Real-time Graphics

1. Graphics Pipeline, Shaders

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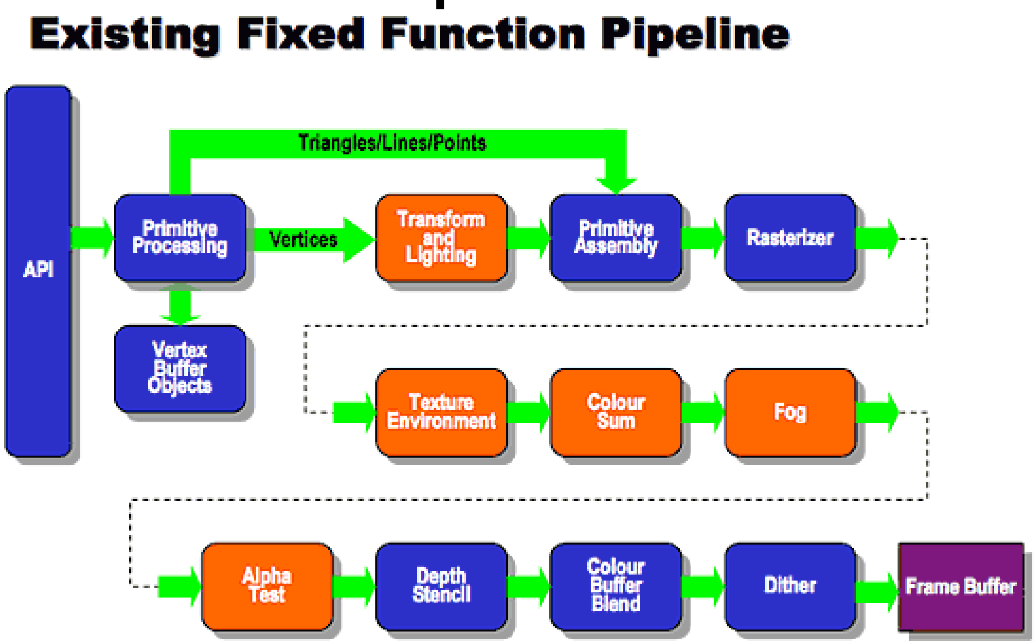
Graphics Pipeline

- Rasterization-based real-time rendering
- Supported by common hardware - graphics cards
- Input = 3D representation of scene
- Output = 2D raster image
- Stream processing
- Another ways of rendering: raytracing, global illumination (radiosity), REYES, …

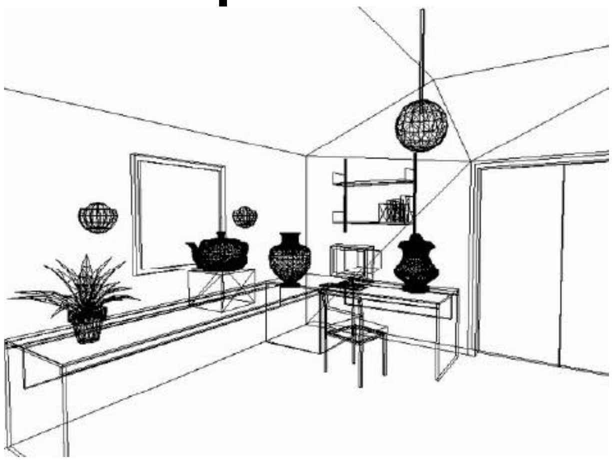
OpenGL Graphics Pipeline

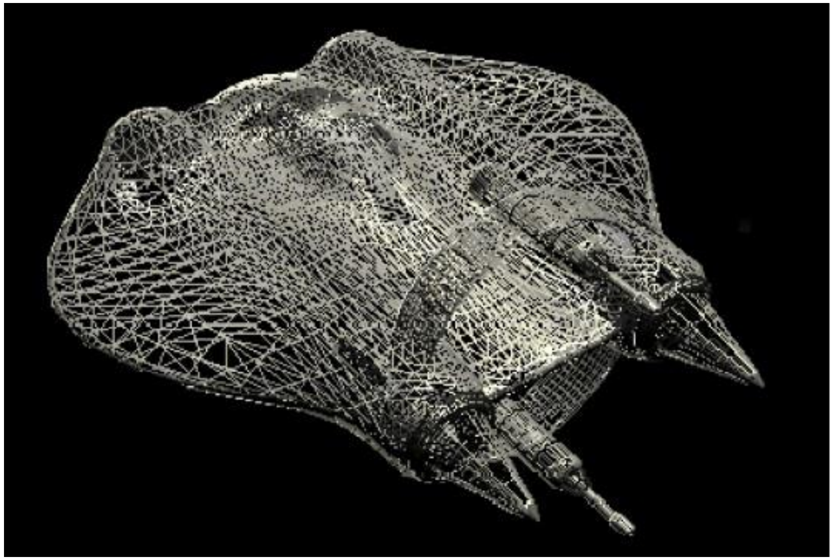
- Fixed pipeline - prerequisite for this course
- Knowledge of extensions mechanism
- Some parts are depreciated



First generation

- Vertex: transform, clip, project
- Pixel: color interpolation of lines
- Frame buffer: overwrite
- Dates: prior to 1987





Second generation

- Vertex: lighting generation
- Pixel: depth interpolation, triangles
- Frame buffer: depth buffer, blending
- Dates: 1987-1992

Third generation

- Vertex: texture coordinate transformation
- Pixel: texture coordinate interpolation, texture evaluation and filtering
- Dates: 1992 - 2000

Fourth generation

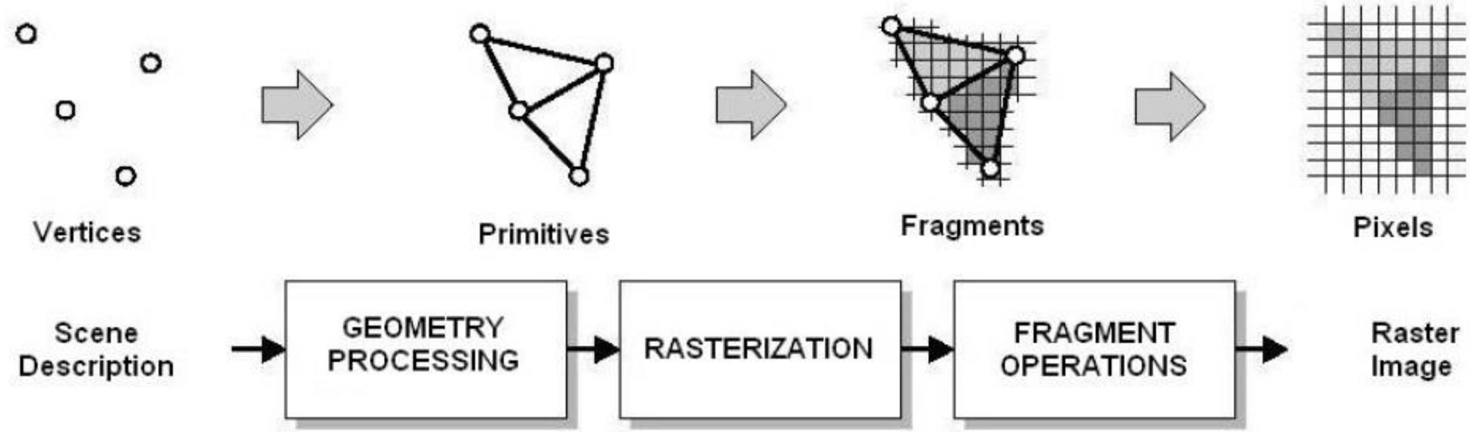
- Programmable shading: Vertex, Pixel, Geometry
- Multi GPU (SLI, Crossfire), Full floating point, GPGPU

