL_VERSION_ES_CL_1_0 GL_VERSION_ES_CM_1_1 GL_VERSION_ES_CL_1_1  /* ClearBufferMask */ GL_DEPTH_BUFFER_BIT GL_STENCIL_BUFFER_BIT GL_COLOR_BUFFER_BIT  /* Boolean */ GL_FALSE GL_TRUE  /* BeginMode */ GL_POINTS GL_LINES GL_LINE_LOOP GL_LINE_STRIP GL_TRIANGLES GL_TRIANGLE_STRIP GL_TRIANGLE_FAN  /* AlphaFunction */ GL_NEVER GL_LESS GL_EQUAL GL_LEQUAL GL_GREATER GL_NOTEQUAL GL_GEQUAL GL_ALWAYS	/* OpenGL ES core versions */ GL_ES_VERSION_2_0  /* ClearBufferMask */ GL_DEPTH_BUFFER_BIT GL_STENCIL_BUFFER_BIT GL_COLOR_BUFFER_BIT  /* Boolean */ GL_FALSE GL_TRUE  /* BeginMode */ GL_POINTS GL_LINES GL_LINE_LOOP GL_LINE_STRIP GL_TRIANGLES GL_TRIANGLE_STRIP GL_TRIANGLE_FAN



OpenGL ES 1	OpenGL ES 2
GL_BUFFER_USAGE	GL_BUFFER_USAGE GL_CURRENT_VERTEX_ATTRIB
/* ClipPlaneName */ GL_CLIP_PLANE0 GL_CLIP_PLANE1 GL_CLIP_PLANE2 GL_CLIP_PLANE3 GL_CLIP_PLANE4 GL_CLIP_PLANE5	
/* ColorMaterialFace */ GL_FRONT_AND_BACK	
/* ColorMaterialParameter */ GL_AMBIENT_AND_DIFFUSE	
/* ColorPointerType */ GL_UNSIGNED_BYTE GL_FLOAT GL_FIXED	
/* CullFaceMode */ GL_FRONT GL_BACK GL_FRONT_AND_BACK	/* CullFaceMode */ GL_FRONT GL_BACK GL_FRONT_AND_BACK
/* DepthFunction */ GL_NEVER GL_LESS GL_EQUAL GL_LEQUAL GL_GREATER GL_NOTEQUAL GL_GEQUAL GL_ALWAYS	/* DepthFunction */ GL_NEVER GL_LESS GL_EQUAL GL_LEQUAL GL_GREATER GL_NOTEQUAL GL_GEQUAL GL_ALWAYS
/* EnableCap */ GL_FOG GL_LIGHTING GL_TEXTURE_2D GL_CULL_FACE GL_ALPHA_TEST GL_BLEND GL_COLOR_LOGIC_OP GL_DITHER GL_STENCIL_TEST GL_DEPTH_TEST GL_LIGHT0 GL_LIGHT1 GL_LIGHT2 GL_LIGHT3 GL_LIGHT4 GL_LIGHT5 GL_LIGHT6	/* EnableCap */  GL_TEXTURE_2D GL_CULL_FACE  GL_BLEND  GL_DITHER GL_STENCIL_TEST GL_DEPTH_TEST



OpenGL ES 1	OpenGL ES 2
GL_LIGHT7 GL_POINT_SMOOTH GL_LINE_SMOOTH GL_SCISSOR_TEST GL_COLOR_MATERIAL GL_NORMALIZE GL_RESCALE_NORMAL GL_POLYGON_OFFSET_FILL GL_VERTEX_ARRAY GL_NORMAL_ARRAY GL_COLOR_ARRAY GL_TEXTURE_COORD_ARRAY GL_MULTISAMPLE GL_SAMPLE_ALPHA_TO_COVERAGE GL_SAMPLE_ALPHA_TO_ONE GL_SAMPLE_COVERAGE  /* ErrorCode */ GL_NO_ERROR GL_INVALID_ENUM GL_INVALID_VALUE GL_INVALID_OPERATION GL_STACK_OVERFLOW GL_STACK_UNDERFLOW GL_OUT_OF_MEMORY  /* FogMode */ GL_LINEAR GL_EXP GL_EXP2  /* FogParameter */ GL_FOG_DENSITY GL_FOG_START GL_FOG_END GL_FOG_MODE GL_FOG_COLOR  /* FrontFaceDirection */ GL_CW GL_CCW  /* GetPName */ GL_CURRENT_COLOR GL_CURRENT_NORMAL GL_CURRENT_TEXTURE_COORDS GL_POINT_SIZE GL_POINT_SIZE_MIN GL_POINT_SIZE_MAX GL_POINT_FADE_THRESHOLD_SIZE GL_POINT_DISTANCE_ATTENUATION GL_SMOOTH_POINT_SIZE_RANGE GL_LINE_WIDTH GL_SMOOTH_LINE_WIDTH_RANGE GL_ALIASED_POINT_SIZE_RANGE	GL_SCISSOR_TEST  GL_POLYGON_OFFSET_FILL  GL_SAMPLE_ALPHA_TO_COVERAGE  GL_SAMPLE_COVERAGE  /* ErrorCode */ GL_NO_ERROR GL_INVALID_ENUM GL_INVALID_VALUE GL_INVALID_OPERATION GL_OUT_OF_MEMORY  /* FrontFaceDirection */ GL_CW GL_CCW  /* GetPName */  GL_LINE_WIDTH  GL_ALIASED_POINT_SIZE_RANGE

