CS4621/5621 Fall 2015

Computer Graphics Practicum
Intro to OpenGL/GLSL

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Instructor: Nicolas Savva

with slides from Balazs Kovacs, Eston Schweickart, Daniel Schroeder, Jiang Huang and Pramook Khungurn over the years.

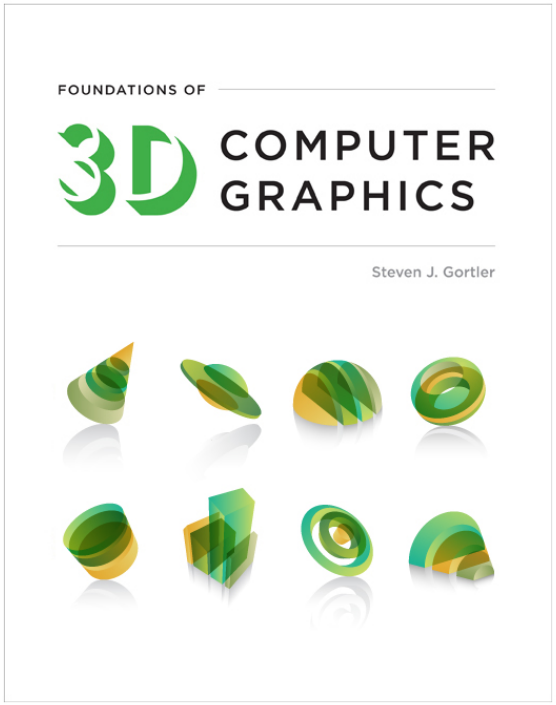
Announcements

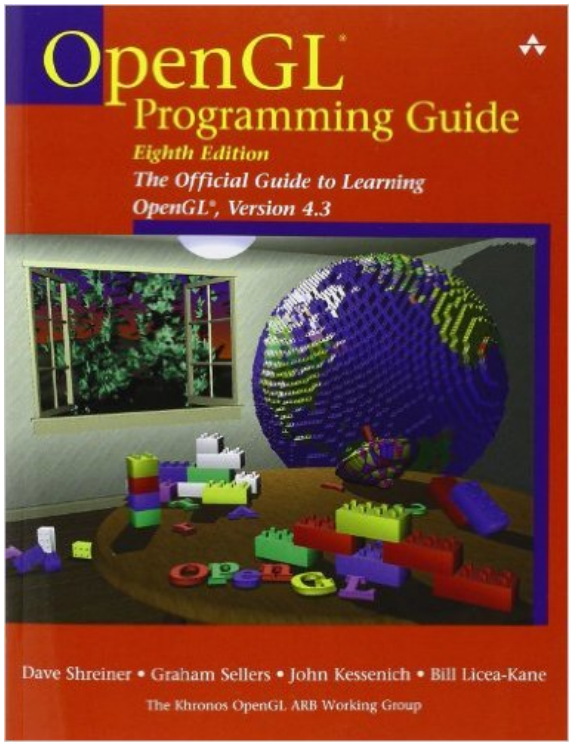
- Course website:

  http://www.cs.cornell.edu/courses/CS4621/2015fa/
- Piazza for practicum:

  https://piazza.com/cornell/fall2015/cs46215621/
- First assignment GPUray (out soon)
- Graphics hardware diagnostic package

Books and resources





OpenGL

LWJGL
Lightweight Java Game Library

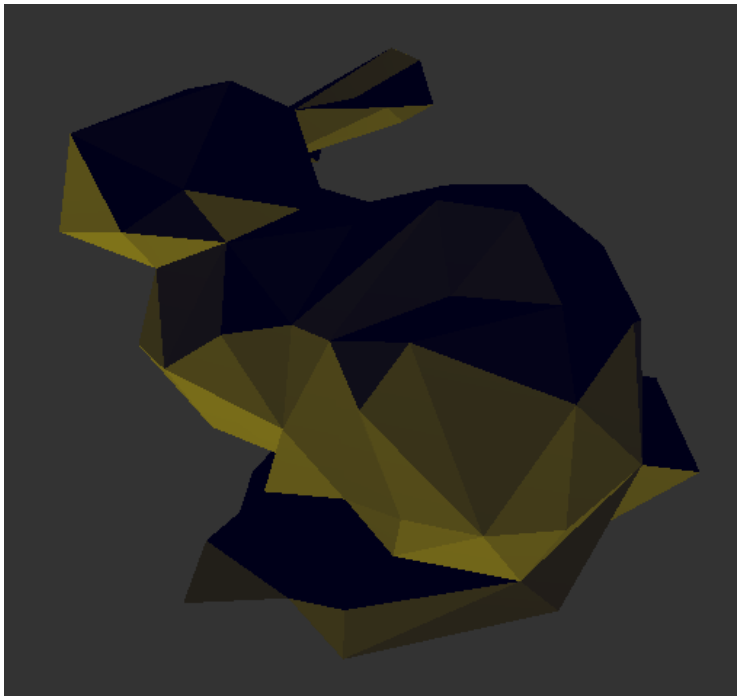
Today

- OpenGL over the decades
- Graphics Pipeline overview
- LWJGL basics (more of this next time)
- GLSL basics (our focus today)
- GPUray

