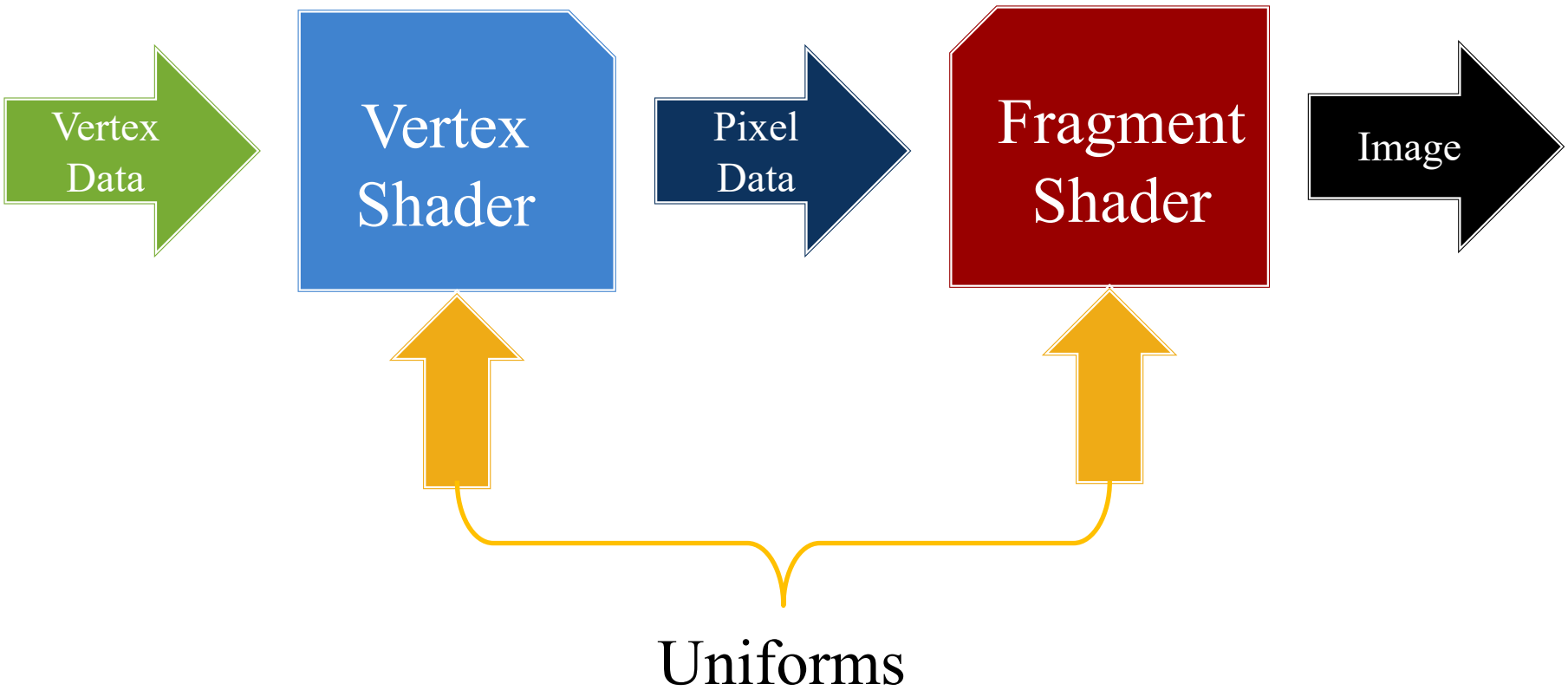
the gamedesigninitiative at cornell university

Lecture 12

Custom Pipelines

Recall: Graphics Shaders



Recall: Shader Basics

Vertex

- Should contain
  - An `in` for each **attribute**
  - An `out` for each **interpolant**
  - A `uniform` (?) for **camera**
  - A `main()` function
- Anything else is optional

Fragment

- Should contain
  - An `in` for each **interpolant**
  - An `out` for the **pixel color**
  - A `uniform` (?) for **texture**
  - A `main()` function
- Anything else is optional

Linking requires interpolants match

A Color-Texture Shader (GLSL 3.0)

Vertex Shader

```
// Attributes
in vec4 aPosition;
in vec4 aColor;
in vec4 aCoord;
// Interpolants
out vec4 outColor;
out vec4 outCoord;

uniform mat4 uCamera;

void main(void) {
   gl_Position = uCamera*aPosition;
   outColor = aColor;
   outCoord = aCoord;
}
```

Fragment Shader

```
// The output color
out vec4 frag_color;

// Interpolants
in vec4 outColor;
in vec4 outCoord;

uniform sampler2D uTexture;

void main(void) {
   frag_color = texture(uTexture,
                        outCoord);

   frag_color *= outColor;
}
```

Some Nomenclature Issues

- We are using **shader** to mean **vertex** + **fragment**
  - Some people use shader to refer just one of these
  - Combining them together is often called a **pipeline**
- But only graphics programmers talk like this
  - Hobbyists typically use **shader** to mean **pipeline**
- In CUGL we use the following terminology
  - `ShaderSource` is single GLSL program
  - `GraphicsShader` is a pipeline combination
  - This thinking is motivated by Vulkan

The ShaderSource Class

- Meant to be on the stack: no alloc
  - initOpenGL(const string source, ShaderStage stage)
  - initVulkan(const vector<byte>& bytes, ShaderStage stage)
- In OpenGL, the source is a **string**, not a **file**
  - You could load files and read into strings
  - But this means pipeline *waits* on asset loading
- CUGL approach: **raw strings**
  - Write shader code into a header file
  - Special include assigns contents to a variable