OpenGL ES 1	OpenGL ES 2
GL_ALIASED_LINE_WIDTH_RANGE	GL_ALIASED_LINE_WIDTH_RANGE
GL_CULL_FACE_MODE	GL_CULL_FACE_MODE
GL_FRONT_FACE	GL_FRONT_FACE
GL_SHADE_MODEL	
GL_DEPTH_RANGE	GL_DEPTH_RANGE
GL_DEPTH_WRITEMASK	GL_DEPTH_WRITEMASK
GL_DEPTH_CLEAR_VALUE	GL_DEPTH_CLEAR_VALUE
GL_DEPTH_FUNC	GL_DEPTH_FUNC
GL_STENCIL_CLEAR_VALUE	GL_STENCIL_CLEAR_VALUE
GL_STENCIL_FUNC	GL_STENCIL_FUNC
GL_STENCIL_FAIL	GL_STENCIL_FAIL
GL_STENCIL_PASS_DEPTH_FAIL	GL_STENCIL_PASS_DEPTH_FAIL
GL_STENCIL_PASS_DEPTH_PASS	GL_STENCIL_PASS_DEPTH_PASS
GL_STENCIL_REF	GL_STENCIL_REF
GL_STENCIL_VALUE_MASK	GL_STENCIL_VALUE_MASK
GL_STENCIL_WRITEMASK	GL_STENCIL_WRITEMASK
	GL_STENCIL_BACK_FUNC
	GL_STENCIL_BACK_FAIL
	GL_STENCIL_BACK_PASS_DEPTH_FAIL
	GL_STENCIL_BACK_PASS_DEPTH_PASS
	GL_STENCIL_BACK_REF
	GL_STENCIL_BACK_VALUE_MASK
	GL_STENCIL_BACK_WRITEMASK
GL_MATRIX_MODE	
GL_VIEWPORT	GL_VIEWPORT
GL_MODELVIEW_STACK_DEPTH	
GL_PROJECTION_STACK_DEPTH	
GL_TEXTURE_STACK_DEPTH	
GL_MODELVIEW_MATRIX	
GL_PROJECTION_MATRIX	
GL_TEXTURE_MATRIX	
GL_ALPHA_TEST_FUNC	
GL_ALPHA_TEST_REF	
GL_BLEND_DST	
GL_BLEND_SRC	
GL_LOGIC_OP_MODE	
GL_SCISSOR_BOX	GL_SCISSOR_BOX
GL_SCISSOR_TEST	GL_SCISSOR_TEST
GL_COLOR_CLEAR_VALUE	GL_COLOR_CLEAR_VALUE
GL_COLOR_WRITEMASK	GL_COLOR_WRITEMASK
GL_UNPACK_ALIGNMENT	GL_UNPACK_ALIGNMENT
GL_PACK_ALIGNMENT	GL_PACK_ALIGNMENT
GL_MAX_LIGHTS	
GL_MAX_CLIP_PLANES	
GL_MAX_TEXTURE_SIZE	GL_MAX_TEXTURE_SIZE
GL_MAX_MODELVIEW_STACK_DEPTH	
GL_MAX_PROJECTION_STACK_DEPTH	
GL_MAX_TEXTURE_STACK_DEPTH	
GL_MAX_VIEWPORT_DIMS	GL_MAX_VIEWPORT_DIMS
GL_MAX_TEXTURE_UNITS	
GL_SUBPIXEL_BITS	GL_SUBPIXEL_BITS
GL_RED_BITS	GL_RED_BITS
GL_GREEN_BITS	GL_GREEN_BITS
GL_BLUE_BITS	GL_BLUE_BITS
GL_ALPHA_BITS	GL_ALPHA_BITS