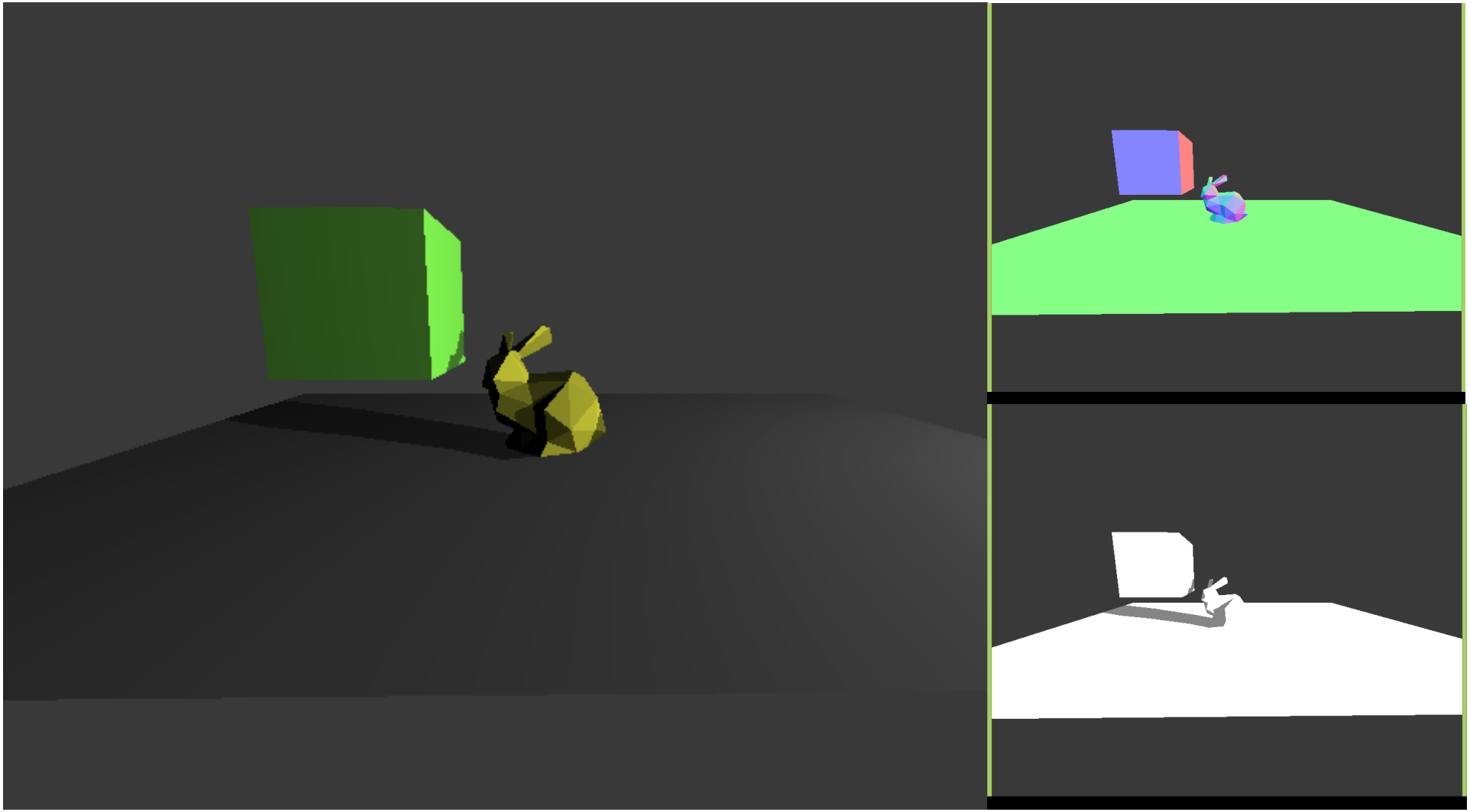
GPUray Overview

- PPA1: port a simplified version of ray1 to GPU
- Mostly deal with the fragment shader
- LWJGL bindings

  (communicating with the GPU)
- Shader compiling and linking
- GLSL code



GPUray Demo



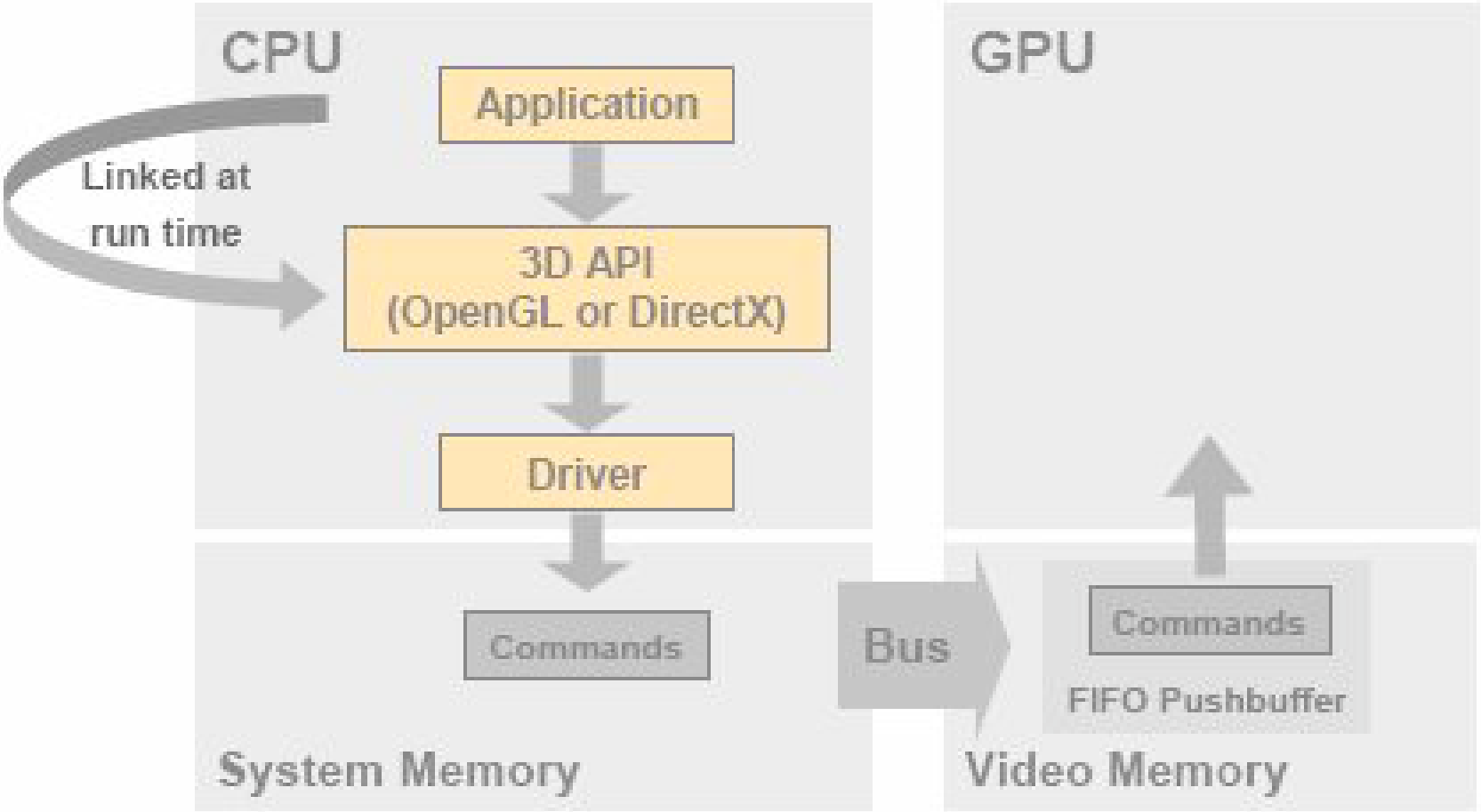
What is OpenGL?

- **Open G**raphics **L**ibrary
- A low level API for 2D/3D rendering with the Graphics Hardware (GPU)
- Cross-platform (Windows, OS X, Linux, iOS, Android, ...)

- Developed by SGI in 1992
  - 2014: OpenGL 4.5
  - 2008: OpenGL 3.0
  - 2006: OpenGL 2.1
- Main alternative: DirectX/3D

How does it fit in?

- Tap massive power of GPU hardware to render images
- Use GPU without caring about the exact details of the hardware