The ShaderSource Class

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  - initVulkan(const vector<byte>& bytes, [illegible]ge)
- In O[illegible]ource is a **string**,
  - Yo[illegible]es and read into strings
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- CUGL approach: **raw strings**
  - Write shader code into a header file
  - Special include assigns contents to a variable

Not yet supported

Vertex or Fragment

Ready to go at start-up

C++ Raw Strings

- Raw strings are multiline strings
  - Work like """…""" in Python
  - Great for inlining interpreted code
- Delimit as R"(…)"
  - Parentheses are **not** part of string
  - Often put string in a header file
- Header usage

```
const std::string rawString =
#include "rawstring.h"
;
```

Assigns contents of file to string

The GraphicsShader Class

- Call alloc with ShaderSource (vertex & fragment)
- But this does not complete the shader set-up!
  - You need to **declare** all variables in the shaders
  - That creates data structures to use the shader
- There are three declaration types
  - AttributeDef: Declare an **attribute**
  - UniformDef: Declare a simple **uniform/push constant**
  - ResourceDef: Declare a **texture** or **uniform buffer**
- When done, compile the shader (this step can **fail**)

The GraphicsShader Class

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  - Unifor tant
  - Resou r
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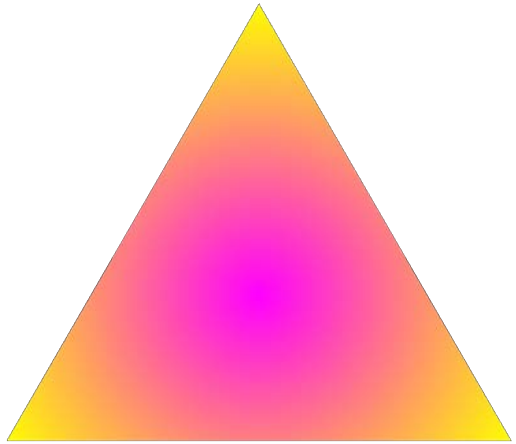
See the Pipeline Demo

Recall: Make a Vertex Type

- Can be **any class** of your making
  - Should have **position** (`Vec2`, `Vec3`, or `Vec4`)
  - Can have anything else that you want
  - There are (almost) no restrictions
- **Example**: `SpriteVertex`
  - Position (`Vec2`)
  - Color (`unsigned int`)
  - Texture coords (`Vec2`)
  - Gradient coords (`Vec2`)



Declaring Attributes in GraphicsShader

```
AttributeDef attrib;
attrib.location = 0;
attrib.group = 0;
attrib.type = GLSLType::VEC2;
attrib.offset = offsetof(SpriteVertex,position);
shader->declareAttribute("aPosition", attrib);

attrib.location = 1;
attrib.type = GLSLType::UCOLOR;
attrib.offset = offsetof(SpriteVertex,color);
shader->declareAttribute("aColor", attrib);
```

Declaring Attributes in GraphicsShader

```
AttributeDef attrib;
attrib.location = 0;
attrib.group = 0;
attrib.type = GLSLType::VEC2;
attrib.offset = offsetof(SpriteVertex,position);
shader->declareAttribute("aPosition", attrib);

attrib.location = 1;
attrib.type = GLSLType::UCOLOR4;
attrib.offset = offsetof(SpriteVertex,color);
shader->declareAttribute("aColor", attrib);
```

Shader Type

Position in C++ class

Name in shader

Declaring Attributes in GraphicsShader

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attrib.offset = offsetof(SpriteVertex,position);
shader->declareAttribute("aPosition", attrib);

attrib.location = 1;
attrib.type = GLSLType::UCOLOR;
attrib.offset = offsetof(SpriteVertex,color);
shader->declareAttribute("aColor", attrib);
```

Can reuse declaration

Declaring Attributes in GraphicsShader

```
AttributeDef attrib;
attrib.location = 0;
attrib.group = 0;
attrib.type = GLSLT
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shader->declareAttribute("aPosition", attrib);

attrib.location = 1;
attrib.type = GLSLType::UCOLOR;
attrib.offset = offsetof(SpriteVertex,color);
shader->declareAttribute("aColor", attrib);
```

Location in shader

Mesh "instance"

CUGL Meshes

- The type is `Mesh<T>` (in cugl::graphics)
  - Type `T` must be a vertex type
  - Also includes the drawing geometry
- This is not a standard game mesh
  - Stores data on the **CPU side**
  - Allows you to make lots of little changes
- True meshes are `VertexBuffer` objects
  - Stores the drawing data on **GPU side**
  - Designed to be updated once a frame

The VertexBuffer Class

- VertexBuffer::alloc(size,sizeof(VertexClass),access)
  - size is the maximum number of vertices
  - sizeof tells it number of bytes per vertex
  - access indicates how often we update it
- Load data from Mesh into the VertexBuffer
  - verts->loadData(mesh.vertices.data(), _mesh.vertices.size())
  - Each **attribute group** gets separate Mesh/VertexBuffer
- There is also an associated IndexBuffer
  - **Optional:** not required to use VertexBuffer
  - But only one; applies to all VertexBuffer objects

Aside: VertexBuffer Access Rules

Static

- Vertex buffer is **fixed**
  - Object altered via *uniforms*
  - **Example**: Transform matrix
- Used if **lots of vertices**
  - Uniform changes stall drawing
  - But reloading vertices is worse
- Common in **3d rendering**
  - Models are **large meshes**
  - Each model its own buffer

Dynamic

- Vertex buffer **changes often**
  - Always updating position
  - Always updating geometry
- Used if **low complexity**
  - Few vertices per object (quads)
  - Can't give each sprite a buffer
- Common in **2d rendering**
  - Data is very **heterogeneous**
  - How `SpriteBatch` works

Using a GraphicsShader