OpenGL ES 1	OpenGL ES 2
GL_DEPTH_BITS GL_STENCIL_BITS GL_POLYGON_OFFSET_UNITS GL_POLYGON_OFFSET_FILL GL_POLYGON_OFFSET_FACTOR GL_TEXTURE_BINDING_2D GL_VERTEX_ARRAY_SIZE GL_VERTEX_ARRAY_TYPE GL_VERTEX_ARRAY_STRIDE GL_NORMAL_ARRAY_TYPE GL_NORMAL_ARRAY_STRIDE GL_COLOR_ARRAY_SIZE GL_COLOR_ARRAY_TYPE GL_COLOR_ARRAY_STRIDE GL_TEXTURE_COORD_ARRAY_SIZE GL_TEXTURE_COORD_ARRAY_TYPE GL_TEXTURE_COORD_ARRAY_STRIDE GL_VERTEX_ARRAY_POINTER GL_NORMAL_ARRAY_POINTER GL_COLOR_ARRAY_POINTER GL_TEXTURE_COORD_ARRAY_POINTER GL_SAMPLE_BUFFERS GL_SAMPLES GL_SAMPLE_COVERAGE_VALUE GL_SAMPLE_COVERAGE_INVERT  /* GetTextureParameter */ GL_TEXTURE_MAG_FILTER GL_TEXTURE_MIN_FILTER GL_TEXTURE_WRAP_S GL_TEXTURE_WRAP_T  GL_NUM_COMPRESSED_TEXTURE_FORMATS GL_COMPRESSED_TEXTURE_FORMATS  /* HintMode */ GL_DONT_CARE GL_FASTEST GL_NICEST  /* HintTarget */ GL_PERSPECTIVE_CORRECTION_HINT GL_POINT_SMOOTH_HINT GL_LINE_SMOOTH_HINT GL_FOG_HINT GL_GENERATE_MIPMAP_HINT  /* LightModelParameter */ GL_LIGHT_MODEL_AMBIENT GL_LIGHT_MODEL_TWO_SIDE  /* LightParameter */ GL_AMBIENT GL_DIFFUSE GL_SPECULAR	GL_DEPTH_BITS GL_STENCIL_BITS GL_POLYGON_OFFSET_UNITS GL_POLYGON_OFFSET_FILL GL_POLYGON_OFFSET_FACTOR GL_TEXTURE_BINDING_2D     GL_SAMPLE_BUFFERS GL_SAMPLES GL_SAMPLE_COVERAGE_VALUE GL_SAMPLE_COVERAGE_INVERT  /* GetTextureParameter */ GL_TEXTURE_MAG_FILTER GL_TEXTURE_MIN_FILTER GL_TEXTURE_WRAP_S GL_TEXTURE_WRAP_T  GL_NUM_COMPRESSED_TEXTURE_FORMATS GL_COMPRESSED_TEXTURE_FORMATS  /* HintMode */ GL_DONT_CARE GL_FASTEST GL_NICEST  /* HintTarget */  GL_GENERATE_MIPMAP_HINT

OpenGL ES 1	OpenGL ES 2
GL_POSITION GL_SPOT_DIRECTION GL_SPOT_EXPONENT GL_SPOT_CUTOFF GL_CONSTANT_ATTENUATION GL_LINEAR_ATTENUATION GL_QUADRATIC_ATTENUATION  /* DataType */ GL_BYTE GL_UNSIGNED_BYTE GL_SHORT GL_UNSIGNED_SHORT  GL_FLOAT GL_FIXED  /* LogicOp */ GL_CLEAR GL_AND GL_AND_REVERSE GL_COPY GL_AND_INVERTED GL_NOOP GL_XOR GL_OR GL_NOR GL_EQUIV GL_INVERT GL_OR_REVERSE GL_COPY_INVERTED GL_OR_INVERTED GL_NAND GL_SET  /* MaterialFace */ GL_FRONT_AND_BACK  /* MaterialParameter */ GL_EMISSION GL_SHININESS GL_AMBIENT_AND_DIFFUSE GL_AMBIENT GL_DIFFUSE GL_SPECULAR  /* MatrixMode */ GL_MODELVIEW GL_PROJECTION GL_TEXTURE  /* NormalPointerType */ GL_BYTE GL_SHORT	/* DataType */ GL_BYTE GL_UNSIGNED_BYTE GL_SHORT GL_UNSIGNED_SHORT GL_INT GL_UNSIGNED_INT GL_FLOAT GL_FIXED