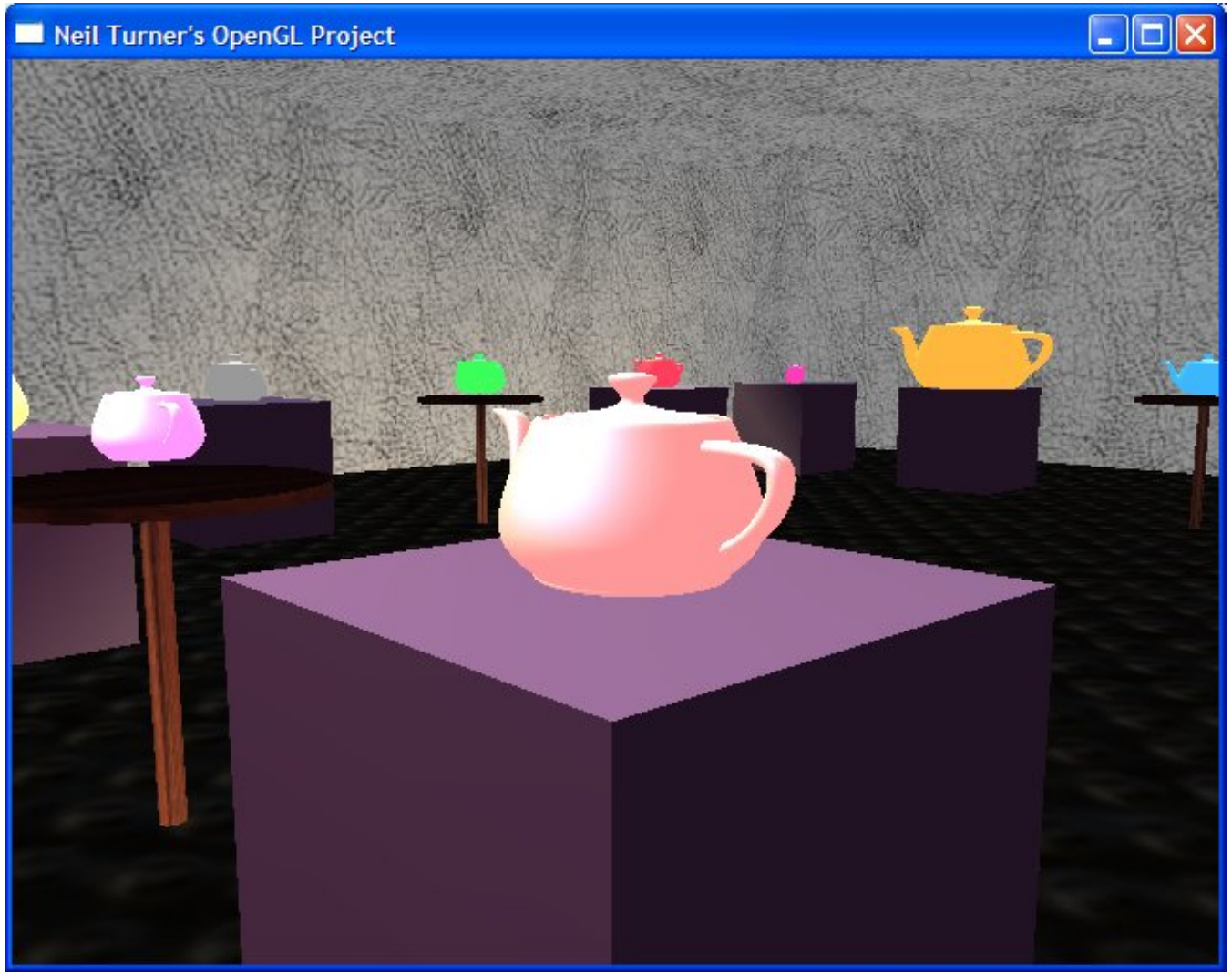
What OpenGL does for us

- Controls GPU
- Lets user specify resources...:
  - Geometry (vertices and primitives)
  - Textures
  - Shaders (programmable pieces of rendering pipeline)
  - Etc.
- ...and use them:
  - Rasterize and draw geometry

How we will use OpenGL

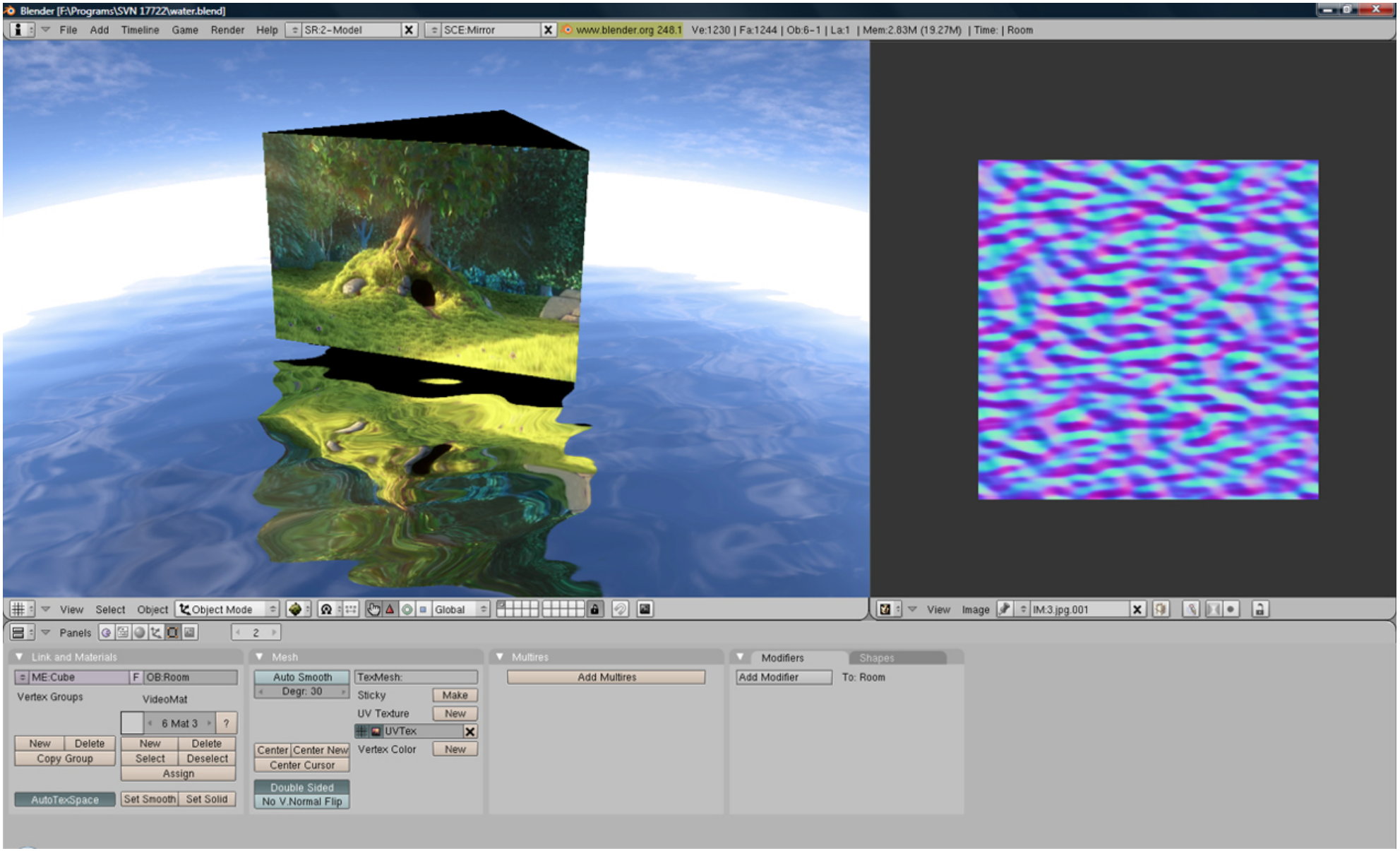
- OpenGL version
  - We use 2.x-3.x (plus extensions)
  - Code avoids older, deprecated parts of OpenGL standard
- LWJGL
  - Lightweight Java Game Library
  - Java bindings for OpenGL API
- CS 4620/4621 Framework
  - Simplifies creating and using OpenGL resources

OpenGL 25 years ago



http://www.neilturner.me.uk/shots/opengl-big.jpg

OpenGL 2009 ->


Blender [F:\Programs\SVN 17722\water.blend]
File Add Timeline Game Render Help
SR:2-Model
SCE:Mirror
www.blender.org 248.1 Ve:1230 | Fa:1244 | Ob:6-1 | La:1 | Mem:2.83M (19.27M) | Time: | Room
View Select Object Object Mode
Global
View Image IM:3.jpg.001
Panels
Link and Materials
ME:Cube
OB:Room
Vertex Groups
VideoMat
6 Mat 3
New Delete
Copy Group
New Delete
Select Deselect
Assign
AutoTexSpace
Set Smooth Set Solid
Mesh
Auto Smooth
Degr: 30
TexMesh:
Sticky Make
UV Texture New
UVTex
Center Center New
Center Cursor
Vertex Color New
Double Sided
No V.Normal Flip
Multires
Add Multires
Modifiers
Shapes
Add Modifier
To: Room

What changed?

