The Little Grasshopper

presents

MODERN OPENGL

APRIL 2012

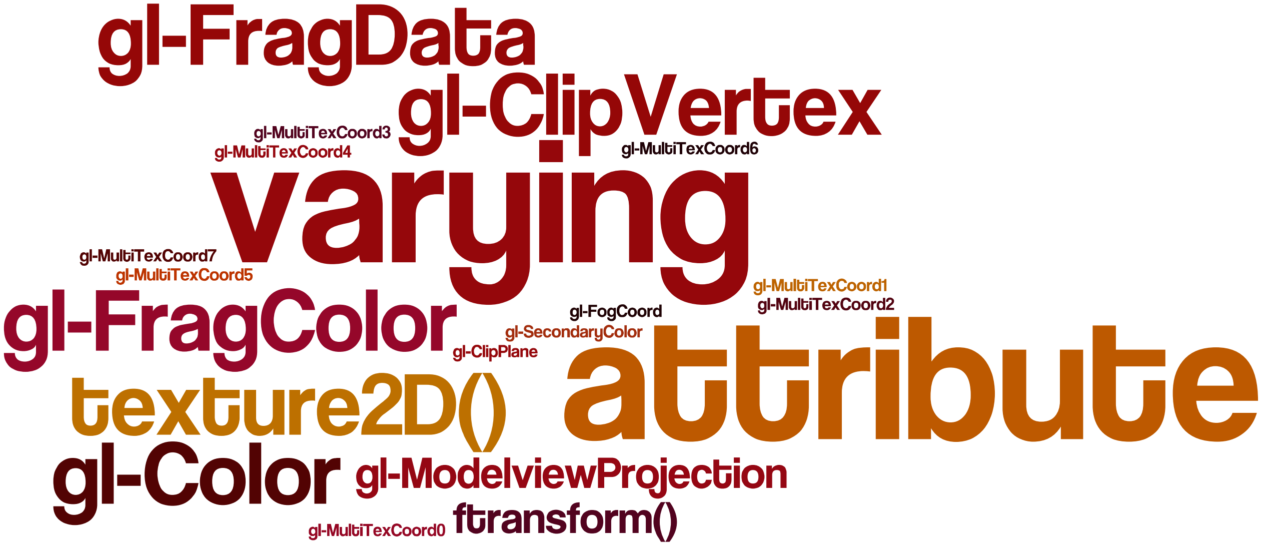
A *profile* is a subset of OpenGL that you choose to work in when you create a context. The **core** profile restricts you to the modern API. There's even an **ES** profile if you want your code to be portable to mobile platforms! Here's how you select a profile with **Qt** or **X**.

```
QGLFormat format;
format.setVersion(4,2);
format.setProfile(QGLFormat::CoreProfile);
QGLWidget *myWidget = new QGLWidget(format);
```

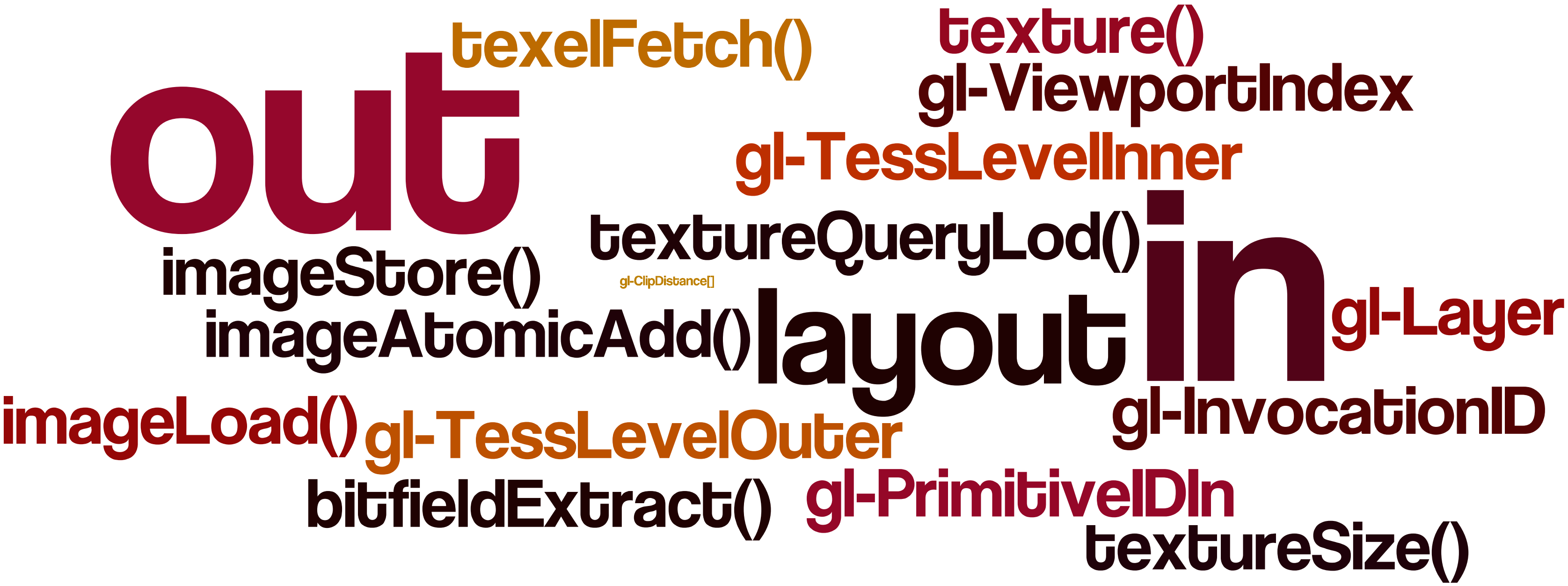
```
int attribs[] = {
    GLX_CONTEXT_MAJOR_VERSION_ARB, 4,
    GLX_CONTEXT_MINOR_VERSION_ARB, 2,
    GLX_CONTEXT_PROFILE_MASK_ARB, GLX_CONTEXT_CORE_PROFILE_BIT_ARB,
    NULL
};
GLXContext glc = glXCreateContextAttribs(diplay, config, NULL, True, attribs);
```

Core Profile

These word clouds depict how deprecated GLSL functions and built-in variables have changed.