Migration from OpenGL ES 1.0 to OpenGL ES 2.0  
Revision 1.1f

OpenGL ES 1	OpenGL ES 2
<pre> /* StencilOp */ GL_ZERO GL_KEEP GL_REPLACE GL_INCR GL_DECR GL_INVERT  /* StringName */ GL_VENDOR GL_RENDERER GL_VERSION GL_EXTENSIONS  /* TexCoordPointerType */ GL_SHORT GL_FLOAT GL_FIXED GL_BYTE  /* TextureEnvMode */ GL_MODULATE GL_DECAL GL_BLEND GL_ADD GL_REPLACE  /* TextureEnvParameter */ GL_TEXTURE_ENV_MODE GL_TEXTURE_ENV_COLOR  /* TextureEnvTarget */ GL_TEXTURE_ENV  /* TextureMagFilter */ GL_NEAREST GL_LINEAR  /* TextureMinFilter */ GL_NEAREST GL_LINEAR GL_NEAREST_MIPMAP_NEAREST GL_LINEAR_MIPMAP_NEAREST GL_NEAREST_MIPMAP_LINEAR GL_LINEAR_MIPMAP_LINEAR  /* TextureParameterName */ GL_TEXTURE_MAG_FILTER GL_TEXTURE_MIN_FILTER GL_TEXTURE_WRAP_S GL_TEXTURE_WRAP_T GL_GENERATE_MIPMAP </pre>	<pre> /* StencilOp */ GL_ZERO GL_KEEP GL_REPLACE GL_INCR GL_DECR GL_INVERT GL_INCR_WRAP GL_DECR_WRAP  /* StringName */ GL_VENDOR GL_RENDERER GL_VERSION GL_EXTENSIONS  /* TextureMagFilter */ GL_NEAREST GL_LINEAR  /* TextureMinFilter */ GL_NEAREST GL_LINEAR GL_NEAREST_MIPMAP_NEAREST GL_LINEAR_MIPMAP_NEAREST GL_NEAREST_MIPMAP_LINEAR GL_LINEAR_MIPMAP_LINEAR  /* TextureParameterName */ GL_TEXTURE_MAG_FILTER GL_TEXTURE_MIN_FILTER GL_TEXTURE_WRAP_S GL_TEXTURE_WRAP_T </pre>

OpenGL ES 1	OpenGL ES 2
<pre> /* TextureTarget */ GL_TEXTURE_2D </pre>	<pre> /* TextureTarget */ GL_TEXTURE_2D GL_TEXTURE  GL_TEXTURE_CUBE_MAP GL_TEXTURE_BINDING_CUBE_MAP GL_TEXTURE_CUBE_MAP_POSITIVE_X GL_TEXTURE_CUBE_MAP_NEGATIVE_X GL_TEXTURE_CUBE_MAP_POSITIVE_Y GL_TEXTURE_CUBE_MAP_NEGATIVE_Y GL_TEXTURE_CUBE_MAP_POSITIVE_Z GL_TEXTURE_CUBE_MAP_NEGATIVE_Z GL_MAX_CUBE_MAP_TEXTURE_SIZE </pre>
<pre> /* TextureUnit */ GL_TEXTURE0 GL_TEXTURE1 GL_TEXTURE2 GL_TEXTURE3 GL_TEXTURE4 GL_TEXTURE5 GL_TEXTURE6 GL_TEXTURE7 GL_TEXTURE8 GL_TEXTURE9 GL_TEXTURE10 GL_TEXTURE11 GL_TEXTURE12 GL_TEXTURE13 GL_TEXTURE14 GL_TEXTURE15 GL_TEXTURE16 GL_TEXTURE17 GL_TEXTURE18 GL_TEXTURE19 GL_TEXTURE20 GL_TEXTURE21 GL_TEXTURE22 GL_TEXTURE23 GL_TEXTURE24 GL_TEXTURE25 GL_TEXTURE26 GL_TEXTURE27 GL_TEXTURE28 GL_TEXTURE29 GL_TEXTURE30 GL_TEXTURE31 GL_ACTIVE_TEXTURE GL_CLIENT_ACTIVE_TEXTURE </pre>	<pre> /* TextureUnit */ GL_TEXTURE0 GL_TEXTURE1 GL_TEXTURE2 GL_TEXTURE3 GL_TEXTURE4 GL_TEXTURE5 GL_TEXTURE6 GL_TEXTURE7 GL_TEXTURE8 GL_TEXTURE9 GL_TEXTURE10 GL_TEXTURE11 GL_TEXTURE12 GL_TEXTURE13 GL_TEXTURE14 GL_TEXTURE15 GL_TEXTURE16 GL_TEXTURE17 GL_TEXTURE18 GL_TEXTURE19 GL_TEXTURE20 GL_TEXTURE21 GL_TEXTURE22 GL_TEXTURE23 GL_TEXTURE24 GL_TEXTURE25 GL_TEXTURE26 GL_TEXTURE27 GL_TEXTURE28 GL_TEXTURE29 GL_TEXTURE30 GL_TEXTURE31 GL_ACTIVE_TEXTURE </pre>
<pre> /* TextureWrapMode */ GL_REPEAT GL_CLAMP_TO_EDGE </pre>	<pre> /* TextureWrapMode */ GL_REPEAT GL_CLAMP_TO_EDGE GL_MIRRORED_REPEAT </pre>