```
shader->setDrawMode(mesh.command);

shader->setVertices(0, vertbuff);
shader->setIndices(indxbuff);

shader->setTexture("uTexture",texture);

shader->begin();

shader->pushInt("uType", type);
shader->pushMat4("uPerspective", camera->getCombined());

shader->drawIndexed(mesh.indices.size());

shader->end();
```

Using a GraphicsShader

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```

Pass data to the GPU

SpriteBatch-style drawing pass

Using a GraphicsShader

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shader->begin();

shader->pushInt("uType", type);
shader->pushMat4("uPerspective", camera->getC

shader->drawIndexed(mesh.indices.size());

shader->end();
```

Only need to be set once

Must be called every frame

Using a GraphicsShader

```
shader->setDrawMode(mesh.command);

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shader->begin();

shader->pushInt("uType", type);
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shader->end();
```

Resource Uniform

Pushed Uniforms

Resources: UniformBuffer

- Vulkan limits **push constants** to 196 bytes
  - Just enough to hold three matrices
  - Effectively camera, modelview, and normal
  - OpenGL does not enforce this, but also a good idea
- Larger uniform data should be in a UniformBuffer
  - Similar format to a VertexBuffer
  - Same access controls and data loading
  - Difference is that it applies to all vertices
- Unlike push constants, attach to shader once

Pipeline Settings

- A graphics shader has other non-uniform values
  - **Examples**: Color blending, stencil support, depth testing
  - These are called **pipeline settings**
  - They are very specific to the backend API
- CUGL is designed to be backend agnostic
  - `BlendMode`: How to blend colors together
  - `StencilMode`: Use a stencil to constrain drawing
  - `CullMode`: Whether to eliminate backwards-facing triangles
  - `FrontFace`: How the "front" of a triangle is deteremined

Color Blending

- `BlendMode` is the most important setting for 2d
  - Defines how images are composited together
  - `BlendMode::ALPHA` is often used for alpha blending
- But the CUGL default is `BlendMode::PREMULT`
  - Premultiplied means color is multiplied by alpha
  - Clear **must** be (0,0,0,0); (1,1,1,0) is impossible
  - Why? Because that is how SDL3 loads images
- If you use `BlendMode::ALPHA`, edges will look **black**
  - Because transparency fades to black
  - `BlendMode::PREMULT` adjusts for this and fixes it.

Color Blending Images in SDL3

BlendMode::ALPHA

BlendMode::PREMULT

Pipeline Demo

Recall: Texture Atlases

- CUGL support
  - Specify in asset directory
  - Subentry of texture
- **Example**

```
"progress": {
    "file" : "progress.png",
    "atlas" : {
        "back" : [0,    0, 320, 45],
        "fore"  : [24,  45, 296, 90],
        "left"   : [0,   45,  24, 90],
        "right" : [296, 45, 320, 90]
    } }
```

- But the class is Texture!