OLD



NEW

Jurassic Vertices

```
glBegin(GL_TRIANGLES);
glColor4f(1, 0, 0, 0
glVertex3f(0, 1, 1
glVertex3f(1, 1,
glVertex3f(1, 0  1);
glEnd();
```

```
glVertexPointe
glColorPointer
glNormalPointer
```

```
glNewList
glCallList
```

```
GL_QUAD_STRIP, GL_QUADS, GL_POLYGON
```

Don't use any of this stuff -- it's old!

Modern Vertices

```
glVertexAttrib3d
glVertexAttrib4i
glVertexAttribI4i
glVertexAttribL2d
etc...
```

```
glVertexAttribPointer
glVertexAttribIPointer
glVertexAttribLPointer
```

```
GL_PATCHES
```

Note the optional capital letters (**I** and **L**) in the function signatures. The capital letter denotes the width of stored data, while the small letter indicates the type of data you're passing in.

GL_PATCHES is used in lieu of GL_TRIANGLES when tessellation shaders are attached to the current program.

Vertex Array Objects

VAO's encapsulate the vertex attribute state that you need to change when rendering new geometry. The default VAO has a handle of 0, which isn't valid in the core profile. You **must** create a VAO in the core profile!

```
const GLuint PositionSlot = 0;
const GLuint NormalSlot = 1;

GLuint vao;
glGenVertexArrays(1, &vao);
glBindVertexArray(vao);

glEnableVertexAttribArray(PositionSlot);
glEnableVertexAttribArray(NormalSlot);

glBindBuffer(GL_ARRAY_BUFFER, positionsVbo);
glVertexAttribPointer(PositionSlot, 3, GL_FLOAT, GL_FALSE,
                      sizeof(float)*3, 0);
glBindBuffer(GL_ARRAY_BUFFER, normalsVbo);
glVertexAttribPointer(NormalSlot, 3, GL_FLOAT, GL_FALSE,
                      sizeof(float)*3, 0);
```

Buffer Objects

All Buffer Targets

glBufferData
glBufferSubData
glMapBufferRange
glCopyBufferSubData

GL_PIXEL_PACK_BUFFER

glTexImage*
glTexSubImage*
glDrawPixels

GL_PIXEL_UNPACK_BUFFER

glGetTexImage*
glGetTexSubImage*
glReadPixels

GL_ARRAY_BUFFER

glVertexAttrib*

GL_ELEMENT_ARRAY_BUFFER

glDrawElements (etc)

GL_DRAW_INDIRECT_BUFFER

glDrawArraysIndirect
glDrawElementsIndirect

GL_UNIFORM_BUFFER

glUniformBlockBinding

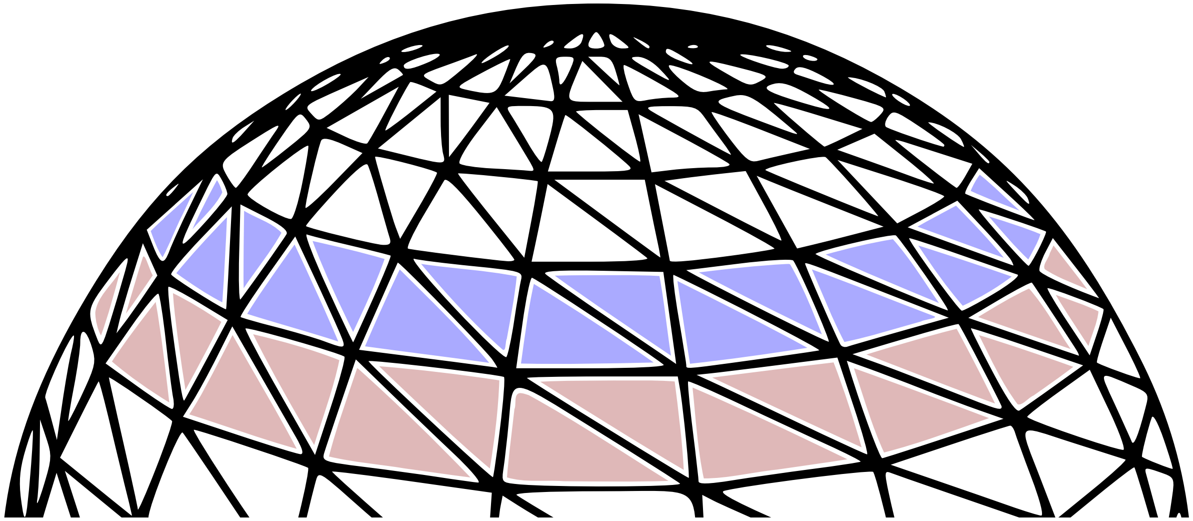
GL_TEXTURE_BUFFER

glTexBuffer

In OpenGL, a **buffer object** is an unstructured blob of data. The above categories are various **targets** to which you can bind a buffer. For example, binding a buffer to **GL_ARRAY_BUFFER** effects subsequent calls to **glVertexAttrib***. Even though it contains vertex data, you can also bind that same buffer object to **GL_TEXTURE_BUFFER**. Remember, buffers are just blobs!

Most buffers are bound using **glBindBuffer**. However, some targets, like **GL_UNIFORM_BUFFER**, have multiple binding points; these are called **indexed buffers**. They're bound using **glBindBufferBase** or **glBindBufferRange** instead of glBindBuffer.

Primitive Restart



```
glEnable(GL_PRIMITIVE_RESTART);
glPrimitiveRestartIndex(1200);
```

```
// somewhat similar:
GLint starts[3] = ...;
GLint counts[3] = ...;
glMultiDrawArrays(GL_TRIANGLE_STRIP, starts, counts, 3);
```

glDraw*

```
glDrawArrays(enum mode, int first, sizei count)
glDrawElements(enum mode, sizei count, enum type, const void *indices)

glDrawRangeElements(enum mode, uint start, uint end, sizei count, enum type, const void *indices)
glDrawArraysInstanced(enum mode, int first, sizei count, sizei primcount)
glDrawElementsInstanced(enum mode, sizei count, enum type, const void *indices, sizei primcount)
glDrawElementsBaseVertex(enum mode, sizei count, enum type, const void *indices, int basevertex)
glDrawRangeElementsBaseVertex(enum mode, uint start, uint end, sizei count, enum type, ...

glDrawArraysInstancedBaseInstance(enum mode, int first, sizei count, sizei primcount, uint baseinstance)
glDrawArraysIndirect(enum mode, const void *indirect) // GL_DRAW_INDIRECT_BUFFER

glDrawElementsInstancedBaseVertex(enum mode, sizei count, enum type, const void *indices, ...
glDrawElementsInstancedBaseInstance(enum mode, sizei count, enum type, const void *indices, ...
glDrawElementsInstancedBaseVertexBaseInstance(enum mode, sizei count, enum type, ...
glDrawElementsIndirect(enum mode, enum type, const void *indirect) // GL_DRAW_INDIRECT_BUFFER

glDrawTransformFeedback(enum mode, uint id)
glDrawTransformFeedbackStream(enum mode, uint id, uint stream)
glDrawTransformFeedbackInstanced(enum mode, uint id, sizei primcount)
glDrawTransformFeedbackStreamInstanced(enum mode, uint id, uint stream, sizei primcount)
```