Fifth generation

- Multi cores
- Merging CPU and GPU
  - IBM Cell (8+1cores)
  - AMD Fusion (CPU+GPU)
  - Intel Larabee – canceled
- Programming
  - Tesselation shader
  - DX11 (Compute shader)
  - CUDA, AMD Brook
  - OpenCL

Parts of pipeline

- Application – user settings, scene description
- Geometry – transformations, clipping, projection
- Rasterization – computations, texturing
- Fragments – tests, blending, operations

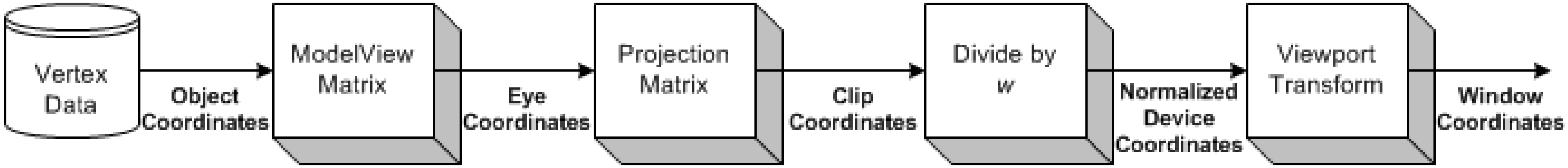


Application stage

- Scene description
- User full control
- Scene complexity – LOD, clipping
- Scene dynamics (physics)
- Handling – mouse, keyboard

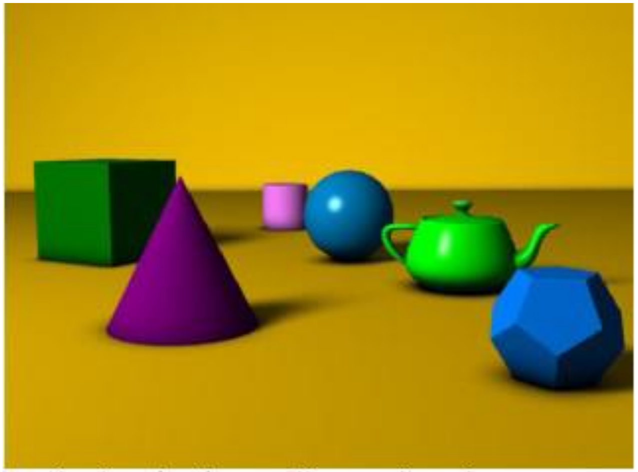
Geometry stage

- Per-primitive operations
  - Model & view transform
  - Per-vertex lightning & shading
  - Projection
  - Clipping
  - Screen mapping



Fragment tests

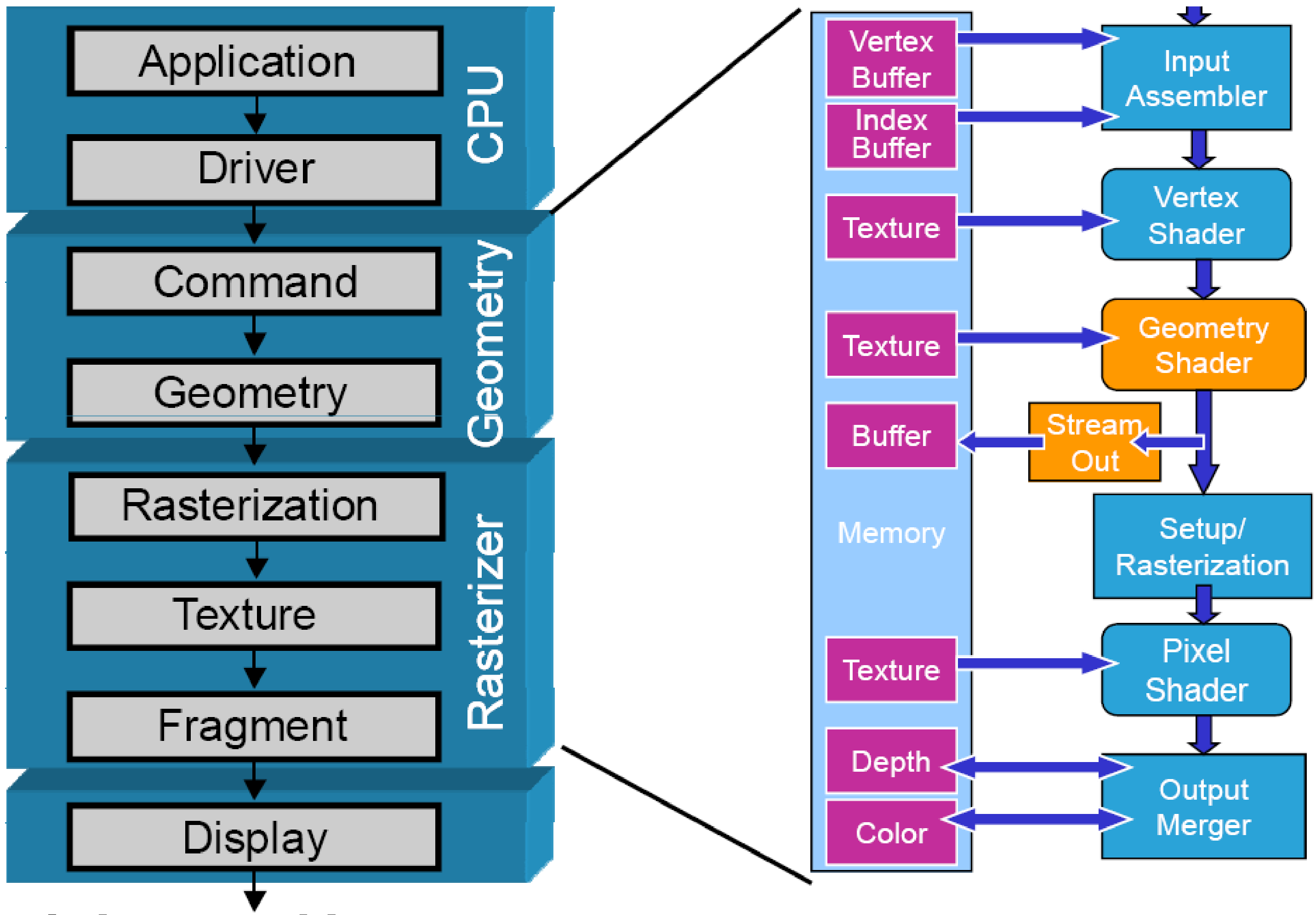
- Ownership
- Scissor test
- Alpha test
- Stencil test
- Depth test
- Alpha blending
- Logical operations