25 years ago:

- Vertex transformation/fragment shading hardcoded into GPUs

Now:

- More parts of the GPU are programmable (but not all)

What changed?

25 years ago (Fixed pipeline)**:**

- Transform vertices with modelview/projection matrices
- Shade with Phong lighting model only

Contemporary (Programmable hardware)**:**

- Custom vertex transformation
- Custom lighting model
- More complicated visual effects
- Shadows
- Displaced and detailed surfaces
- Simple reflections and refractions

WebGL shader demo

- Shadertoy
  https://www.shadertoy.com/browse
- GLSL sandbox
  http://glslsandbox.com/
- three.js
  http://threejs.org/examples/

Creating an OpenGL Program using LWJGL

LWJGL

- OpenGL originally written for C.
- LWJGL contains OpenGL binding for Java
  www.lwjgl.org/

- Gives Java interface to C OpenGL commands
- Manages framebuffer

(framebuffer: a buffer that holds the image that is displayed on the monitor)

MainGame

- A window which can display GameScreens
- Initializes OpenGL context
- Forwards keyboard and mouse events to the event dispatcher

- Usage
  - Inherit from MainGame and implement methods
  - Create instance and call run method

MainGame

```
@Override
protected void buildScreenList() {
   // Create objects inherited from GameScreen and
   // initialize screenList attribute
}

@Override
protected void fullInitialize() {
   // Code Executed Before Window Is Created
}

@Override
protected void fullLoad() {
   // Code Executed With An Active OpenGL Context
}
```

GameScreen

- Can display images created by OpenGL
- OpenGL “context”
  - Stores OpenGL state (geometry, buffers, etc.)

- Usage:
  - Inherit from class and implement methods
  - Create instance in MainGame.buildScreenList

GameScreen

```
@Override
public void update(GameTime gameTime) {
  // Animation: Update position of scene objects, camera
}

@Override
public void draw(GameTime gameTime) {
  // Drawing: Use LWJGL to draw to the screen
}

@Override
public void onEntry(GameTime gameTime) {
  // Initialization code
}

@Override
public void onExit(GameTime gameTime) {
  // Destruction, free allocated resources here
}
```

Events

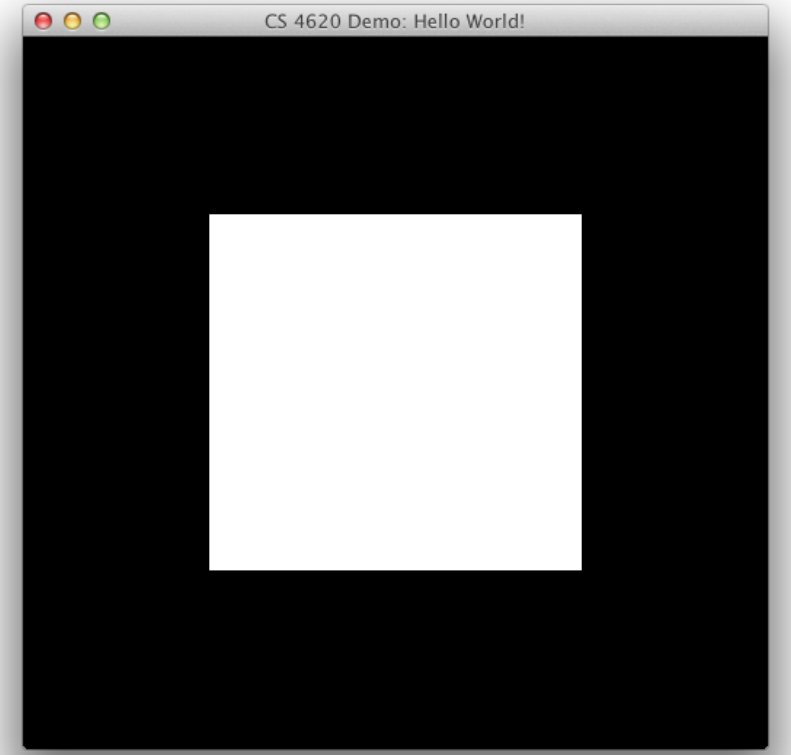
- MainGame can trigger certain events
  - Something happens (e.g. user resizes window)
  - MainGame forwards event to the event dispatcher
    - KeyboardEventDispatcher
    - MouseEventDispatcher
  - Objects interested in the event can sign up as listeners
    - e.g. KeyboardEventDispatcher.OnKeyPressed.add(…)

- These events let us interact with OpenGL

OpenGL Commands and Resources

(a quick demo today – more on this next time)

Demo: Hello World!



Framework and GL Resources

- OpenGL API has “objects” that hold rendering resources
  - Geometry, textures, shader programs, etc.
- Framework represents these with Java classes
  - GLProgram (shader programs)
  - GLBuffer (used to specify geometry)
- Constructing an object creates OpenGL resource
  - Object's data lives in GPU memory
  - Allows faster access while rendering

To use a GLSL program…

Follow the next 7 steps:

1. Create shader objects.
2. Read source code from files and feed them to the shader objects just created.
3. Compile the shader.
4. Create a program object.
5. Attach the shaders to the program.
6. Link the program.
7. Tell OpenGL to use your shader program.