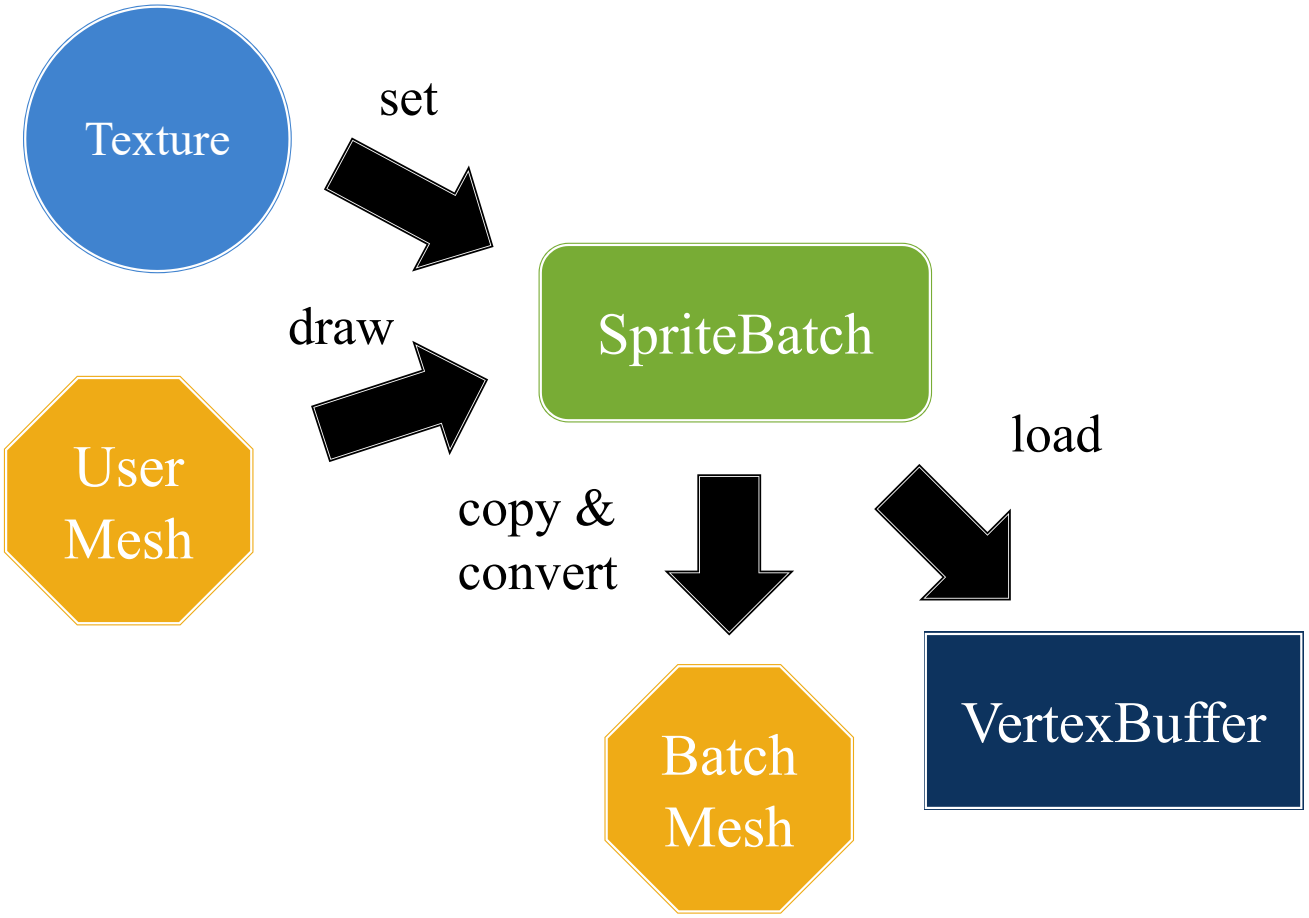
Subtextures

- `sub = texture->getSubtexture(minS,minT,maxS,maxT);`
  - Parameters are in **texture coordinates** not pixels
  - Returns a texture (`sub`) spanning that area
- **Analogy:** `TextureRegion` in LibGDX
  - That was a separate class that did same thing
  - But it forced us to "double" all methods
  - So CUGL just uses one class: `Texture`
- However, does not work the way you think
  - Passing it to a texture sends the **whole** texture
  - You have to adjust your texture coordinates

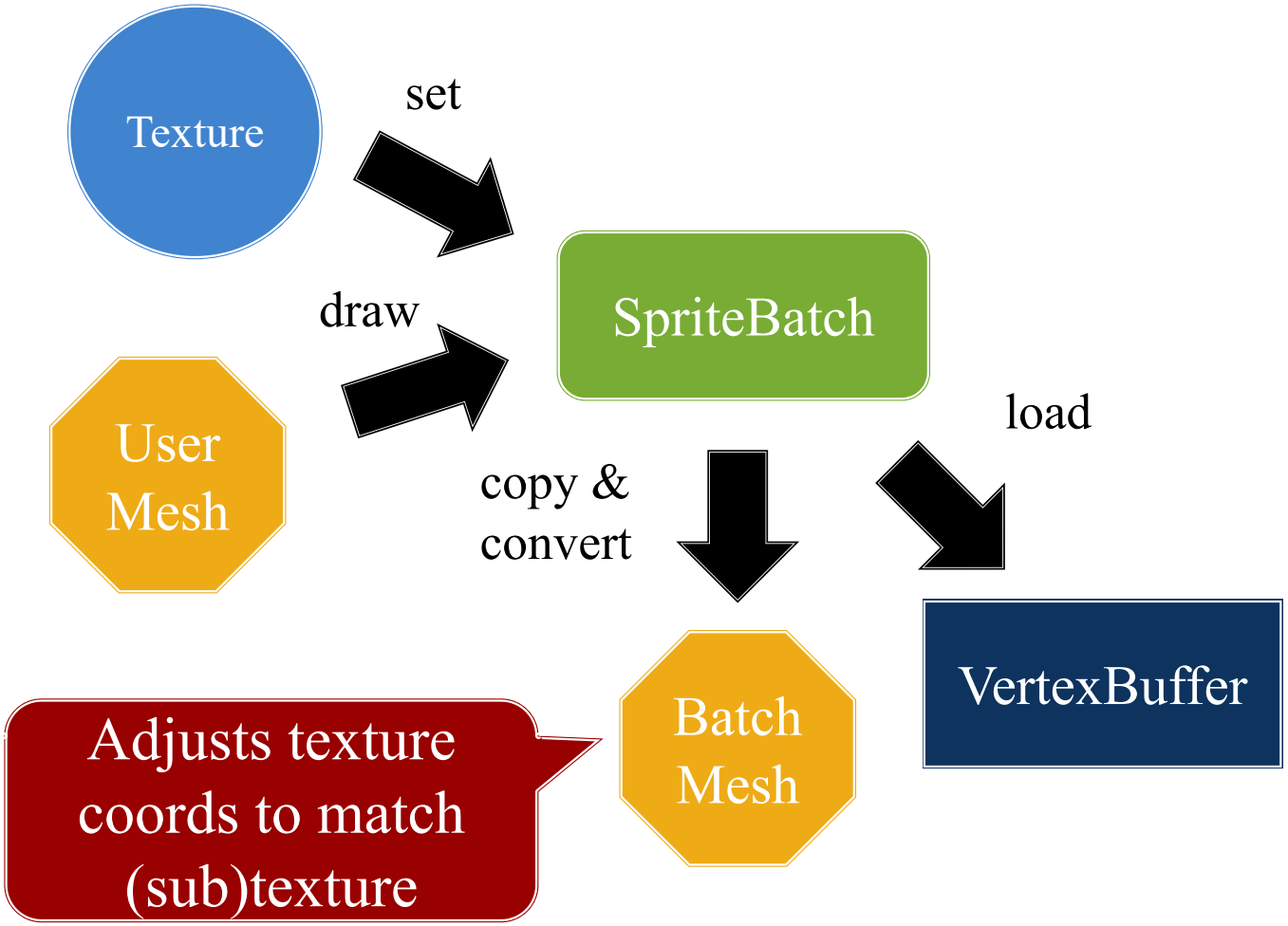
Using a Subtexture

- Use isSubtexture() to check if a subtexture
- Has getter methods for the texture range
  - getMinS(), getMaxS(), getMinT(), getMaxT()
  - By default, the values are 0,1,0,1
- Must convert mesh texture coordinates (s,t)
  - s => getMinS()+s*(getMaxS()-getMinS())
  - t => getMinT()+t*(getMaxT()-getMinT())
- This is how SpriteBatch works

How SpriteBatch Works



How SpriteBatch Works



So When Do We Do This?