OpenGL ES 1	OpenGL ES 2
<pre> /* VertexPointerType */ GL_SHORT GL_FLOAT GL_FIXED GL_BYTE  /* Texture combine + dot3 */ GL_SUBTRACT GL_COMBINE GL_COMBINE_RGB GL_COMBINE_ALPHA GL_RGB_SCALE GL_ADD_SIGNED GL_INTERPOLATE GL_CONSTANT GL_PRIMARY_COLOR GL_PREVIOUS GL_OPERAND0_RGB GL_OPERAND1_RGB GL_OPERAND2_RGB GL_OPERAND0_ALPHA GL_OPERAND1_ALPHA GL_OPERAND2_ALPHA GL_ALPHA_SCALE GL_SRC0_RGB GL_SRC1_RGB GL_SRC2_RGB GL_SRC0_ALPHA </pre>	<pre> /* Uniform Types */ GL_FLOAT_VEC2 GL_FLOAT_VEC3 GL_FLOAT_VEC4 GL_INT_VEC2 GL_INT_VEC3 GL_INT_VEC4 GL_BOOL GL_BOOL_VEC2 GL_BOOL_VEC3 GL_BOOL_VEC4 GL_FLOAT_MAT2 GL_FLOAT_MAT3 GL_FLOAT_MAT4 GL_SAMPLER_2D GL_SAMPLER_CUBE  /* Vertex Arrays */ GL_VERTEX_ATTRIB_ARRAY_ENABLED GL_VERTEX_ATTRIB_ARRAY_SIZE GL_VERTEX_ATTRIB_ARRAY_STRIDE GL_VERTEX_ATTRIB_ARRAY_TYPE GL_VERTEX_ATTRIB_ARRAY_NORMALIZED GL_VERTEX_ATTRIB_ARRAY_POINTER GL_VERTEX_ATTRIB_ARRAY_BUFFER_BINDING </pre>





OpenGL ES 1	OpenGL ES 2
	GL_RGB5_A1 GL_RGB565 GL_DEPTH_COMPONENT16 GL_STENCIL_INDEX GL_STENCIL_INDEX8  GL_RENDERBUFFER_WIDTH GL_RENDERBUFFER_HEIGHT GL_RENDERBUFFER_INTERNAL_FORMAT GL_RENDERBUFFER_RED_SIZED GL_RENDERBUFFER_GREEN_SIZED GL_RENDERBUFFER_BLUE_SIZED GL_RENDERBUFFER_ALPHA_SIZED GL_RENDERBUFFER_DEPTH_SIZED GL_RENDERBUFFER_STENCIL_SIZED  GL_FRAMEBUFFER_ATTACHMENT_OBJECT_TYPE GL_FRAMEBUFFER_ATTACHMENT_OBJECT_NAME GL_FRAMEBUFFER_ATTACHMENT_TEXTURE_LEVEL GL_FRAMEBUFFER_ATTACHMENT_TEXTURE_CUBE_MAP_FACE  GL_COLOR_ATTACHMENT0 GL_DEPTH_ATTACHMENT GL_STENCIL_ATTACHMENT  GL_NONE  GL_FRAMEBUFFER_COMPLETE GL_FRAMEBUFFER_INCOMPLETE_ATTACHMENT GL_FRAMEBUFFER_INCOMPLETE_MISSING_ATTACHMENT GL_FRAMEBUFFER_INCOMPLETE_DIMENSIONS GL_FRAMEBUFFER_UNSUPPORTED  GL_FRAMEBUFFER_BINDING GL_RENDERBUFFER_BINDING GL_MAX_RENDERBUFFER_SIZE  GL_INVALID_FRAMEBUFFER_OPERATION