A simple three dimensional scene

Z-buffer representation

DirectX 10 pipeline



DirectX 11 pipeline

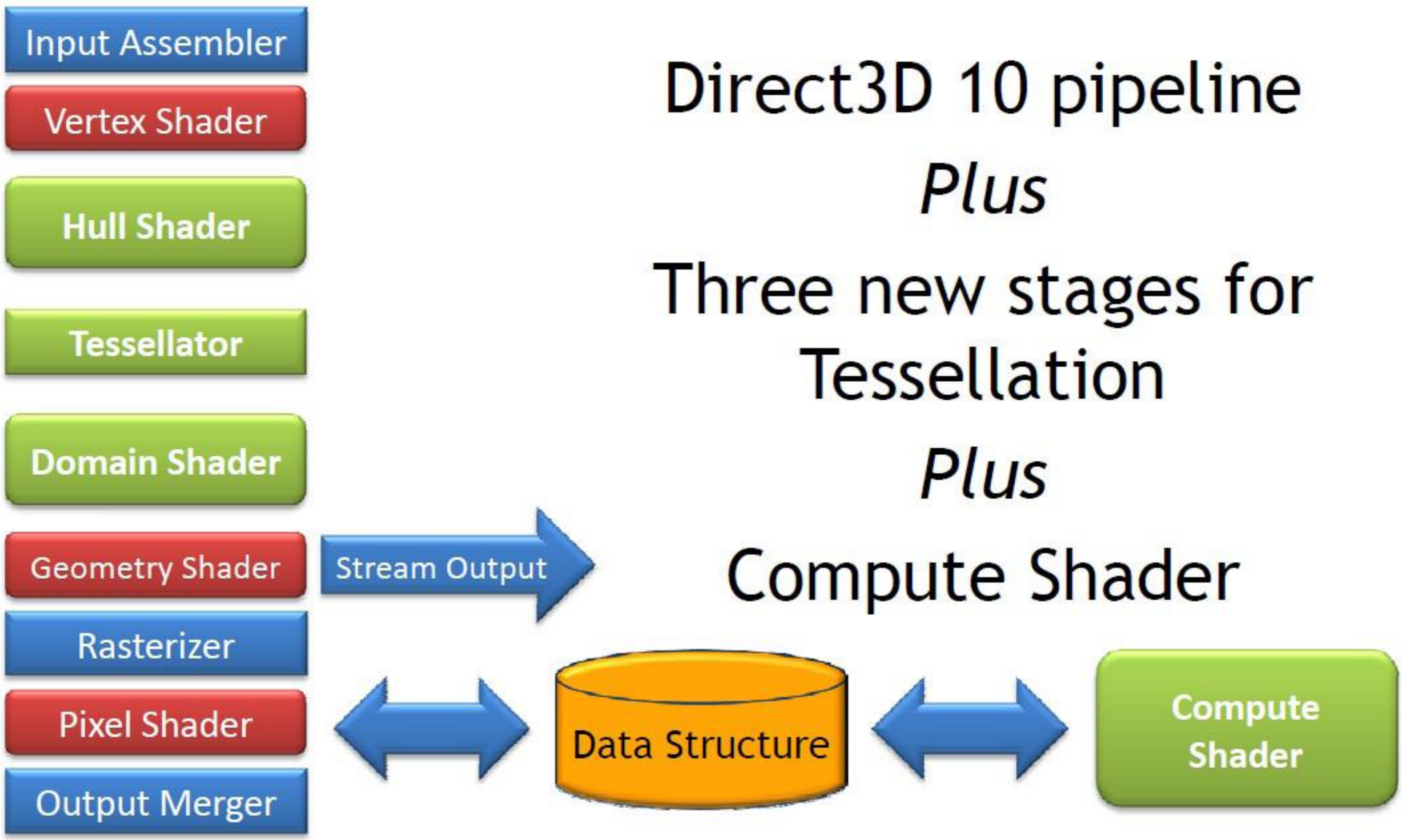
Direct3D 10 pipeline

Plus

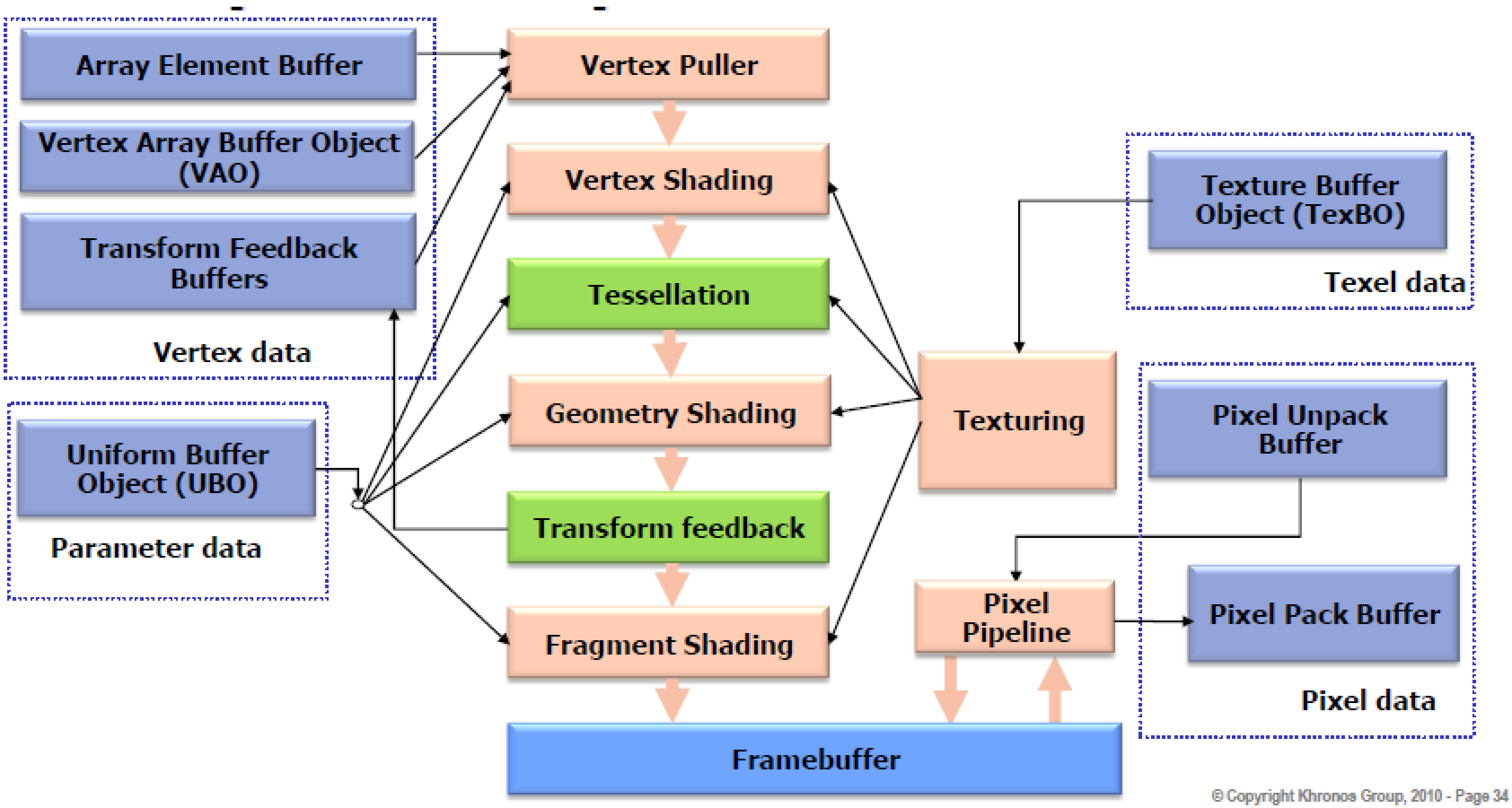
Three new stages for Tessellation

Plus

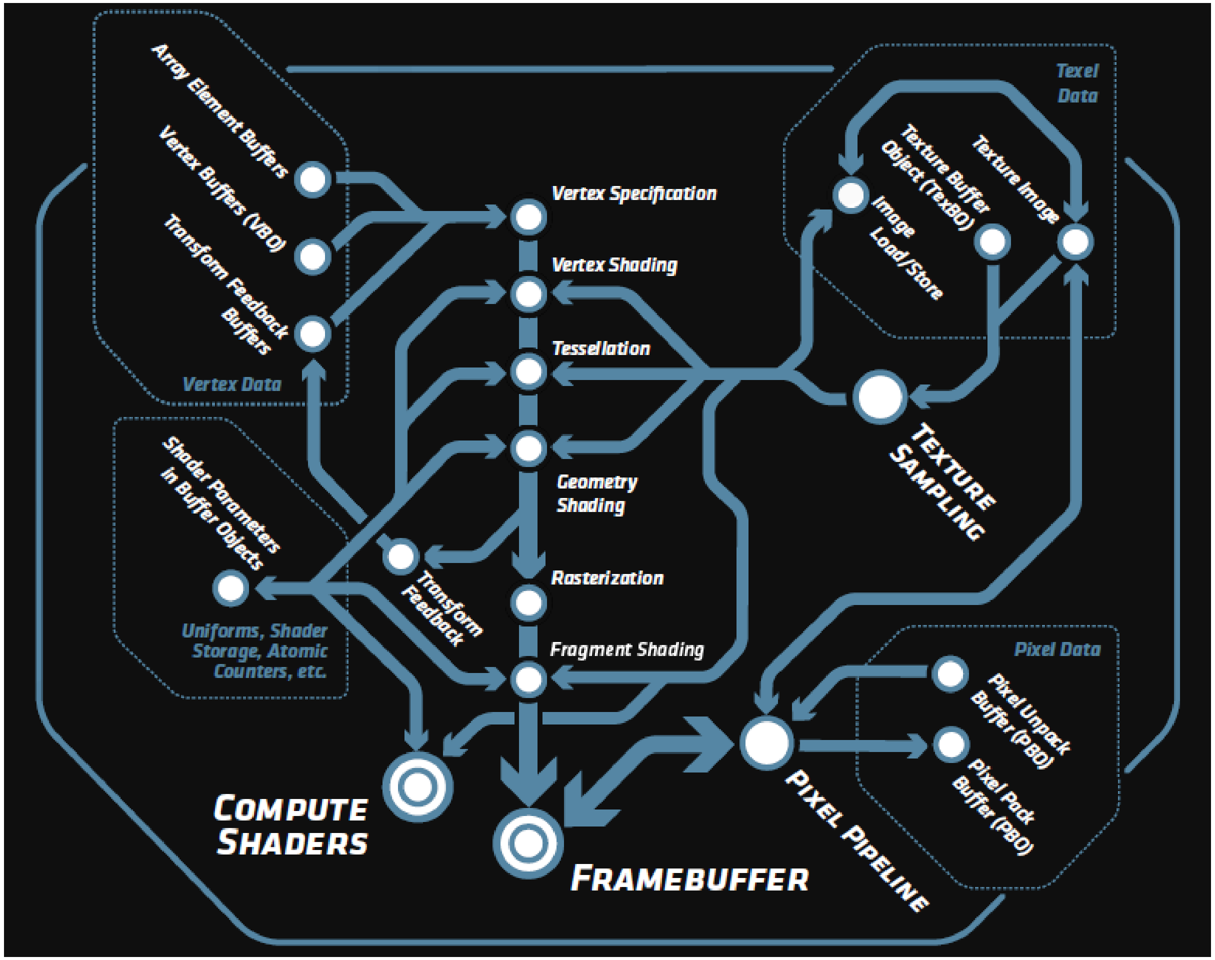
Compute Shader



OpenGL 4.0 pipeline

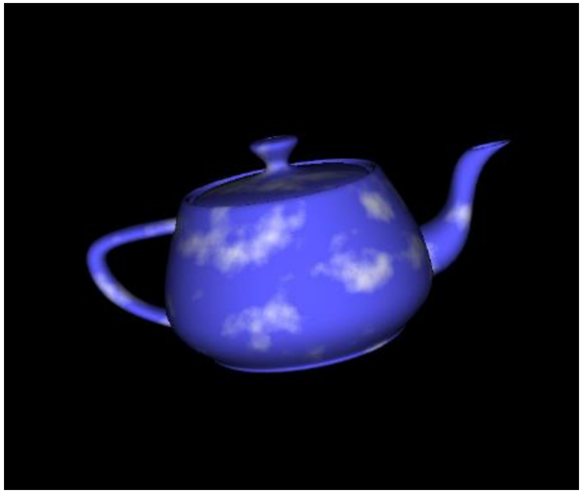


OpenGL 4.3 pipeline



Shaders

- Programs for creating new geometry, changing vertices and shaders
- Take control of processing on GPU
- Move some computation from CPU to GPU