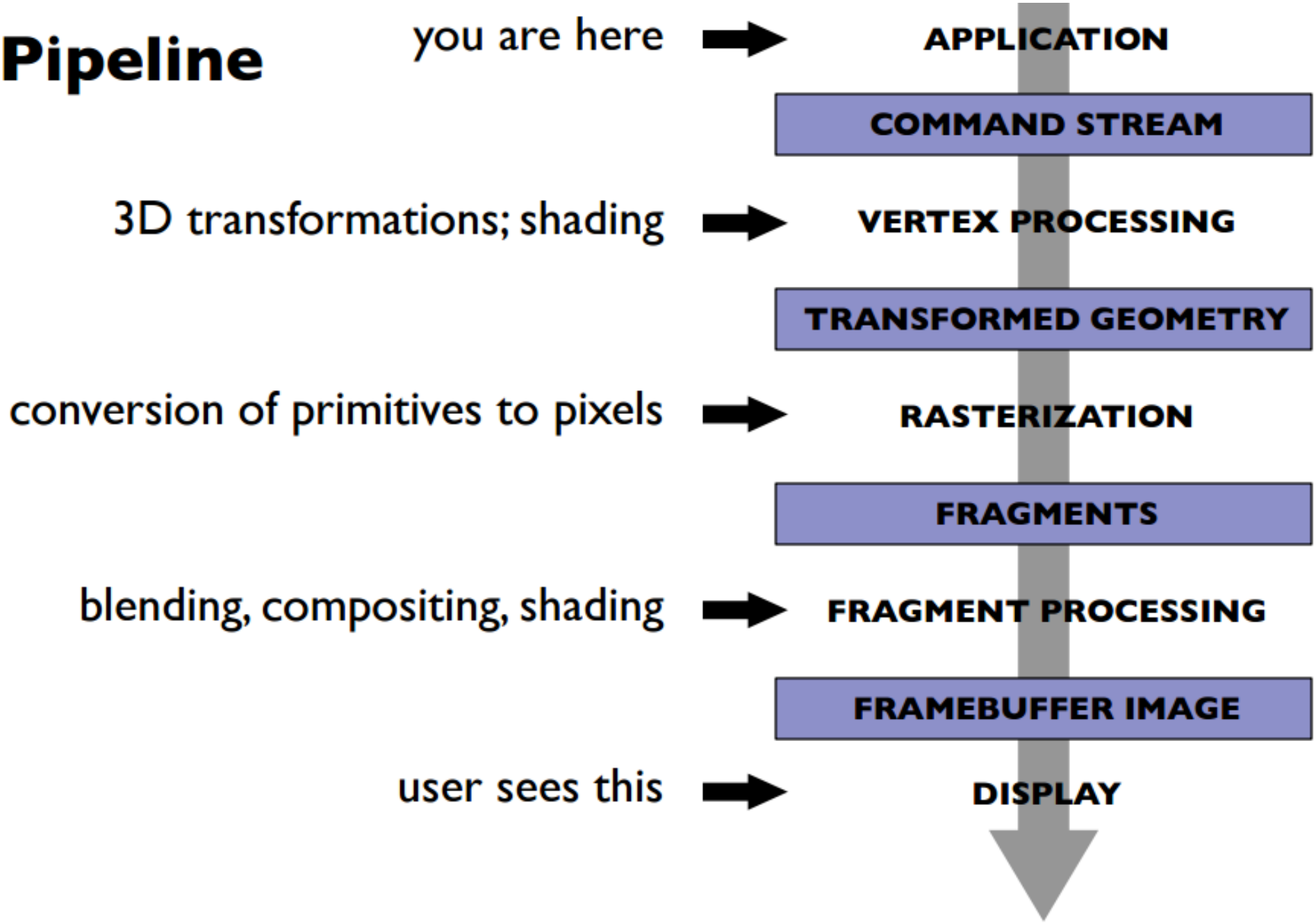
GLSL basics

GLSL

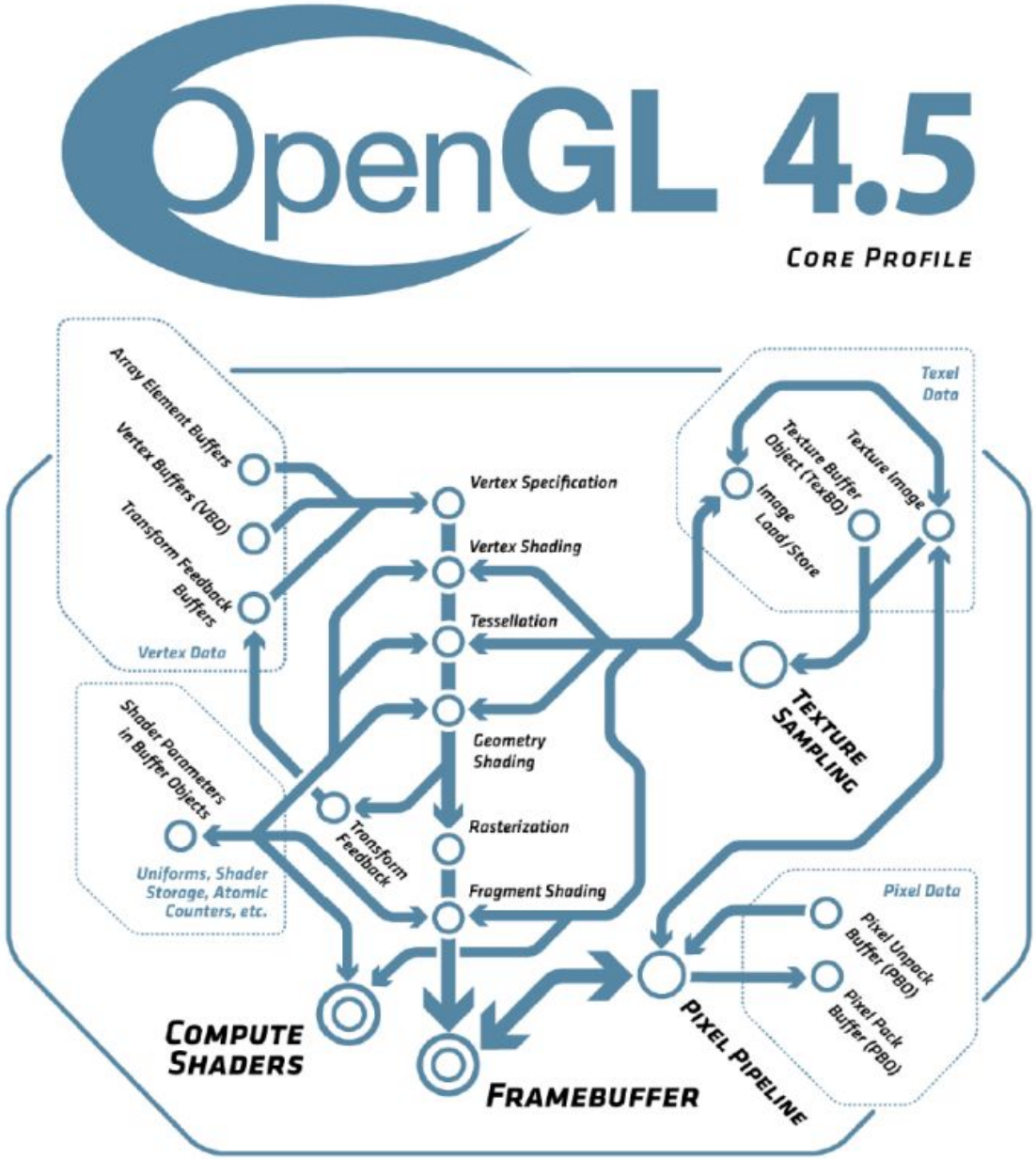
GLSL : **G**raphics **L**ibrary **S**hading **L**anguage

- Syntax similar to C/C++
- Language used to write shaders
  - vertex, tessellation, geometry, fragment, compute
  - We only mostly cover fragment shaders today
- Based on OpenGL
  - First available in OpenGL 2.0 (2004)
- Alternatives: Nvidia Cg and Microsoft HLSL