Indirect Drawing

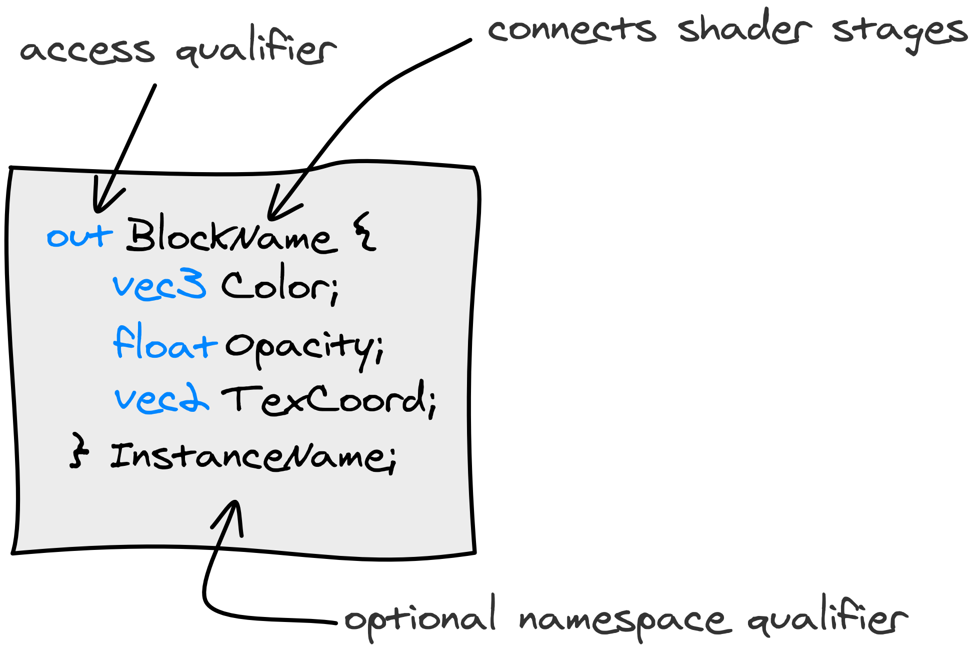
```
GLuint mydrawcall[] = {
    62, /* count */
    12, /* primcount */
    0,  /* first */
    0,  /* baseInstance */
};

// Get parameters from GPU memory:
GLuint bufObj;
glGenBuffers(1, &bufObj);
glBindBuffer(GL_DRAW_INDIRECT_BUFFER, bufObj);
glBufferData(GL_DRAW_INDIRECT_BUFFER, sizeof(mydrawcall), mydrawcall, GL_STATIC_DRAW);
glDrawArraysIndirect(GL_TRIANGLES, 0);

// Generate parameters from OpenCL:
glGenBuffers(1, &bufObj);
glBindBuffer(GL_DRAW_INDIRECT_BUFFER, bufObj);
glBufferData(GL_DRAW_INDIRECT_BUFFER, sizeof(mydrawcall), NULL, GL_STATIC_DRAW);
clCreateFromGLBuffer(context, CL_MEM_READ_WRITE, bufObj, &err);
```

This is Christophe Riccio's categorization of all GLSL types; you'll see this in the forthcoming book *OpenGL Insights*.

		vert in	varying	frag out	uniform
double	scalar	✓	✓	✓	✓
uvec3	vector	✓	✓	✓	✓
dmat4x2	matrix	✓	✓	✖	✓
	array	✓	✓	✓	✓
	structure	✖	✓	✖	✓
isampler1d isamplercubeArray	samplers	✖	✖	✖	✓
	images	✖	✖	✖	✓
atomic_uint	atomic counters	✖	✖	✖	✓
	block	✖	✓	✖	✓

Anatomy of a Block

blocks are not structs!



```
out BlockName {
    vec3 Color;
    float Opacity;
    vec2 TexCoord;
} InstanceName;
```

```
-- Vertex Shader

out MyBlock {
    vec3 Position;
    vec3 Color[2];
    float Opacity;
} Out;

-- Geometry Shader

in MyBlock {
    vec3 Position;
    vec3 Color[2];
    float Opacity;
} In[];
```

```
-- Vertex Shader

// Built-ins:
out gl_PerVertex {
    vec4 gl_Position;
    float gl_PointSize;
    float gl_ClipDistance[];
};

// User-defined:
in MyBlock {
    float w; // glGetAttribLocation(program, "MyBlock.w");
} In;

void main()
{
    gl_Position = vec4(1, 0, 0, In.w);
}
```

Uniform Blocks

```
uniform float Deformation;

uniform Crazy80s {
    float Madonna;
    int DuranDuran;
};

uniform Transform {
    mat4 ModelViewMatrix;
    float Scale;
} transforms[4];

...

float a = Deformation;
float b = Madonna;
float c = transforms[2].Scale;
```

```
GLuint loc = glGetUniformLocation(prog, "Deformation");
glUniform1f(loc, 3.14159f);

GLuint idx = glGetUniformBlockIndex(prog, "Transform[2]");
```

Uniform Buffers

UBO handle (aka name)

passed to `glBindBufferBase` to affect subsequent `glBufferData`, `glMapBuffer`, etc

block index

queried from the shader via `glGetUniformBlockIndex`

binding point

passed to `glBindBufferBase` to affect subsequent `glBufferData`, `glMapBuffer`, etc

passed to `glUniformBlockBinding` to "link" the UBO to the uniform block

note:this can now be specified in GLSL using **layout** rather than `glUniformBlockBinding`

```
layout(std140) uniform Crazy80s { float Madonna[2]; };
```

```
GLuint ubo;
glGenBuffers(1, &ubo);

// Choose a binding point in the UBO; must be < GL_MAX_UNIFORM_BUFFER_BINDINGS
GLuint bp = 7;

// Fill the buffer with data at the chosen binding point
glBindBufferBase(GL_UNIFORM_BUFFER, bp, ubo);
float data[2] = { 3.142f, 2.712f }
glBufferData(GL_UNIFORM_BUFFER, sizeof(data), data, GL_STATIC_DRAW);

// Query the shader for block index of 'Crazy80s' and hook it up
GLuint idx = glGetUniformBlockIndex(prog, "Crazy80s");
glUniformBlockBinding(prog, idx, bp);
```