Shader languages

- Assembler - different for ATI, Nvidia
- Source code shaders - ATI
- Cg – C for graphics (Nvidia), HLSL (DirectX)
- GLSL - OpenGL Shading Language
  - OpenGL 2.0 standard
  - ATI, Nvidia

Cg

- Nvidia extensions
- Various profiles
- Compiler, runtime libraries
- Examples – Cg Toolkit
- http://developer.nvidia.com/object/cg_toolkit.html

Cg shaders

```
struct input_data
{
  float4 position   : POSITION;
};

struct output_data
{
  float4 position   : POSITION;
};

output_data main(input_data IN)
{
  output_data OUT;
  OUT.position  = IN.position;
  return OUT;
}
```

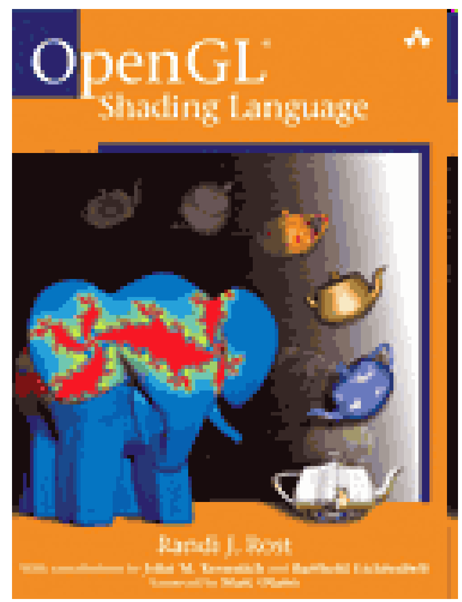
Vertex shader

```
struct input_data{
  float2 tc : TEXCOORD0;
};
struct output_data{
  float4 color  : COLOR;
};

output_data main(input_data IN,
          uniform sampler2D textureIn )
{
  output_data OUT;
  OUT.color = tex2D(textureIn, IN.tc);
  return OUT;
}
```

Fragment shader

GL shading language

- ANSI C-like language for writing shaders
- http://www.opengl.org/registry/doc/GLSLangSpec.4.10.6.clean.pdf
- Extended with mechanisms from C++ and vector and matrix types
- Part of core specification
- Older functionality is depreciated



OpenGL extension for GLSL

- New language for writing shaders
  - GL_ARB_shading_language_100, …
- New shader programs
  - GL_ARB_fragment_shader
  - GL_ARB_vertex_shader
  - GL_ARB_geometry_shader4
  - GL_ARB_tessellation_shader, …
- Management using shader objects
  - GL_ARB_shader_objects
- http://www.opengl.org/registry/

GLSL basic types

- void
- float vec2 vec3 vec4
- mat2 mat3 mat4
- int ivec2 ivec3 ivec4
- bool bool bvec2 bvec3 bvec4
- samplernD samplerCube
- samplerShadownD

GLSL type qualifiers

- Const – compile-time constant
- Attribute – for passing data for vertex
- Uniform – global variable, read-only
- Varying – vertex->fragment sh. data
- In – parameters passed into function
- Out – passed out of function
- Inout – in & out of function

GLSL scalar constructors

- int(bool) // converts a Boolean value to an int
- int(float) // converts a float value to an int
- float(bool) // converts a Boolean value to a float
- float(int) // converts an integer value to a float
- bool(float) // converts a float value to a Boolean
- bool(int) // converts an integer value to a Boolean

GLSL matrix constructors

```
vec3(float)     // initializes each component of a vec3 with the float
vec4(ivec4)     // makes a vec4 from an ivec4, with component-wise conversion

vec2(float, float)               // initializes a vec2 with 2 floats
ivec3(int, int, int)             // initializes an ivec3 with 3 ints
bvec4(int, int, float, float)    // initializes with 4 Boolean conversions

vec2(vec3) // drops the third component of a vec3
vec3(vec4) // drops the fourth component of a vec4

vec3(vec2, float) // vec3.x = vec2.x, vec3.y = vec2.y, vec3.z = float
vec3(float, vec2) // vec3.x = float, vec3.y = vec2.x, vec3.z = vec2.y
vec4(vec3, float)
vec4(float, vec3)
vec4(vec2, vec2)
```

```
mat2(float)
mat3(float)
mat4(float)
```

```
mat2(vec2, vec2);
mat3(vec3, vec3, vec3);
mat4(vec4, vec4, vec4, vec4);

mat2(float, float,
     float, float);

mat3(float, float, float,
     float, float, float,
     float, float, float);

mat4(float, float, float, float,
     float, float, float, float,
     float, float, float, float,
     float, float, float, float);
```

GLSL vectors & matrices

- Component access:
  - {x,y,z,w}, {r,g,b,a}, {s,t,p,q}
  - Allows access to multiple components
  - Allows access using indexing []

```
vec4 pos = vec4(1.0, 2.0, 3.0, 4.0);
pos.xw = vec2(5.0, 6.0);     // pos = (5.0, 2.0, 3.0, 6.0)
pos.wx = vec2(7.0, 8.0);     // pos = (8.0, 2.0, 3.0, 7.0)
pos.xx = vec2(3.0, 4.0);     // illegal - 'x' used twice
pos.xy = vec3(1.0, 2.0, 3.0);// illegal - mismatch between vec2 and vec3
```

- Simple addition and multiplication:
  - vec3 u, v, w; w = u + v; w = u * v;
  - mat3 m, n, o; m = n * o; m = n + o