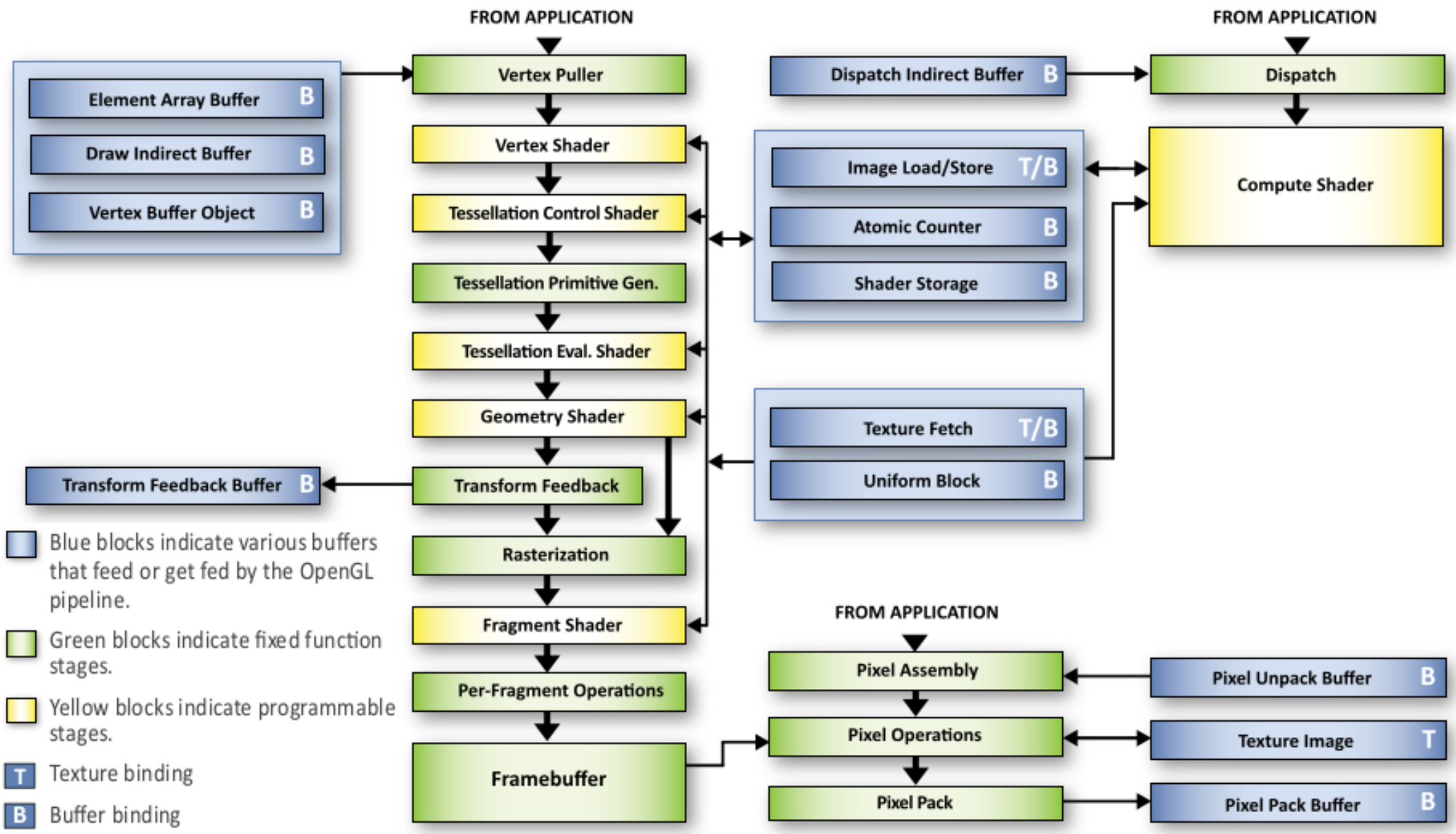
Pipeline


you are here
APPLICATION
COMMAND STREAM
3D transformations; shading
VERTEX PROCESSING
TRANSFORMED GEOMETRY
conversion of primitives to pixels
RASTERIZATION
FRAGMENTS
blending, compositing, shading
FRAGMENT PROCESSING
FRAMEBUFFER IMAGE
user sees this
DISPLAY

Modern Graphics Pipeline



Modern Graphics Pipeline



What is a Shader Program?

- A small program to control parts of the graphics pipeline
- Consists of 2 (or more) separate parts:
  - Vertex shader controls vertex transformation
  - Fragment shader controls fragment shading

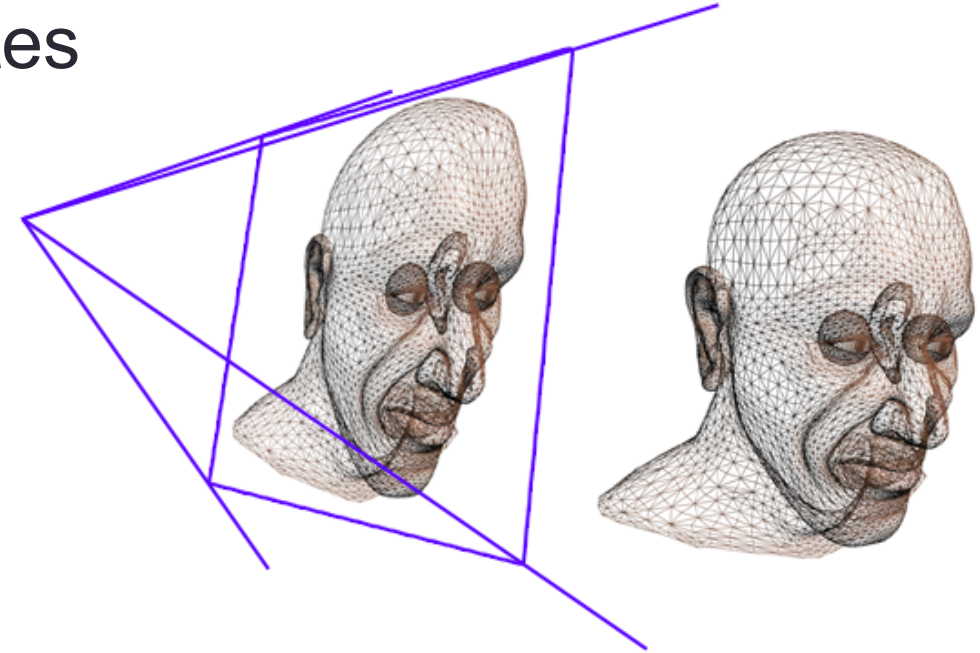
GLSL Program

- Specifies how OpenGL should draw geometry
- Program: A collection of shaders that run together
  - At least one vertex shader or one fragment shader
- At any time, the GPU runs only one program
  - Must specify program to use before drawing geometry

Vertex Shader

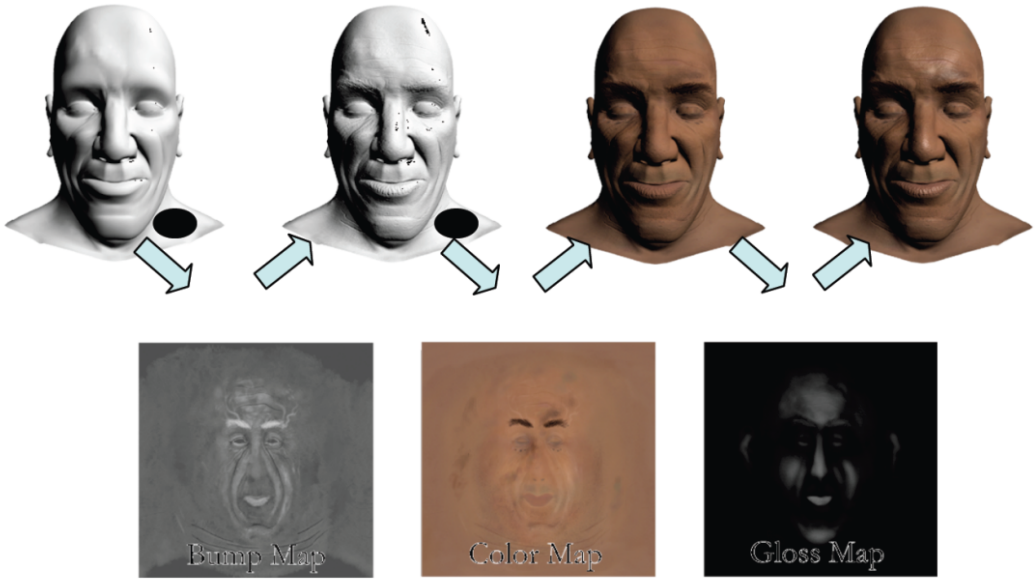
- Transform vertices from object space to clip space

- Compute other data that are interpolated with vertices
  - Color
  - Normals
  - Texture coordinates
  - Etc.