- Do not touch the SpriteBatch shader
  - It is not "user serviceable"
  - You will break the UI code
- There are two classic options
  - Make a shader for a **custom scene graph node**
  - Make a shader for **post-processing an image**
- Anything more is beyond the scope of course
  - Covered in **CS 5625:** Interactive Graphics
  - Might be offered next year

Pipelines and Scene Graphs

```
void CustomNode::draw(const std::shared_ptr<SpriteBatch>& batch,
                      const Affine2& transform, Color4 tint) {

    // Stop the previous graphics pipeline
    batch->end();

    // Adjust pipeline camera by the node transform
    Mat4 camera = _scene->getCombined()*transform;

    // Custom drawing code
    ...
    ...

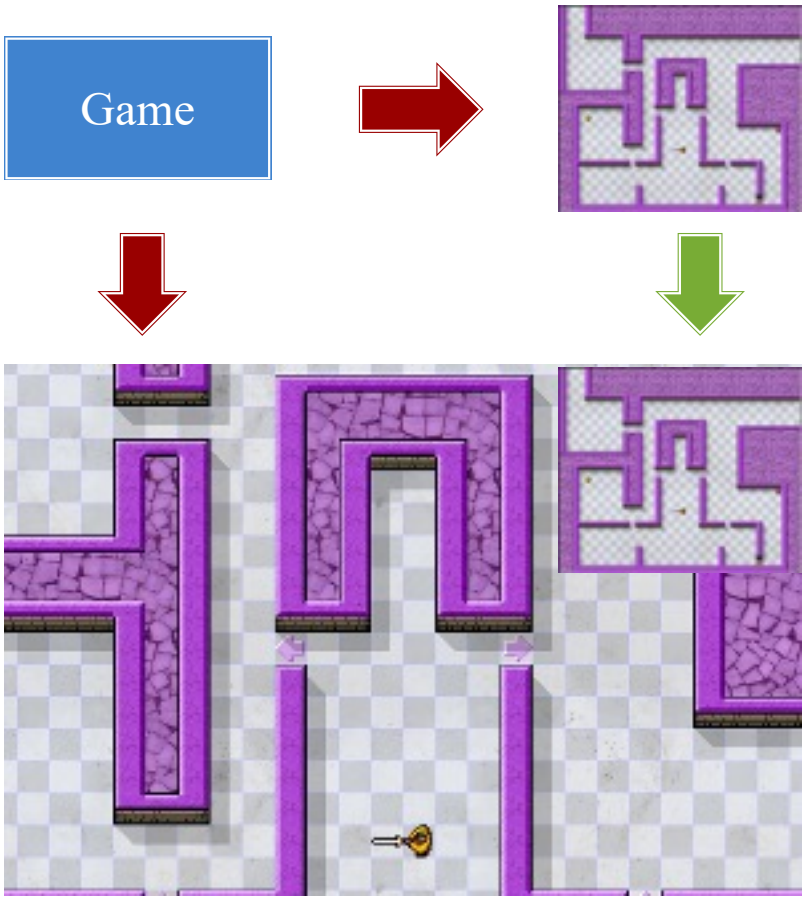
    // Restart the sprite batch
    batch->begin();
}
```

Pipeline and Postprocessing

Pipeline and Postprocessing

Offscreen Rendering

- Can create *dynamic* textures
  - Draw an image to a texture
  - Draw that texture to screen
  - Called *offscreen rendering*
- Applications
  - Mini-maps
  - Scene Transitions
  - Light & Shadow
- Made easy in CUGL
  - Class `FrameBuffer`
  - Uses begin/end pattern