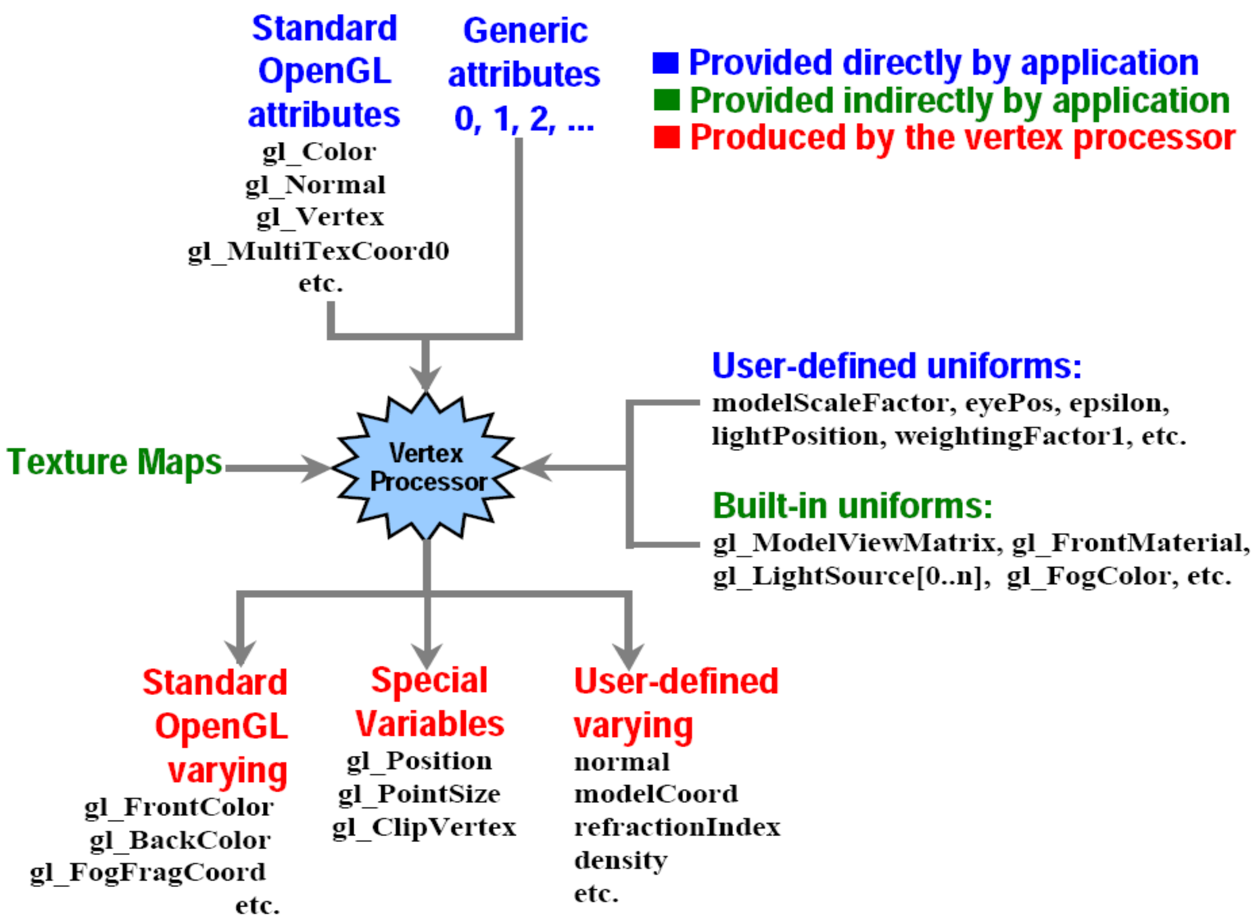
GLSL built-in functions

- Angle and Trigonometry (radians, degrees, sin, cos, tan, asin, acos, …)
- Exponential (pow, exp, log, sqrt, …)
- Math (abs, floor, mod, min, max, clamp, mix, step, mod, …)
- Geometric (length, distance, dot, cross, normalize, ftransform, reflect, …)
- Matrix (matrixCompMult)
- Vector Relational (lessThan, graterThan, equal, any, all, …)
- Texture Lookup (texturenD, texturenDLod, texturenDProj, textureCube, shadownD, …)
- Noise (noise1, noise2, …)
- Fragment processing (discard, dFdx, dFdy, fwidth, …)

GLSL built-in variables

- For access of data
- Part from OpenGL state
- User defined data
- Variables for input and output of shaders
- Based on fixed functionality pipeline