Fragment Shaders

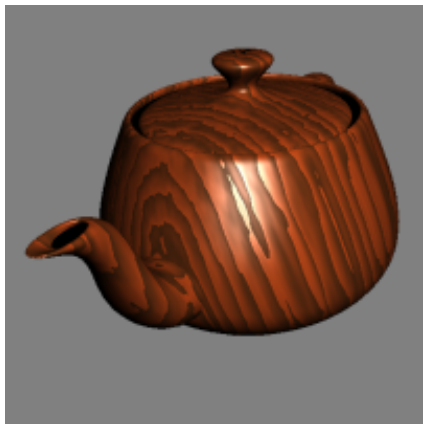
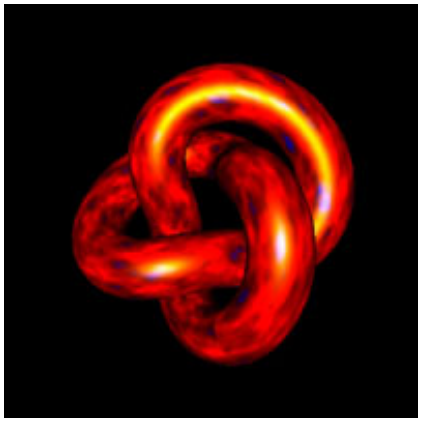
- Compute the color of a fragment (i.e. a pixel)
- Take interpolated data from vertex shaders
- Can read more data from:
  - Textures
  - User specified values



What Can a Fragment Shader Do?

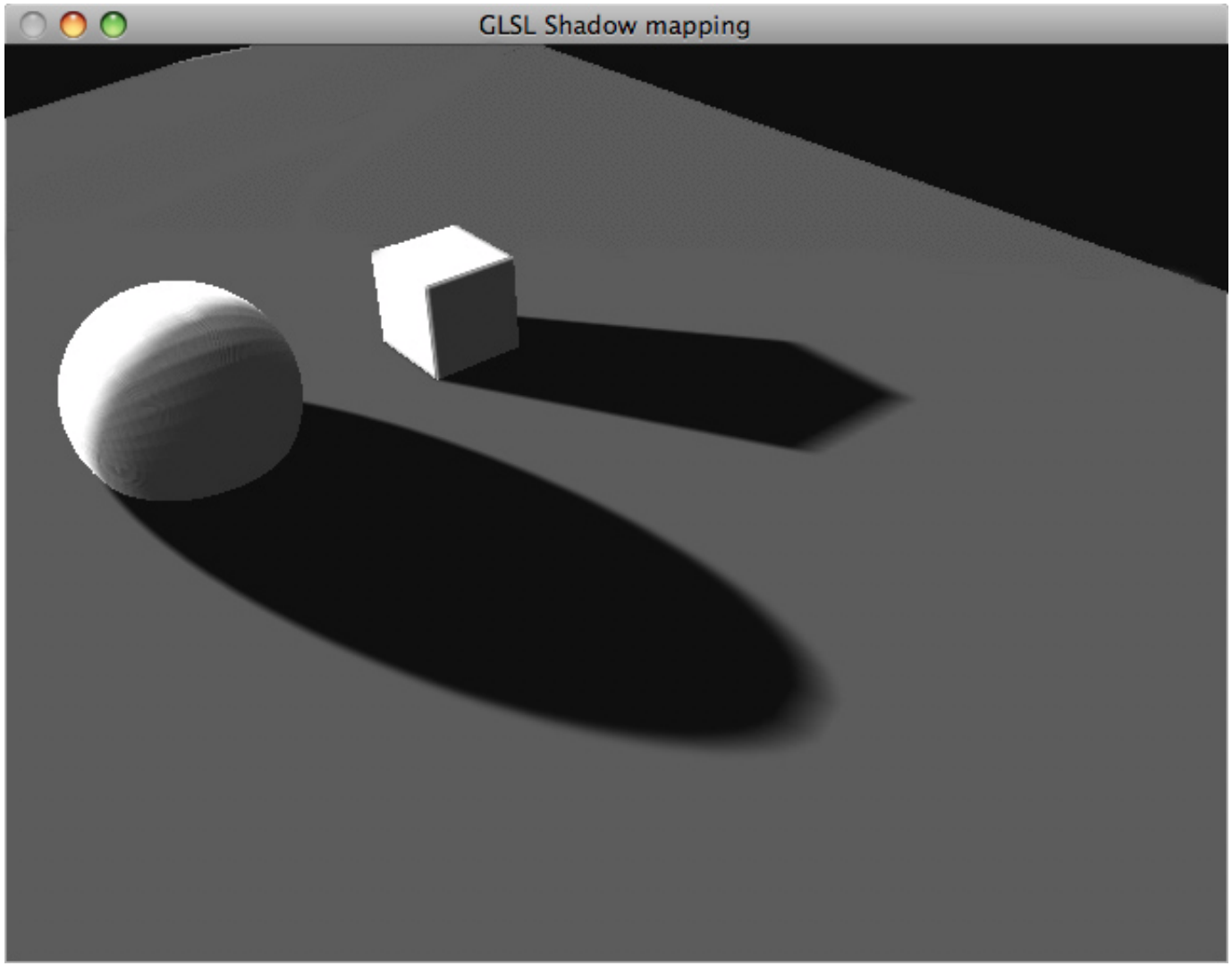
More complicated, detailed materials:

- Glossy
- Reflective, refractive
- Rough, bumpy, lots of nooks and crannies
- Wooden

What Can a Fragment Shader Do?

Shadows (including soft edges)



http://www.fabiensanglard.net/shadowmappingPCF/8x8kernel_nVidia.jpg

GLSL Data Types

- Both in GLSL and Java
  - float, int
- GLSL has, but Java does not have
  - vec2, vec3, vec4: vectors
  - mat2, mat3, mat4: matrices
  - sampler1D, sampler2D, sample3D, samplerCube, etc: textures
- Java has, but GLSL does not have
  - Object
  - String
  - etc...