Binding Vertex Attributes

```
// Worst: let the compiler decide
GLuint foo = glGetAttribLocation(program, "MyBlock.w");
```

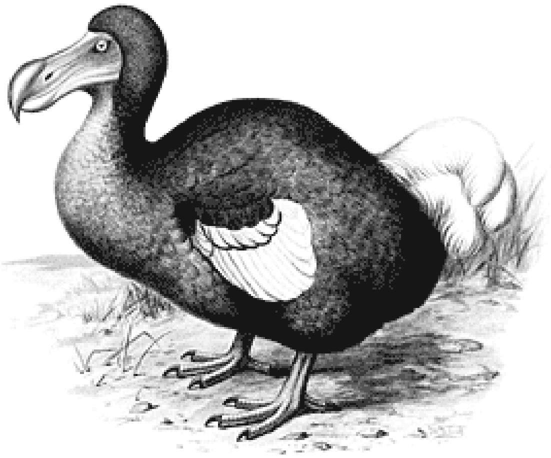
```
// Better: Specify in application code
GLuint foo = 3;

glCompileShader(vsHandle);
glAttachShader(programHandle, vsHandle);
glBindAttribLocation(programHandle, foo, "MyBlock.w");
glLinkProgram(programHandle);
```

```
// Best: Declare in GLSL
in MyBlock {
    layout(location = 3) vec3 w;
}
```

```
GLuint vao;
glGenVertexArrays(1, &vao);
glBindVertexArray(vao);
glBindBuffer(GL_ARRAY_BUFFER, vbo);
glVertexAttribPointer(foo, 1, GL_FLOAT, GL_FALSE, stride, 0);
glEnableVertexAttribArray(foo);
```

Don't use these built-ins; they're extinct! Provide custom names & types for your fragment shader outputs according to what's actually being stored in your FBO.

vec4 gl_FragColor
vec4 gl_FragData[*n*]



Binding Fragment Outputs

```
// Let the compiler decide (not recommended)
GLuint colorNumber = glGetFragDataLocation(program, "MyColorVariable");
```

```
// Specify in application code
GLuint colorNumber = 3;
glBindFragDataLocation(programHandle, colorNumber, "MyColorVariable");
```

```
// Declare in GLSL
layout(location = 3) out vec4 factor;
```

```
 // Beware, a level of indirection!
glBindFramebuffer(GL_DRAW_FRAMEBUFFER, myFbo);

GLenum buffers[] = {GL_COLOR_ATTACHMENT0, GL_COLOR_ATTACHMENT1};
glDrawBuffers(2, &buffers[0]);
```

OpenGL lets you manipulate depth in your fragment shader. However, for best performance you might want to let OpenGL perform depth testing earlier by using the **early_fragment_tests** flag. You can also give it hints about how you're manipulating Z, e.g., **depth_greater**.

```
in vec4 gl_FragCoord; // has a valid z value

out float gl_FragDepth;
```

```
layout(early_fragment_tests) in;

layout (depth_greater) out float gl_FragDepth;
```

Subroutines

Subroutines act like function pointers, allowing you to hot-swap pieces of shader in and out.

```
-- Vertex Shader

subroutine vec3 IlluminationFunc(vec3 N, vec3 L);

subroutine(IlluminationFunc)
vec3 diffuse(vec3 N, vec3 L)
{
    return max(0, dot(N, L));
}

subroutine(IlluminationFunc)
vec3 specular(vec3 N, vec3 L)
{
    vec3 E = vec3(0, 0, 1);
    vec3 H = normalize(L + E);
    return pow(dot(N, H), Shininess);
}

uniform float Shininess = 1.0;
subroutine uniform IlluminationFunc IlluminationVar;

out vec4 vColor;
void main()
{
    vec3 n = vec3(0, 0, 1);
    vec3 p = vec3(3, 1, 4);
    vec3 c = IlluminationVar(n, p);
    vColor = vec4(c, 1);
}

-- Geometry Shader

// normal uniforms are scoped to the program object:
uniform float Shininess = 1.0;

// subroutines are scoped to the shader stage:
subroutine vec3 IlluminationFunc(float foo);
subroutine uniform IlluminationFunc IlluminationVar;
```

```
GLuint prog;
glGetIntegerv(GL_CURRENT_PROGRAM, &prog);

GLenum vs = GL_VERTEX_SHADER;

GLuint illum = glGetSubroutineUniformLocation(prog, vs,
                                              "IlluminationVar");

GLuint diffuse = glGetSubroutineIndex(prog, vs, "diffuse");
GLuint specular = glGetSubroutineIndex(prog, vs, "specular");

// This sets per-context state:
GLuint indices[MAX_SUBROUTINE_VARIABLES];
indices[illum] = diffuse;
glUniformSubroutinesuiv(GL_VERTEX_SHADER, 1, indices);

// This sets per-program state:
GLuint shiny = glGetUniformLocation(prog, "Shininess");
glUniform1f(prog, shiny, 1.0);
```

Separable programs also allow you to hot-swap shaders, but at a higher level of granularity than subroutines.

```
static GLuint LoadPipeline(
        const char* vsSource,
        const char* gsSource,
        const char* fsSource)
{
    GLuint vsProgram = glCreateShaderProgramv(GL_VERTEX_SHADER, 1, &vsSource);
    GLuint gsProgram = glCreateShaderProgramv(GL_GEOMETRY_SHADER, 1, &gsSource);
    GLuint fsProgram = glCreateShaderProgramv(GL_FRAGMENT_SHADER, 1, &fsSource);

    GLuint pipeline;
    glGenProgramPipelines(1, &pipeline);
    glBindProgramPipeline(pipeline);

    glUseProgramStages(pipeline, GL_VERTEX_SHADER_BIT, vsProgram);
    glUseProgramStages(pipeline, GL_GEOMETRY_SHADER_BIT, gsProgram);
    glUseProgramStages(pipeline, GL_FRAGMENT_SHADER_BIT, fsProgram);

    // glUniform* now heed the "active" shader program rather than glUseProgram
    glActiveShaderProgram(pipeline, vsProgram);
    glUniform1f(fooLocation, 1.0f);

    return pipeline;
}
```

Separable Programs

```
...

glProgramParameteri(programHandle, GL_PROGRAM_BINARY_RETRIEVABLE_HINT, GL_TRUE);
glLinkProgram(programHandle);

GLuint bufSize;
glGetProgramiv(programHandle, GL_PROGRAM_BINARY_LENGTH, &bufSize);

std::vector buffer(bufSize);

GLenum binaryFormat;
glGetProgramBinary(programHandle, bufSize, NULL, &binaryFormat, &buffer[0]);
```

```
// use a cached program on subsequent runs:
glProgramBinary(programHandle, binaryFormat, &buffer[0], bufSize);
```

Shader Binaries

Desktop OpenGL inherited this feature from OpenGL ES. Beware however; the binary format isn't portable at all. My personal preference is to avoid this feature unless I desperately need it.