Using the FrameBuffer Class

```
// Set the resolution of the texture
auto target = FrameBuffer::alloc(width, height)

// This indicates this pass if offscreen
batch->begin(target);

...

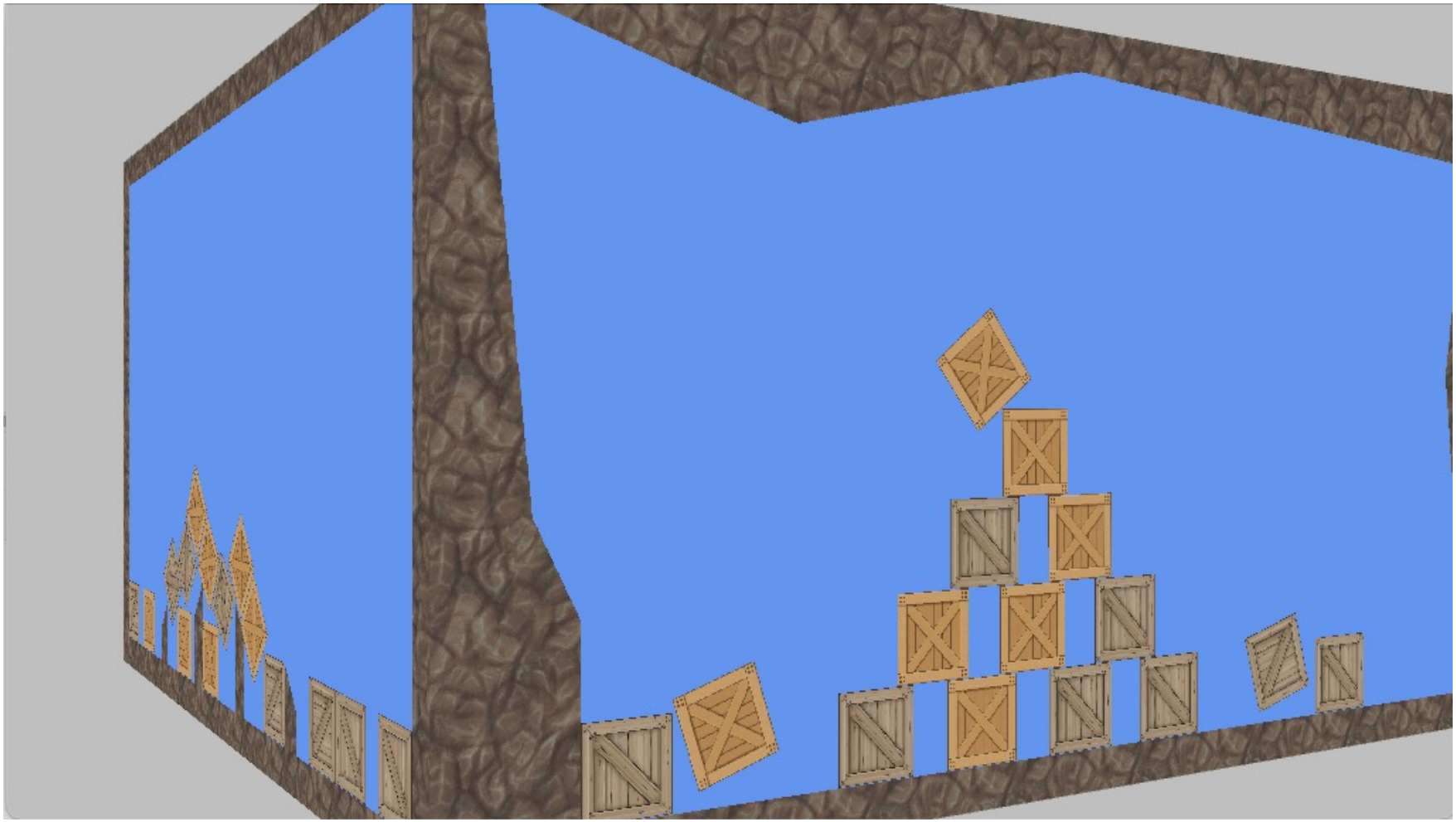
batch->end();

auto texture = target->getTexture();

// Now use texture to draw to screen
```

GraphicsShader **and** SpriteBatch

Example: Cube Transitions

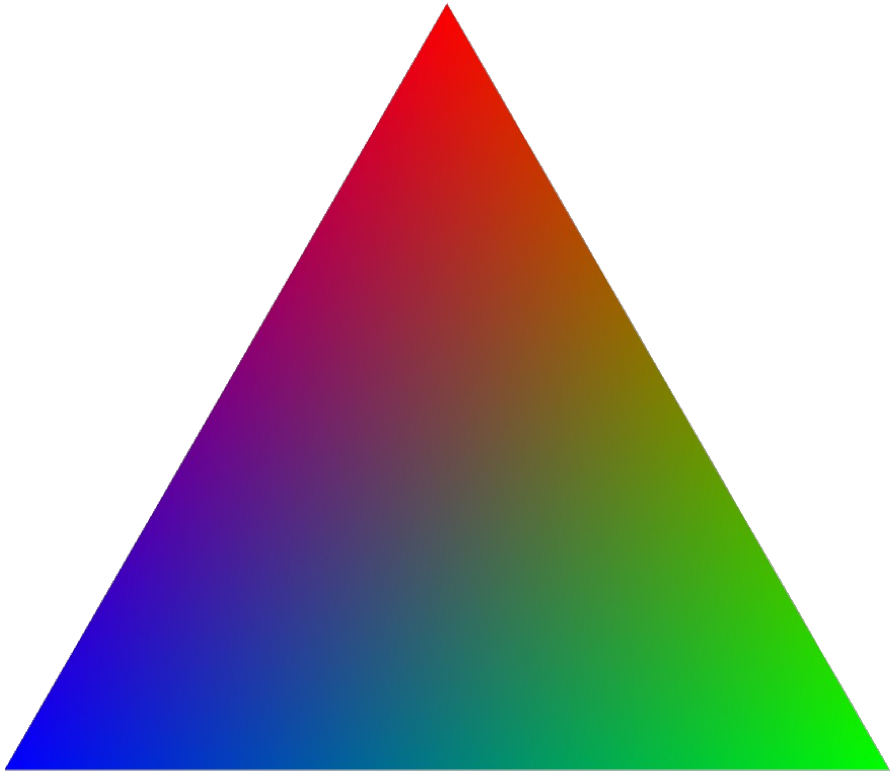


Summary

- Custom shaders require a **separate pipeline**
  - Need a `GraphicsShader` to output to screen
  - Need a `Mesh` to define the geometry
  - Need a `VertexBuffer/IndexBuffer` to pass mesh to shader
  - (Optional) Need a `Texture` to fill in triangles
- Custom pipelines enable postprocessing
  - Use `FrameBuffer` to draw to a texture
  - Create custom `GraphicsShader` to filter texture
- Want more? Take **CS 5625**