vec2

- Represents a vector in 2D (each component is a float)

```
vec2 a;
a.x = 0.0;
a.y = 1.0; // a = (0,1)

vec2 b;
b.s = 10.0;
b.t = 12.5; // b = (10,12.5)

vec2 c;
c[0] = 9.0;
c[1] = 8.0; // c= (9,8)
```

vec3

```
vec3 a;
a.x = 10.0; a.y = 20.0; a.z = 30.0;  // a = (10,  20,  30)
a.r = 0.1;  a.g = 0.2;  a.b = 0.3;   // a = (0.1, 0.2, 0.3)
a.s = 1.0,  a.t = 2.0;  a.p = 3.0;   // a = (1, 2, 3)

vec3 b = vec3(4.0, 5.0, 6.0);

vec3 c = a + b; // c = (5, 7, 9)
vec3 d = a - b; // d = (-3, -3, -3)
vec3 e = a * b; // e = (4, 10, 18)
vec3 f = a * 3; // e = (3, 6, 9)
float g = dot(a,b); // g = 32
vec3 h = cross(a,b); // h = (-5,6,-3)
float i = length(a); // i = 3.742
```

vec4

```
vec4 a;
a.x = 10.0; a.y = 20.0; a.z = 30.0; a.w = 40.0;
// a = (10, 20, 30, 40)
a.r = 0.1;  a.g = 0.2;  a.b = 0.3;  a.a = 0.4;
// a = (0.1, 0.2, 0.3, 0.4)
a.s = 1.0;  a.t = 2.0;  a.p = 3.0;  a.q = 4.0;
// a = (1, 2, 3, 4)

vec4 b = vec4(5, 6, 7, 8);

vec4 c = a + b; // c = (6, 8, 10, 12)
vec4 d = a - b; // d = (-4, -4, -4, -4)
vec4 e = a * b; // e = (5, 12, 21, 32)
vec4 f = a * 3; // f = (3, 6, 9, 12)
float g = length(a); // g = 5.477
```

mat2

- Represents a 2 by 2 matrix (each component is a float)

```
mat2 A = mat2(1.0, 2.0, 3.0, 4.0); // in column-major order

vec2 x = vec2(1.0, 0.0);
vec2 y = vec2(0.0, 1.0);

vec2 a = A * x; // a = (1,2)
vec2 b = A * y; // b = (3,4)
```

mat3

```
mat3 A = mat3(1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0);
// in column-major order

vec3 x = vec3(1.0, 0.0, 0.0);
vec3 y = vec3(0.0, 1.0, 0.0);
vec3 z = vec3(0.0, 0.0, 1.0);

vec3 a = A * x; // a = (1,2,3)
vec3 b = A * y; // b = (4,5,6)
vec3 c = A * z; // c = (6,7,8)
```

mat4

- 4x4 matrices (can store affine transformations)

```
mat4 A = mat4(1.0,  2.0,  3.0,  4.0,
              5.0,  6.0,  7.0,  8.0,
              9.0,  10.0, 11.0, 12.0
              13.0, 14.0, 15.0, 16.0); // in column-major order

vec4 x = vec4(1.0, 0.0, 0.0, 0.0);
vec4 y = vec4(0.0, 1.0, 0.0, 0.0);
vec4 z = vec4(0.0, 0.0, 1.0, 0.0);
vec4 w = vec4(0.0, 0.0, 0.0, 1.0);

vec4 a = A * x; // a = (1,2,3,4)
vec4 b = A * y; // b = (5,6,7,8)
vec4 c = A * z; // c = (9,10,11,12)
vec4 d = A * w; // d = (13,14,15,16)
```

Array

- We can declare fixed-size arrays (size known at compile time)
- Use C syntax.

```
float A[4];
A[0] = 5; A[3] = 10;

vec4 B[10];
B[3] = vec4(1,2,3,4);
B[8].y = 10.0;
```

Swizzling

- Used to construct a vector from another vector by referring to multiple components at one time.

```
vec4 a = vec4(1,2,3,4);

vec3 b = a.xyz;  // b = (1,2,3)
vec2 c = a.qp;   // c = (4,3)
vec4 d = a.xxyy; // d = (1,1,2,2)
```

Type Conversion

- Syntax: <<variable>> = <<type>>(<<value>>);
- Expression on RHS = “constructor expression.”
- Example:

```
float a = 1.0;
int b = int(a);
```

Shader Structure

```
/*
Multiple-lined comment
*/

// Single-lined comment

//
// Global variable definitions
//

void main()
{
    //
    // Function body
    //
}
```

Vertex Shader

Grid.vert:

```
#version 120

uniform mat4 VP;

attribute vec4 vPos;

void main()
{
    gl_Position = VP * vPos;
}
```

Each time the screen is drawn, this main() function is called once per vertex, as if it were in a for loop.

Vertex Shader

Grid.vert:

```
#version 120

uniform mat4 VP;

attribute vec4 vPos;

void main()
{
    gl_Position = VP * vPos;
}
```

The first thing to do is specify the GLSL version.
(Note: syntax in other versions can be rather different!)

Vertex Shader

Grid.vert:

```
#version 120

uniform mat4 VP;

attribute vec4 vPos;

void main()
{
    gl_Position = VP * vPos;
}
```

Uniforms are one type of input to the shader. They are the same for each vertex drawn during one draw function. We will see how to set them later.

Vertex Shader

Grid.vert:

```
#version 120

uniform mat4 VP;

attribute vec4 vPos;

void main()
{
    gl_Position = VP * vPos;
}
```

Attribute variables link to vertex attributes, or data associated with each vertex. This one is set to the vertex position buffer. Each time main() is executed, vPos is set to the vertex currently being processed.

Vertex Shader

Grid.vert:

```
#version 120

uniform mat4 VP;

attribute vec4 vPos;

void main()
{
    gl_Position = VP * vPos;
}
```

gl_Position is a special variable that holds the position of the vertex in clip space.

Since a vertex shader's main output is the position in clip space, it must **always** set gl_Position.

This vertex shader just transforms each vertex position (by the VP matrix).

Fragment Shader

Grid.frag:

```
#version 120

uniform vec4 uGridColor;

void main()
{
  gl_FragColor = uGridColor; //vec4(1,1,1,1);
}
```

Each time the screen is drawn, this main() function is called once per pixel.

Fragment Shader

Grid.frag:

```
#version 120


uniform vec4 uGridColor;


void main()
{
  gl_FragColor = uGridColor; //vec4(1,1,1,1);
}
```

gl_FragColor is a special variable that stores the color of the output fragment.

Since a fragment shader computes the color of a fragment, it must **always** set gl_FragColor.

Fragment Shader

Grid.frag:

```
#version 120


uniform vec4 uGridColor;


void main()
{
  gl_FragColor = uGridColor;
//vec4(1,1,1,1);
}
```

vec4 is a data type of 4D vector.

Can be used to store:
- homogeneous coordinates
- RGBA color

vec4(1,1,1,1) constructs an RGBA tuple with R=1, G=1, B=1, A=1, which is white. (Note it is commented out here. We are passing the same information for the color using the vec4 uniform uGridColor)

OpenGL/GLSL Plumbing

- Suppose we have already created the program
- We tell OpenGL to use it.
- We then instruct OpenGL to draw the two triangles:

HelloWorldScreen.java:

```
// The vertices in our vertex buffer, initialized earlier
float [] vertexPositions = {
           -0.5f, -0.5f,      // vertex 0
            0.5f, -0.5f,      // vertex 1
            0.5f,  0.5f,      // vertex 2
           -0.5f,  0.5f       // vertex 3
                   };
//...
// In the draw method
program.use();

glDrawElements(...);

GLProgram.unuse();
```

CS 4620/4621 Framework

- Contains GLProgram class to abstract OpenGL calls:
  - Added convenience methods
  - Help keep conventions straight
  - Controls mapping between attribute variables and vertex buffers

Now, to create a GLSL program…

- Create a GLProgram object

```
private GLProgram program;

public void onEntry(GameTime gameTime) {

  program = new GLProgram();
  program.quickCreateResource(
      "cs4620/gl/Grid.vert",   // Path to vertex shader
      "cs4620/gl/Grid.frag",   // Path to fragment shader
      null);                  // Optional attribute list
}
```

GLSL passing data around