Transform Feedback

1 Old-Style: query objects

2 Ditto, with multiple VBOs

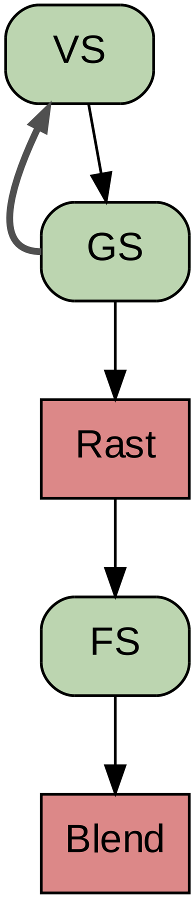
3 New-Style: trans feedback objects

4 Multistream and Pause/Resume

5 Getting data back to the CPU

```
// This goes after glCompileShader but before glLinkProgram...
const char* varyings[3] = { "vPosition", "vBirthTime", "vVelocity" };
glTransformFeedbackVaryings(programHandle, 3, varyings,
                       GL_INTERLEAVED_ATTRIBS);

// Create a query object for transform feedback:
glGenQueries(1, &PrimsWritten);

// Create VBO for input on even frames and output on odd frames:
glGenBuffers(1, &BufferA);
glBindBuffer(GL_ARRAY_BUFFER, BufferA);
glBufferData(GL_ARRAY_BUFFER, sizeof(seed_data), &seed_data[0], GL_STREAM_DRAW);

// Create VBO for output on even frames and input on odd frames:
glGenBuffers(1, &BufferB);
glBindBuffer(GL_ARRAY_BUFFER, BufferB);
glBufferData(GL_ARRAY_BUFFER, sizeof(seed_data), 0, GL_STREAM_DRAW);
```

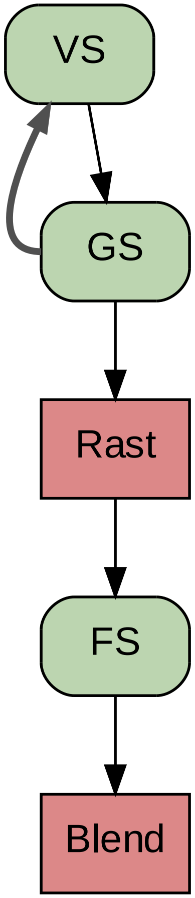
```
glEnable(GL_RASTERIZER_DISCARD);
glBindBuffer(GL_ARRAY_BUFFER, BufferA);                     // Source VBO
glVertexAttribPointer(...);
glBindBufferBase(GL_TRANSFORM_FEEDBACK_BUFFER, 0, BufferB); // Dest VBO
glBeginTransformFeedback(GL_POINTS);
glBeginQuery(GL_TRANSFORM_FEEDBACK_PRIMITIVES_WRITTEN, PrimsWritten);
glDrawArrays(GL_POINTS, 0, inCount);
glEndTransformFeedback();
glEndQuery(GL_TRANSFORM_FEEDBACK_PRIMITIVES_WRITTEN);
glGetQueryObjectuiv(Query, GL_QUERY_RESULT, &outCount);

swap(BufferA, BufferB);

glDisable(GL_RASTERIZER_DISCARD);
glBindBuffer(GL_ARRAY_BUFFER, BufferA);
glVertexAttribPointer(...);
glDrawArrays(GL_POINTS, 0, outCount);
```



Old Transform Feedback (Interleaved VBO)

```
// This goes after glCompileShader but before glLinkProgram...
const char* varyings[2] = { "vPosition", "vBirthTime" };
glTransformFeedbackVaryings(programHandle, 2, varyings,
                        GL_SEPARATE_ATTRIBS);

// Create a query object for transform feedback:
glGenQueries(1, &PrimsWritten);

// Create VBOs for input on even frames and output on odd frames:
glGenBuffers(1, &Buffer0A);
glBindBuffer(GL_ARRAY_BUFFER, Buffer0A);
glGenBuffers(1, &Buffer1A);
glBindBuffer(GL_ARRAY_BUFFER, Buffer1A);

// Create VBOs for output on even frames and input on odd frames:
glGenBuffers(1, &Buffer0B);
glBindBuffer(GL_ARRAY_BUFFER, Buffer0B);
glGenBuffers(1, &Buffer1B);
glBindBuffer(GL_ARRAY_BUFFER, Buffer1B);
```

```
glEnable(GL_RASTERIZER_DISCARD);

glBindBuffer(GL_ARRAY_BUFFER, Buffer0A);                     // Source VBO
glVertexAttribPointer(...);
glBindBuffer(GL_ARRAY_BUFFER, Buffer1A);                     // Source VBO
glVertexAttribPointer(...);
glBindBufferBase(GL_TRANSFORM_FEEDBACK_BUFFER, 0, Buffer0B); // Dest VBO
glBindBufferBase(GL_TRANSFORM_FEEDBACK_BUFFER, 1, Buffer1B); // Dest VBO
glBeginTransformFeedback(GL_POINTS);
glBeginQuery(GL_TRANSFORM_FEEDBACK_PRIMITIVES_WRITTEN, PrimsWritten);
glDrawArrays(GL_POINTS, 0, inCount);
glEndTransformFeedback();
glEndQuery(GL_TRANSFORM_FEEDBACK_PRIMITIVES_WRITTEN);
glGetQueryObjectuiv(Query, GL_QUERY_RESULT, &outCount);

swap(Buffer0A, Buffer0B);
swap(Buffer1A, Buffer1B);

glDisable(GL_RASTERIZER_DISCARD);
glBindBuffer(GL_ARRAY_BUFFER, Buffer0A);
glVertexAttribPointer(...);
glBindBuffer(GL_ARRAY_BUFFER, Buffer1A);
glVertexAttribPointer(...);
glDrawArrays(GL_POINTS, 0, outCount);
```