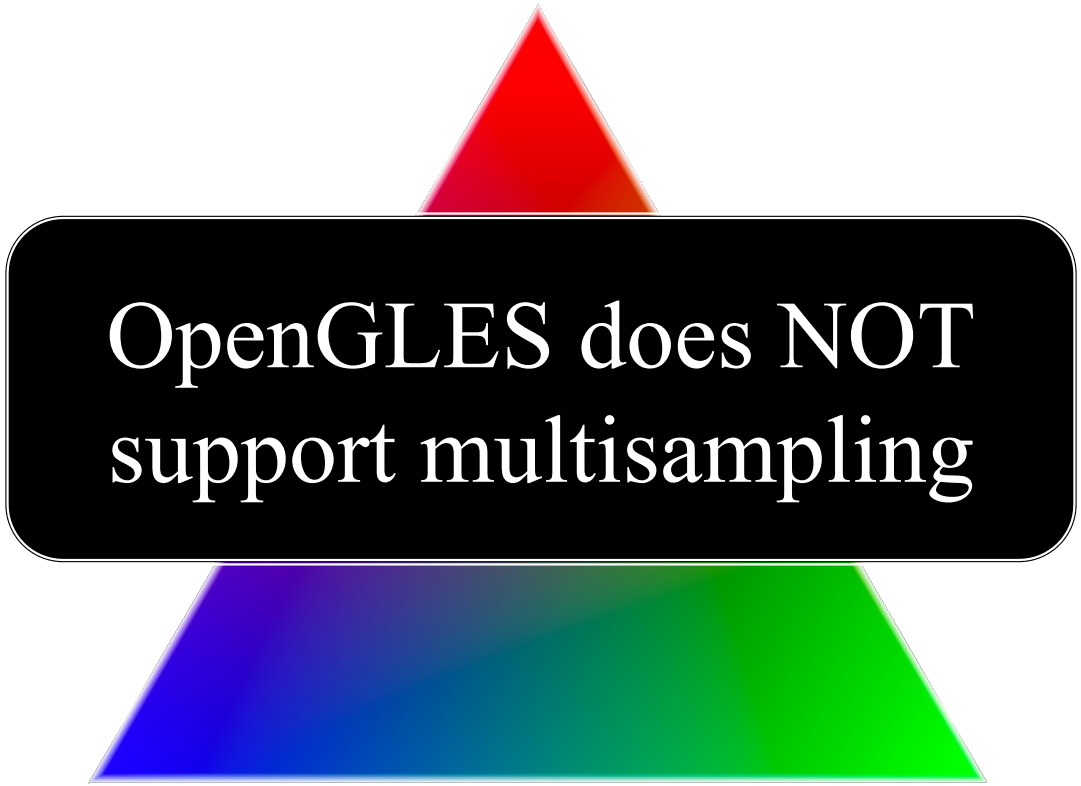
Additional Technique

Triangles Have Hard Edges

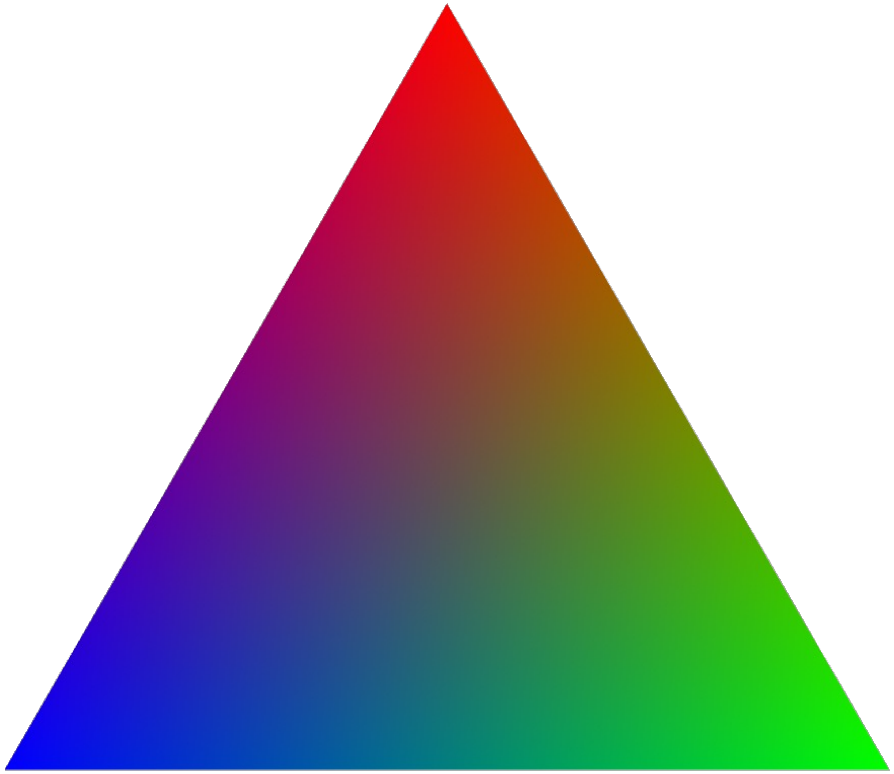


Sometimes Want Softer Edges

Sometimes Want Softer Edges



Extrude The Triangle Boundary