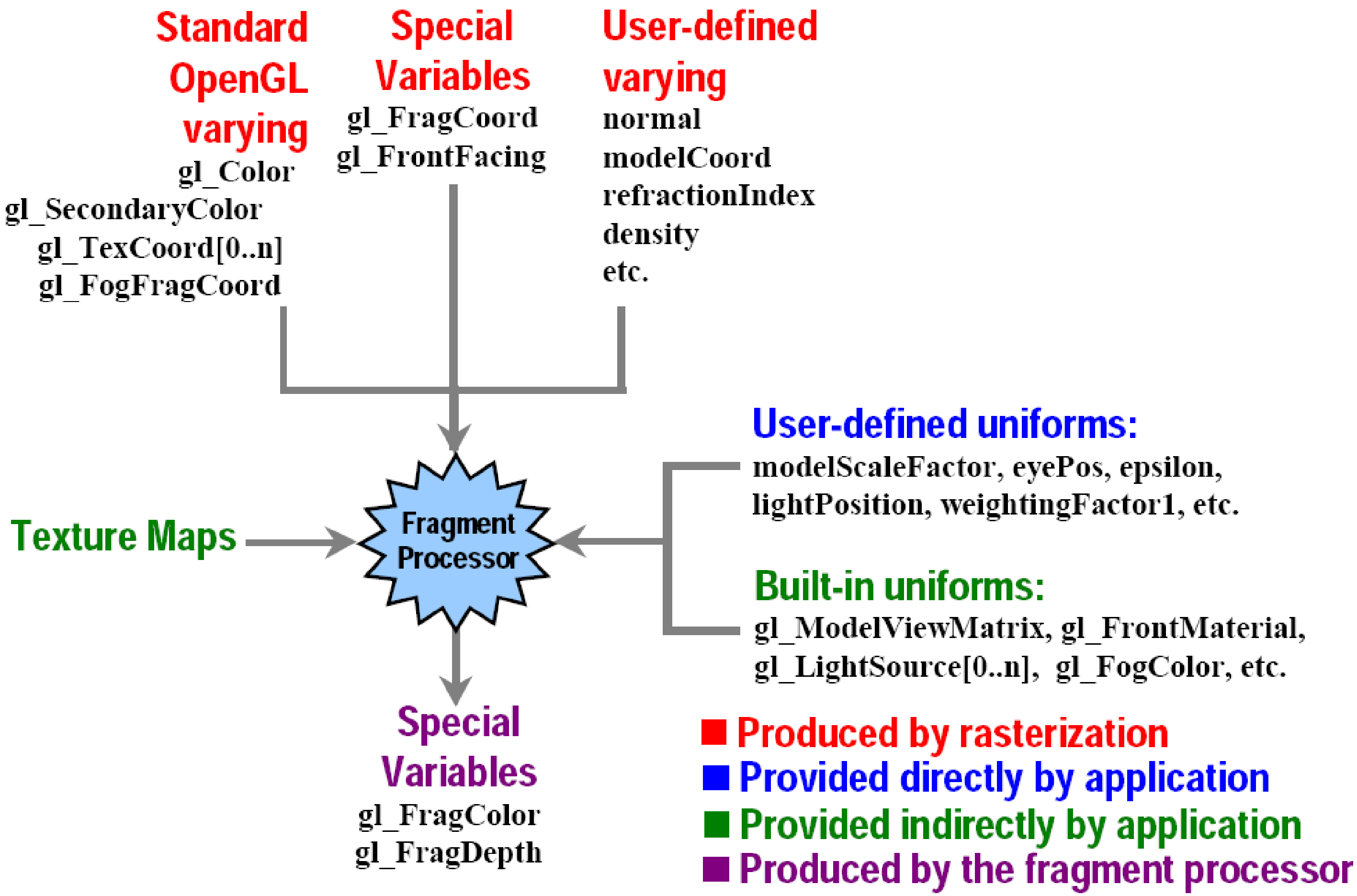
GLSL VS built-in variables



GLSL GS built-in variables

- Input:
  - varying in vec4 gl_FrontColorIn[gl_VerticesIn]
  - varying in vec4 gl_BackColorIn[gl_VerticesIn]
  - varying in vec4 gl_FrontSecondaryColorIn[gl_VerticesIn]
  - varying in vec4 gl_BackSecondaryColorIn[gl_VerticesIn]
  - varying in vec4 gl_TexCoordIn[gl_VerticesIn][]
  - varying in vec4 gl_PositionIn[gl_VerticesIn]
  - varying in float gl_PointSizeIn[gl_VerticesIn]
  - varying in vec4 gl_ClipVertexIn[gl_VerticesIn]
- Output:
  - varying vec4 gl_FrontColor
  - varying vec4 gl_BackColor
  - varying vec4 gl_FrontSecondaryColor
  - varying vec4 gl_BackSecondaryColor
  - varying vec4 gl_TexCoord[]
  - varying out vec4 gl_FrontColor
  - varying out vec4 gl_BackColor
  - varying out vec4 gl_FrontSecondaryColor
  - varying out vec4 gl_BackSecondaryColor
  - varying out vec4 gl_TexCoord[];

GLSL FS built-in variables



GLSL – vertex, fragment

```
const vec4 AMBIENT = vec4( 0.9, 0.9, 0.1, 1.0 );
const vec4 SPECULAR = vec4( 1.0, 1.0, 1.0, 1.0 );
uniform vec4 light;

varying vec4 Ca;
varying vec4 Cd;
varying vec4 Cs;

varying vec4 V_eye;
varying vec4 L_eye;
varying vec4 N_eye;

void main(void)
{
	V_eye = gl_ModelViewMatrix * gl_Vertex;
	L_eye = (gl_ModelViewMatrix * light) - V_eye;
	N_eye = vec4(gl_NormalMatrix * gl_Normal, 1.0);

	gl_Position = gl_ProjectionMatrix * V_eye;
	V_eye = -V_eye;

	Ca = AMBIENT;
	Cd = gl_Color;
	Cs = SPECULAR;
}
```

```
varying vec4 Ca;
varying vec4 Cd;
varying vec4 Cs;

varying vec4 V_eye;
varying vec4 L_eye;
varying vec4 N_eye;

vec3 reflect(vec3 N, vec3 L)
{
	return 2.0*N*dot(N, L) - L;
}

void main(void)
{
	vec3 V = normalize(vec3(V_eye));
	vec3 L = normalize(vec3(L_eye));
	vec3 N = normalize(vec3(N_eye));

	float diffuse = clamp(dot(L, N), 0.0, 1.0);

	vec3 R = reflect(N, L);
	float specular = pow(clamp(dot(R, V), 0.0, 1.0),16);

	gl_FragColor = Ca + (Cd*diffuse) + (Cs*specular);
}
```

Geometry shader example

```
#version 120
#extension GL_EXT_geometry_shader4: enable
uniform float FpNum;
void main()
{
        int num = int( FpNum + 0.99 );
        float dt = 1. / float(num);
        float t = 0.;
        for( int i = 0; i <= num; i++ )
        {
                float omt = 1. - t;
                float omt2 = omt * omt;
                float omt3 = omt * omt2;
                float t2 = t * t;
                float t3 = t * t2;
                vec4 xyzw = omt3 * gl_PositionIn[0].xyzw +
                3. * t * omt2 * gl_PositionIn[1].xyzw +
                3. * t2 * omt * gl_PositionIn[2].xyzw +
                t3 * gl_PositionIn[3].xyzw;
                gl_Position = xyzw;
                EmitVertex();
                t += dt;
        }
        EndPrimitive();
}
```

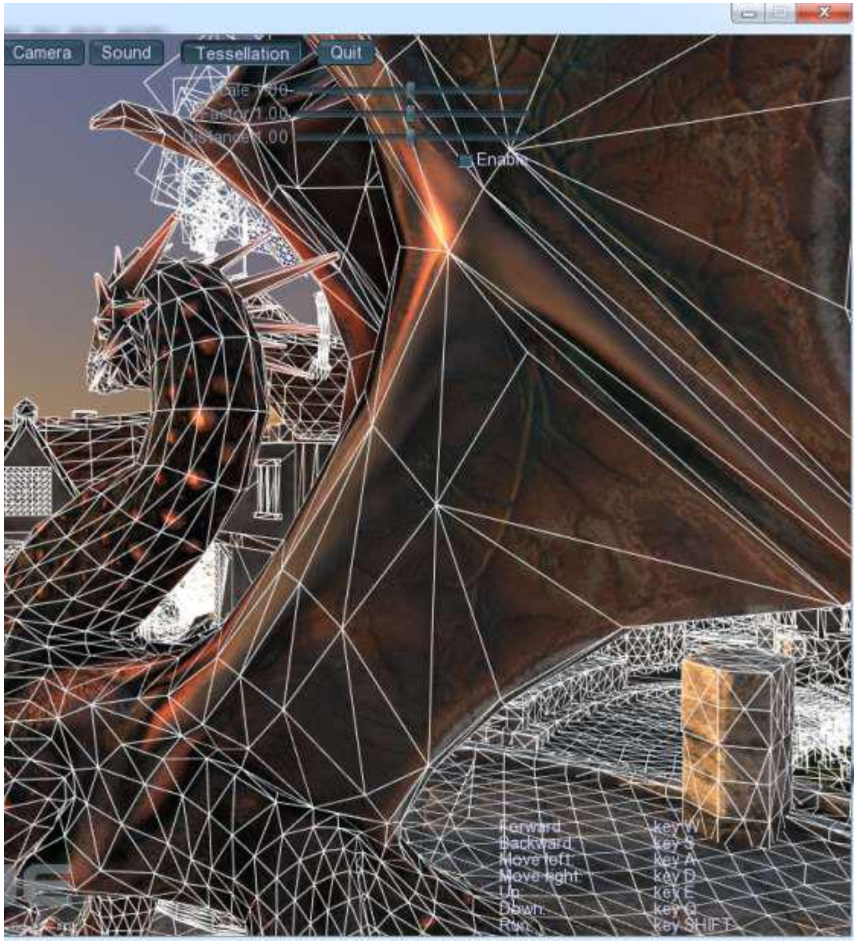
```
void main()
{
        gl_Position = gl_ModelViewProjectionMatrix * gl_Vertex;
}
```

```
void main()
{
        gl_FragColor = vec4( 0., 1., 0., 1. );
}
```