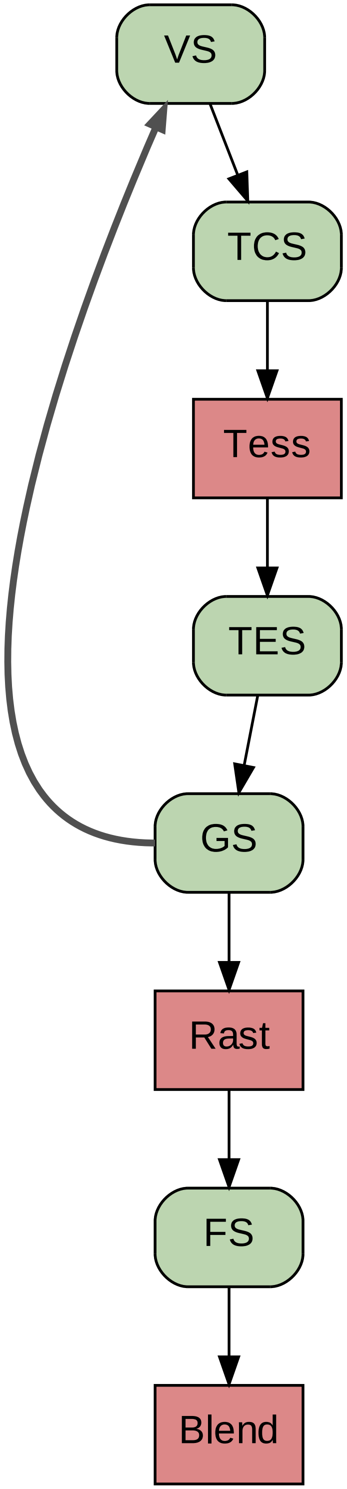


Old Transform Feedback (Separate VBOs)

```
// This goes after glCompileShader but before glLinkProgram...
const char* varyings[4] = { "vPosition", "gl_NextBuffer", "vBirthTime", "vVelocity" };
glTransformFeedbackVaryings(programHandle, 4, varyings, GL_INTERLEAVED_ATTRIBS);

// Create VBO for input on even frames and output on odd frames:
glGenBuffers(1, &BufferA);
glBindBuffer(GL_ARRAY_BUFFER, BufferA);
glBufferData(GL_ARRAY_BUFFER, sizeof(seed_data), &seed_data[0], GL_STREAM_DRAW);

// Create VBO for output on even frames and input on odd frames:
glGenBuffers(1, &BufferB);
glBindBuffer(GL_ARRAY_BUFFER, BufferB);
glBufferData(GL_ARRAY_BUFFER, sizeof(seed_data), 0, GL_STREAM_DRAW);

// Create a transform feedback object:
GLuint Feedback = 0;
glGenTransformFeedbacks(1, &Feedback);
glBindTransformFeedback(GL_TRANSFORM_FEEDBACK, Feedback);
glBindBufferBase(GL_TRANSFORM_FEEDBACK_BUFFER, 0, BufferA);
glBindTransformFeedback(GL_TRANSFORM_FEEDBACK, 0);
```

```
glEnable(GL_RASTERIZER_DISCARD);
glBindBuffer(GL_ARRAY_BUFFER, BufferA);
glVertexAttribPointer(...);
glBindTransformFeedback(GL_TRANSFORM_FEEDBACK, TransformFeedback);
glBeginTransformFeedback(GL_POINTS);
glDrawArrays(GL_POINTS, 0, inCount);
glEndTransformFeedback();
glBindTransformFeedback(GL_TRANSFORM_FEEDBACK, 0);

swap(BufferA, BufferB);

glDisable(GL_RASTERIZER_DISCARD);
glBindBuffer(GL_ARRAY_BUFFER, BufferA);
glVertexAttribPointer(...);
glDrawTransformFeedback(GL_POINTS, TransformFeedback); // similar to glDrawArrays
```

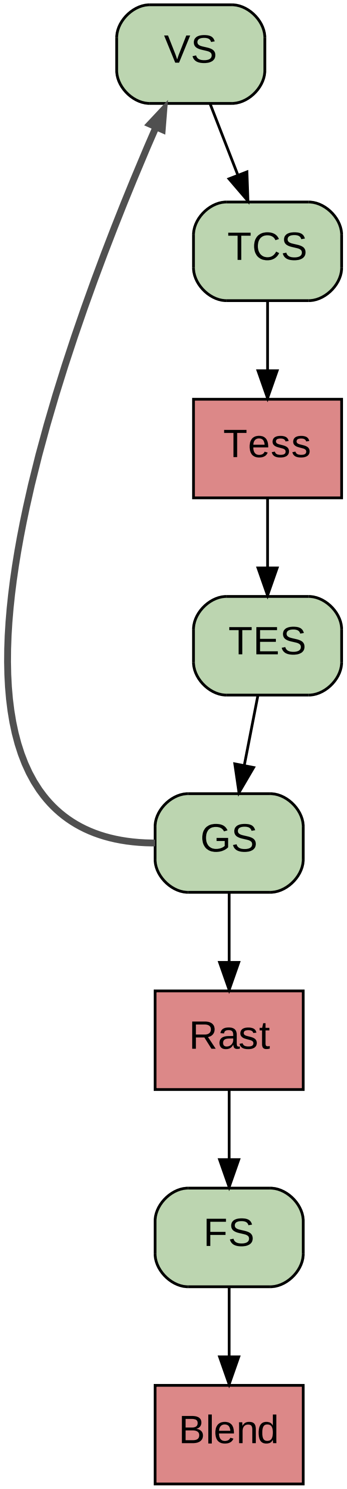
New Transform Feedback



```
// Assign streams in geometry shader
(layout out = 0) out vec4 vPosition;
(layout out = 1) out vec4 vBirthTime;
(layout out = 1) out vec4 vVelocity;
...
EmitStreamVertex(0);
EmitStreamPrimitive(0);
```

```
// Assign varyings to "record" during initialization
const char* varyings[4] = { "vBirthTime", "vVelocity" };
glTransformFeedbackVaryings(programHandle, 2, varyings,
                            GL_INTERLEAVED_ATTRIBS);
```

```
// This time, don't discard rasterization
glBindTransformFeedback(GL_TRANSFORM_FEEDBACK, TransformFeedback);
glBeginTransformFeedback(GL_POINTS);
glDrawArrays(GL_POINTS, offset0, count0);
glPauseTransformFeedback();
glDrawArrays(GL_POINTS, offset1, count1);
glResumeTransformFeedback();
glDrawArrays(GL_POINTS, offset2, count2);
glEndTransformFeedback();
glBindTransformFeedback(GL_TRANSFORM_FEEDBACK, 0);
```