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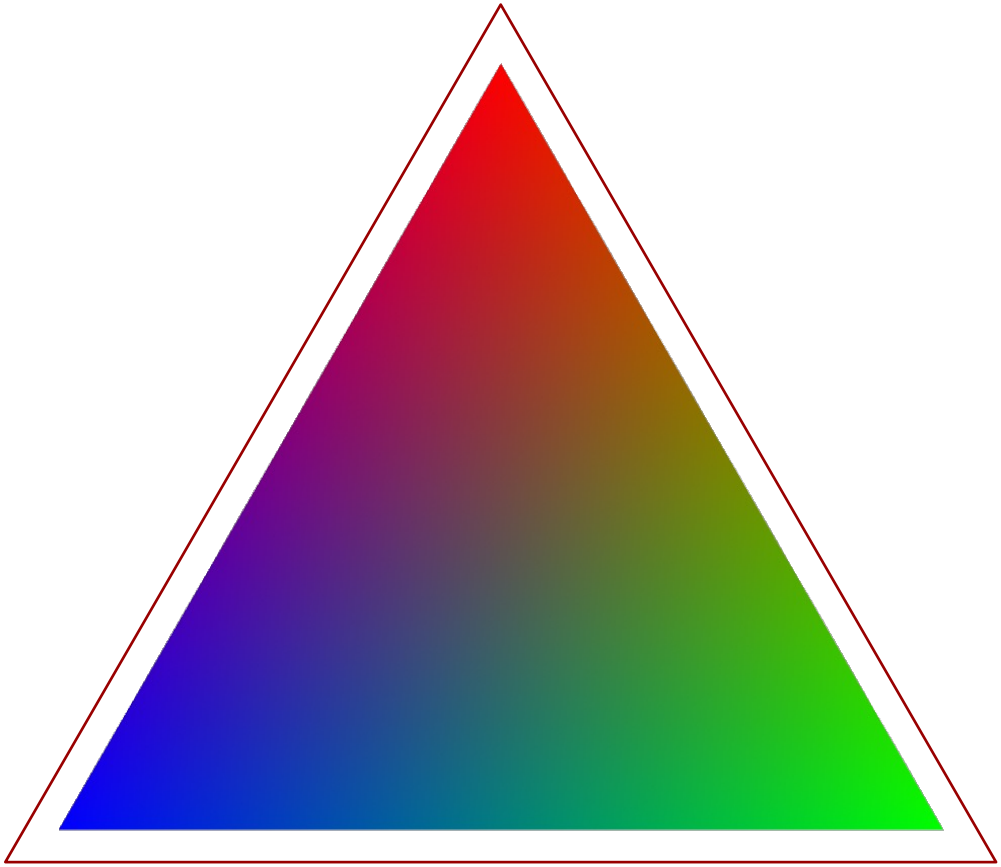
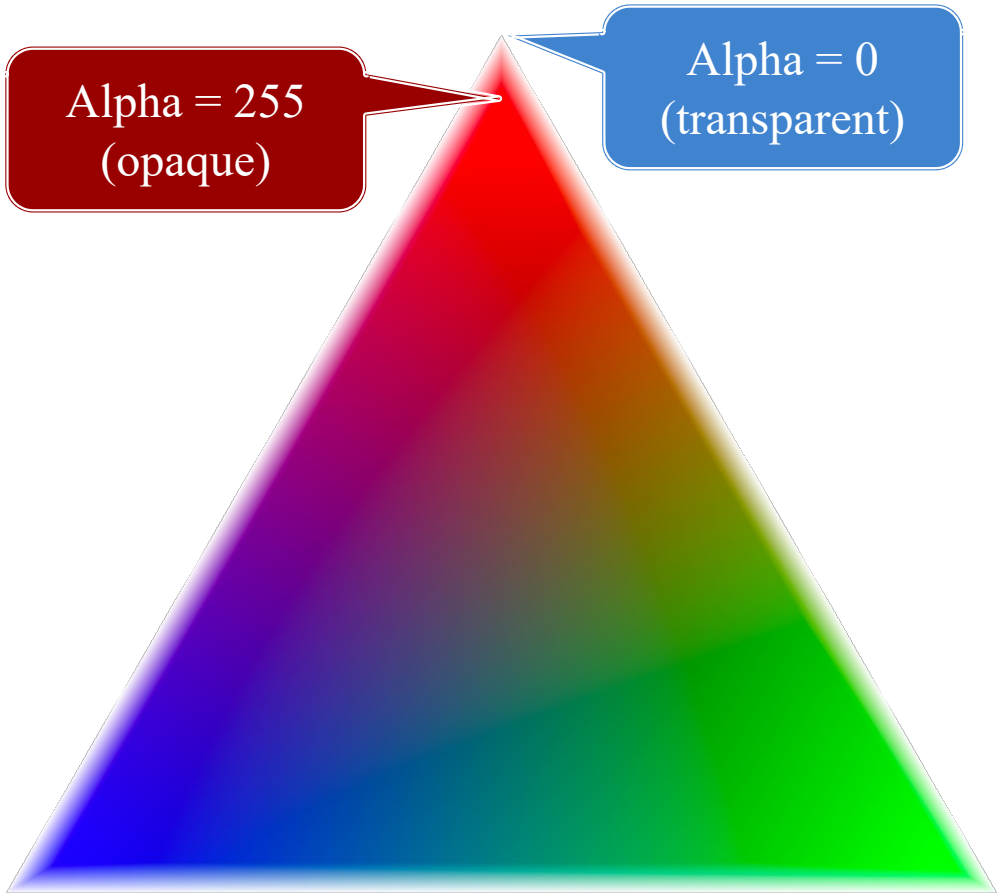


Use Alpha to Fade Out Extrusion



Use Alpha to Fade Out Extrusion