Tesselation shaders

- Works on patch – given by set of vertices and per-patch attributes
- Tessellation control shader transforms per-vertex data and per-patch attr.
- Tessellator decomposes patch into set of new primitives based on tess. level
- Tessellation evaluation shader computes position and attributes of new generated vertices

Tessellation shaders



Shaders management

- Shader objects – shaders with unique identifier
- Creation: *glCreateShaderObject(type),* type:
  - GL_VERTEX_SHADER
  - GL_GEOMETRY_SHADER
  - GL_FRAGMENT_SHADER, ...
- Setting source: *glShaderSource(shaderID, numStrings, strings, length)*
- Compilation: *glCompileShader(shaderID)*

Shaders management

- Shader programs - container for shader objects, set of shaders that are linked together
- Creation: prog = *glCreateProgramObject()*
- Adding shader: *glAttachObject(programID, shaderID)*
- Linking: *glLinkProgram(programID)*
- Set as current: *glUseProgramObject(programID)*

Management example

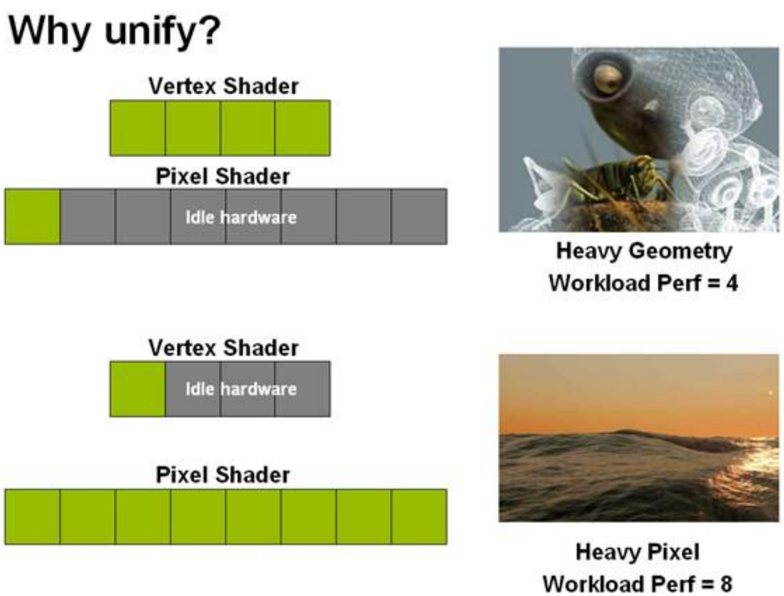
```
GLhandle g_programObj;
GLhandle g_vertexShader;
GLhandle g_fragmentShader;

g_vertexShader = glCreateShaderObjectARB( GL_VERTEX_SHADER );
unsigned char *vertexShaderAssembly = readShaderFile( "vertex_shader.vert" );
vertexShaderStrings[0] = (char*)vertexShaderAssembly;
glShaderSource( g_vertexShader, 1, vertexShaderStrings, NULL );
glCompileShader( g_vertexShader);
delete vertexShaderAssembly;

g_fragmentShader = glCreateShaderObject( GL_FRAGMENT_SHADER );
unsigned char *fragmentShaderAssembly = readShaderFile( "fragment_shader.frag" );
fragmentShaderStrings[0] = (char*)fragmentShaderAssembly;
glShaderSource( g_fragmentShader, 1, fragmentShaderStrings, NULL );
glCompileShader( g_fragmentShader );
delete fragmentShaderAssembly;

g_programObj = glCreateProgramObject();
glAttachObject( g_programObj, g_vertexShader );
glAttachObject( g_programObj, g_fragmentShader );

glLinkProgram( g_programObj );
glGetObjectParameteriv( g_programObj, GL_OBJECT_LINK_STATUS, &bLinked );
```

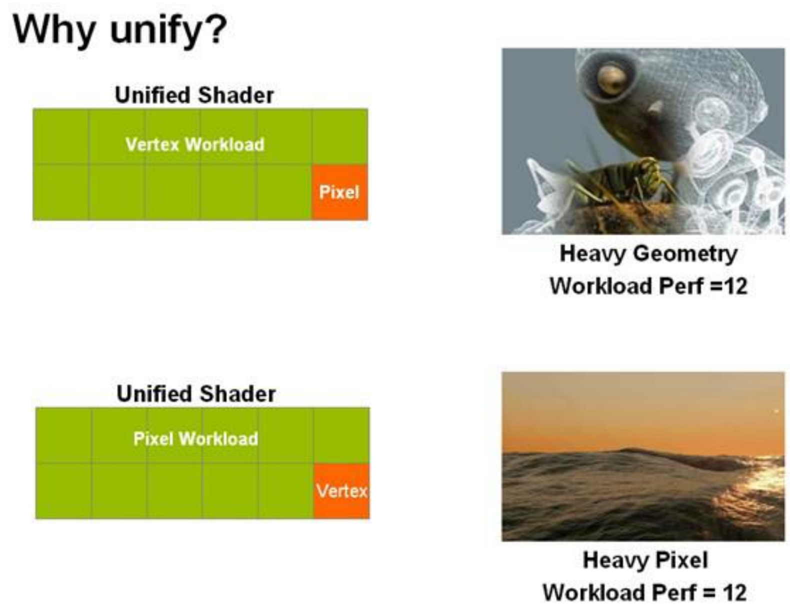
Passing variables

- From application to shaders, based on location of variable in shader program:
  - Glint glGetAttribLocation(GLhandle program, const GLchar* name);
  - Glint glGetUniformLocation(GLhandle program, const GLchar * name);
  - void glUniform{1|2|3|4}{f|i}(GLint location, TYPE val);
  - void glUniform{1|2|3|4}{f|i}v(GLint location, GLuint count, const TYPE * vals);
  - void glUniformMatrix{2|3|4|}fv(GLint location, GLuint count, GLboolean transpose, const GLfloat * vals);
  - void glVertexAttrib{1|2|3|4}{s|f|d}(GLuint index, TYPE val);
  - void glVertexAttrib{1|2|3|4}{s|f|d}v(GLuint index, const TYPE * vals);
- Possibility to sent array of attributes or uniforms

Unified architecture

- Consistent instruction set across all shader types
- Flexible use of the graphics hardware





Tools

- Debugging GLSL: your way, gDEBugger, glslDevil, Fx Composer(+Shader Debugger)
- Extensions: GLEE, GLEW
- Render Monkey - http://developer.amd.com/archive/gpu/rendermonkey/pages/default.aspx
- Shader Designer - http://www.opengl.org/sdk/tools/ShaderDesigner/
- Books: http://www.opengl.org/documentation/books/

Questions?