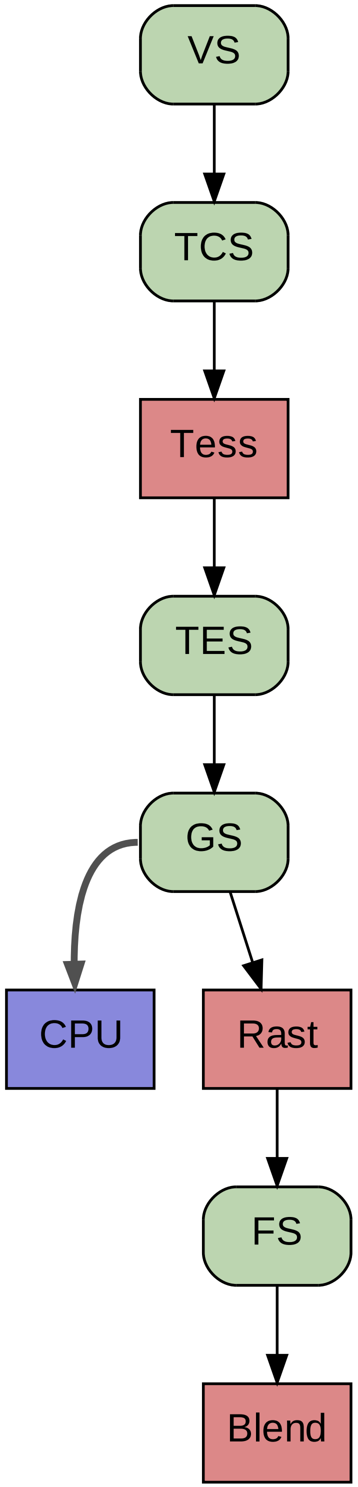
Multiple Streams / Pause / Resume

```
GLuint RecordBuffer, DrawBuffer; // VBOs
GLuint Feedback;                 // TFO

// ...

glGenTransformFeedbacks(1, &Feedback);
glBindTransformFeedback(GL_TRANSFORM_FEEDBACK, Feedback);
glBindBufferBase(GL_TRANSFORM_FEEDBACK_BUFFER, 0, RecordBuffer);
glBindTransformFeedback(GL_TRANSFORM_FEEDBACK, 0);
```

```
glBindBuffer(GL_ARRAY_BUFFER, DrawBuffer);
glVertexAttribPointer(...);
glBindTransformFeedback(GL_TRANSFORM_FEEDBACK, TransformFeedback);
glBeginTransformFeedback(GL_POINTS);
glDrawArrays(GL_POINTS, offset, count);
glEndTransformFeedback();
glBindTransformFeedback(GL_TRANSFORM_FEEDBACK, 0);
```

```
glBindBuffer(GL_ARRAY_BUFFER, RecordBuffer);
void* rawdata = glMapBuffer( GL_ARRAY_BUFFER, GL_READ_ONLY);
// ...do stuff here...
glUnmapBuffer(rawData);
glBindBuffer(GL_ARRAY_BUFFER, 0);
```

Send back to CPU



Texture Formats

```
// LUMINANCE and LUMINANCE_ALPHA et al are gone!
GLenum internalFormat = GL_RGB;
GLenum format = GL_RGB;
GLenum type = GL_UNSIGNED_BYTE;
glTexImage2D(GL_TEXTURE_2D, 0, internalFormat, width, height, 0, format, type, data);
```

INTERNAL FORMATS

DEPTH_COMPONENT	**DEPTH_STENCIL**	**RED**	**RG**	**RGB**	**RGBA**

R8	R8_SNORM	R16	R16_SNORM	RG8	RG8_SNORM	RG16	RG16_SNORM	R3_G3_B2
RGB4	RGB5	RGB8	RGB8_SNORM	RGB10	RGB12	RGB16	RGB16_SNORM	RGBA2
RGBA4	RGB5_A1	RGBA8	RGBA8_SNORM	RGB10_A2	RGB10_A2UI	RGBA12	RGBA16	RGBA16_SNORM
SRGB8	SRGB8_ALPHA8	RGBA	R16F	RG16F	RGB16F	RGBA16F	R32F	RG32F
RGB32F	RGBA32F	R11F_G11F_B10F	RGB9_E5	R8I	R8UI	R16I	R16UI	R32I
R32UI	RG8I	RG8UI	RG16I	RG16UI	RG32I	RG32UI	RGB8I	RGB8UI
RGB16I	RGB16UI	RGB32I	RGB32UI	RGBA8I	RGBA8UI	RGBA16I	RGBA16UI	RGBA32I
RGBA32UI								

FORMATS

DEPTH_COMPONENT	**DEPTH_STENCIL**	**RED**	**RG**	**RGB**	**RGBA**

STENCIL_INDEX	GREEN	BLUE	BGR	BGRA	RED_INTEGER
GREEN_INTEGER	BLUE_INTEGER	RG_INTEGER	RGB_INTEGER	RGBA_INTEGER	BGR_INTEGER
BGRA_INTEGER					

TYPES

UNSIGNED_BYTE	BYTE	UNSIGNED_SHORT	SHORT
UNSIGNED_INT	INT	HALF_FLOAT	FLOAT
UNSIGNED_SHORT_4_4_4_4	UNSIGNED_INT_8_8_8_8	UNSIGNED_INT_8_8_8_8_REV	UNSIGNED_INT_10_10_10_2

etc...

Compressed Textures

```
#define GL_COMPRESSED_RED_RGTC1           0x8DBB // Also known as: DXT_BC5, LATC, RGTC, 3Dc, ATI2
#define GL_COMPRESSED_SIGNED_RED_RGTC1    0x8DBC
#define GL_COMPRESSED_RG_RGTC2            0x8DBD
#define GL_COMPRESSED_SIGNED_RG_RGTC2     0x8DBE

#define GL_COMPRESSED_RGBA_BPTC_UNORM         0x8E8C // Also known as: DXT_BC7
#define GL_COMPRESSED_SRGB_ALPHA_BPTC_UNORM   0x8E8D
#define GL_COMPRESSED_RGB_BPTC_SIGNED_FLOAT   0x8E8E
#define GL_COMPRESSED_RGB_BPTC_UNSIGNED_FLOAT 0x8E8F

glCompressedTexImage3D (enum target, int level, enum internalformat, sizei width, sizei height,
                        sizei depth, int border, sizei imageSize, const void *data)

glCompressedTexImage2D (enum target, int level, enum internalformat, sizei width, sizei height,
                        int border, sizei imageSize, const void *data)

glCompressedTexImage1D (enum target, int level, enum internalformat, sizei width, int border,
                        sizei imageSize, const void *data)

glCompressedTexSubImage3D (enum target, int level, int xoffset, int yoffset, int zoffset,
                           sizei width, sizei height, sizei depth, enum format, sizei imageSize,
                           const void *data)

glCompressedTexSubImage2D (enum target, int level, int xoffset, int yoffset, sizei width,
                           sizei height, enum format, sizei imageSize, const void *data)

glCompressedTexSubImage1D (enum target, int level, int xoffset, sizei width, enum format,
                           sizei imageSize, const void *data)
```

Texture Buffers

```
GLuint bufObj;
glGenBuffers(1, &bufObj);
glBindBuffer(GL_TEXTURE_BUFFER, bufObj);
glBufferData(GL_TEXTURE_BUFFER, sizeof(data), data, GL_STREAM_DRAW);

GLenum sizedFormat = GL_RGBA32F;
glTexBuffer(GL_TEXTURE_BUFFER, sizedFormat, bufObj);
```

```
uniform samplerBuffer Foo;
...
int coord = ...;
vec4 color = texelFetch(Foo, coord);
```

```
glBindBuffer(GL_ARRAY_BUFFER, vbo);   // source
glBindBuffer(GL_TEXTURE_BUFFER, tbo); // destination
glBufferData(GL_TEXTURE_BUFFER, 16384, 0, GL_STREAM); // give it a size

GLintptr readoffset = 0, writeoffset = 0;
glCopyBufferSubData(GL_ARRAY_BUFFER, GL_TEXTURE_BUFFER,
                    readoffset, writeoffset, 16384);
```

Pixel Buffers

```
GLuint bufObj, texObj;

glGenBuffers(1, &bufObj);
glBindBuffer(GL_PIXEL_UNPACK_BUFFER, bufObj);
glBufferData(GL_PIXEL_UNPACK_BUFFER, sizeof(data), data, GL_STREAM_DRAW);

glGenTextures(1, &texObj);
glBindTexture(GL_TEXTURE_2D, texObj);
glTexImage2D(..., NULL);
```

```
// Render with PBO 'A' while uploading PBO 'B'
glBindTexture(GL_TEXTURE_2D, texObj);
glBindBuffer(GL_PIXEL_UNPACK_BUFFER, pboA);
glTexSubImage2D(GL_TEXTURE_2D, 0, 0, 0, w, h, GL_RGBA, GL_UNSIGNED_BYTE, 0);

glBindBuffer(GL_PIXEL_UNPACK_BUFFER, pboB);
glBufferData(GL_PIXEL_UNPACK_BUFFER, byteCount, 0, GL_STREAM_DRAW);

GLubyte* data = glMapBufferRange(GL_PIXEL_UNPACK_BUFFER, 0, byteCount, GL_MAP_WRITE_BIT);
// write stuff to 'data' here...
glUnmapBuffer(GL_PIXEL_UNPACK_BUFFER); // see also: glFlushMappedBufferRange

glBindBuffer(GL_PIXEL_UNPACK_BUFFER, 0);
std::swap(pboA, pboB);

// render here...
```

Direct State Access

```
uniform vec3 foo = vec3(1, 1, 2);
uniform vec3 bar = vec3(3, 5, 8);
```

```
// Old way
glUseProgram(prog1);
glGetUniformLocation("foo", &loc1);
glUniform3f(loc1, 3.14, 2.72, 1.62);
glUseProgram(prog2);
glGetUniformLocation("bar", &loc2);
glUniform3f(loc2, 3.14, 2.72, 1.62);

// New way
glProgramUniform3f(prog1, loc1, 3.14, 2.72, 1.62);
glProgramUniform3f(prog2, loc2, 3.14, 2.72, 1.62);
```

also check out EXT_direct_state_access

Conditional Rendering

```
GLuint query;
glGenQueries(1, &query);
...
glColorMaski(0, GL_FALSE, GL_FALSE, GL_FALSE, GL_FALSE);
glDepthMask(GL_FALSE);
glBeginQuery(GL_ANY_SAMPLES_PASSED, query);
// ...render bounding box...
glEndQuery(...);
glEndQuery(GL_ANY_SAMPLES_PASSED);
glColorMaski(0, GL_TRUE, GL_TRUE, GL_TRUE, GL_TRUE);
glDepthMask(GL_TRUE);

// ...render various stuff while waiting for results...

glBeginConditionalRender(query, GL_QUERY_WAIT);
// ...render full geometry...
glEndConditionalRender();
```

GL_QUERY_NO_WAIT
GL_QUERY_BY_REGION_WAIT, GL_QUERY_BY_REGION_NO_WAIT

Image Load / Store

```
uniform image2D alphaImage;
uniform iimage1D betaImage;
...
vec4 color = ...;
ivec2 coord = ...;
imageStore(alphaImage, coord, color);
...
color = imageLoad(alphaImage, coord);
...
int i = ...; // 1D coordinate
int foo = imageAtomicAdd(betaImage, i, 17)
```

```
GLuint imageLoc = glGetUniformLocation(prog, "alphaImage");
glUniform1i(imageLoc, 3); // must be < GL_MAX_IMAGE_UNITS

glBindImageTexture(3, texObj, miplevel,
                   GL_FALSE, 0, // <-- for layered textures
                   GL_READ_WRITE, GL_RGBA8);
```

see also: coherent volatile restrict readonly writeonly memoryBarrier()

That's all folks!

...lots of stuff we didn't cover...

Tessellation Shaders (stay tuned)

Atomic Counters
GL_ARB_debug_output
Viewport Arrays
Dual Source Blending

Bindless Graphics nv prezo

- NV_bindless_texture
- NV_shader_buffer_load
- NV_vertex_buffer_unified_memory

```
uniform sampler2D* foo; // oo la la !
```

```
glMakeTextureHandleResidentNV(...);
```

http://www.opengl.org/sdk/docs/