CSE 167:
Introduction to Computer Graphics
Lecture #8: GLSL

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Announcements

- Limited office hours this Thursday: only 3:30-5:30pm

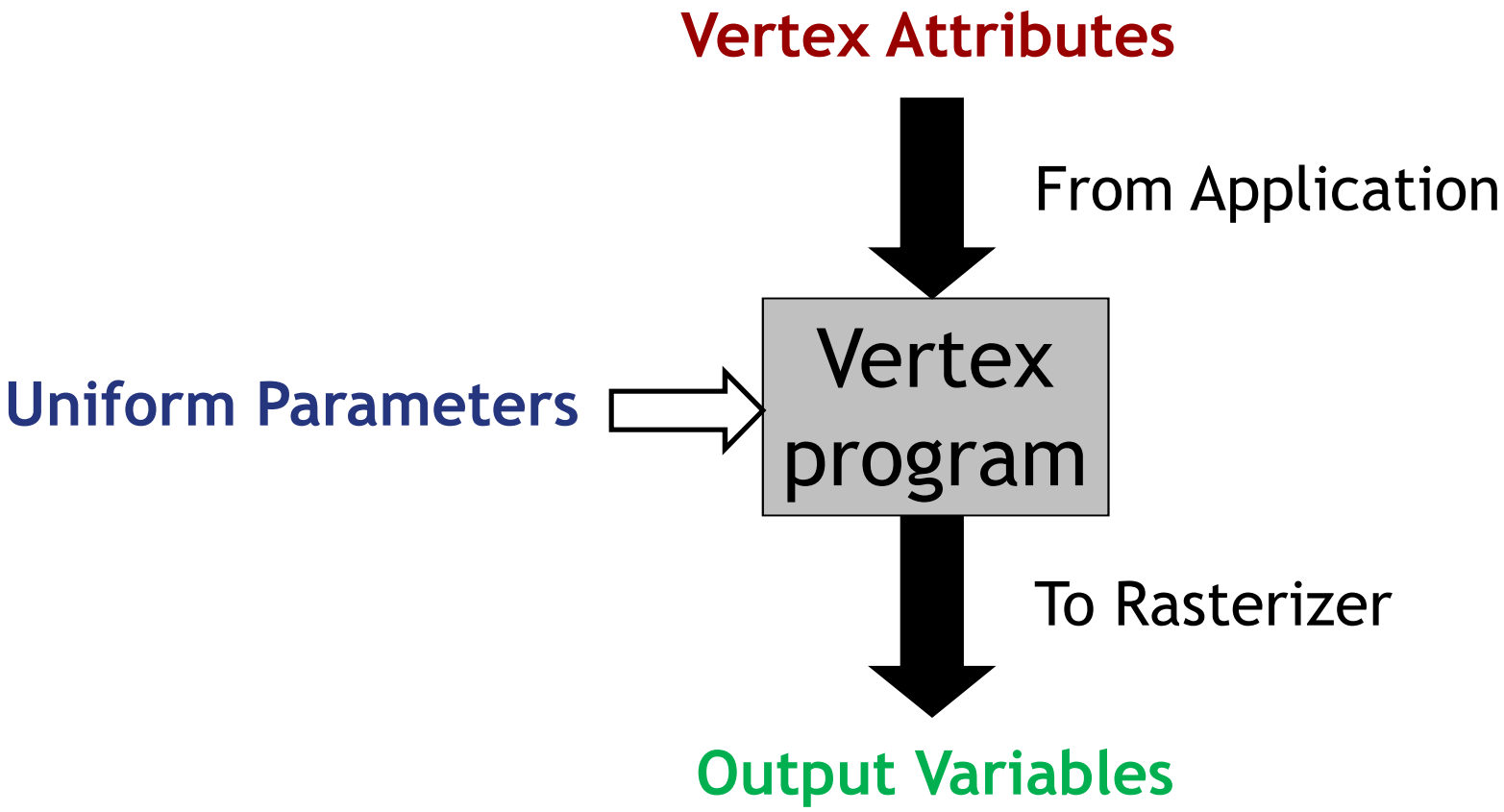
Midterm Exam #1

- This Thursday, Oct 24th
- Location: Center Hall 119
- Time: 2:00pm – 3:20pm
- To bring:
  - Pen/pencil, eraser
  - Ruler
  - Scratch paper
  - Photo ID: put on your table until you got checked off
- Not allowed:
  - Books, written or printed notes, cell phones, other electronic devices

Lecture Overview

- Programmable Shaders
  - Vertex Programs
  - Fragment Programs
  - GLSL

Vertex Programs



Vertex Attributes

- Declared using the `attribute` storage classifier
- Different for each execution of the vertex program
- Can be modified by the vertex program
- Two types:
  - Pre-defined OpenGL attributes. Examples:

```
attribute vec4 gl_Vertex;
attribute vec3 gl_Normal;
attribute vec4 gl_Color;
```

  - User-defined attributes. Example:

```
attribute float myAttrib;
```

Uniform Parameters

- Declared by `uniform` storage classifier
- Normally the same for all vertices
- Read-only
- Two types:
  - Pre-defined OpenGL state variables
  - User-defined parameters

Uniform Parameters: Pre-Defined

- Provide access to the OpenGL state
- Examples for pre-defined variables:

```
uniform mat4 gl_ModelViewMatrix;
uniform mat4 gl_ModelViewProjectionMatrix;
uniform mat4 gl_ProjectionMatrix;
uniform gl_LightSourceParameters
        gl_LightSource[gl_MaxLights];
```

Uniform Parameters: User-Defined

- Parameters that are set by the application
- Should not be changed frequently
  - Especially not on a per-vertex basis!
- To access, use `glGetUniformLocation, glUniform*` in application
- Example:
  - In shader declare
    ```
    uniform float a;
    ```
  - Set value of `a` in application:
    ```
    GLuint p;
    int I = glGetUniformLocation(p,"a");
    glUniform1f(i, 1.0f);
    ```

Vertex Programs: Output Variables

- Required output: homogeneous vertex coordinates
  `vec4 gl_Position`
- **`varying`** output variables
  - Mechanism to send data to the fragment shader
  - Will be interpolated during rasterization
  - Fragment shader gets interpolated data
- Pre-defined `varying` output variables, for example:

```
varying vec4 gl_FrontColor;
varying vec4 gl_TexCoord[];
```

  Any pre-defined output variable that you do not overwrite will have the value of the OpenGL state.
- User-defined `varying` output variables, e.g.:

```
varying vec4 vertex_color;
```

Lecture Overview

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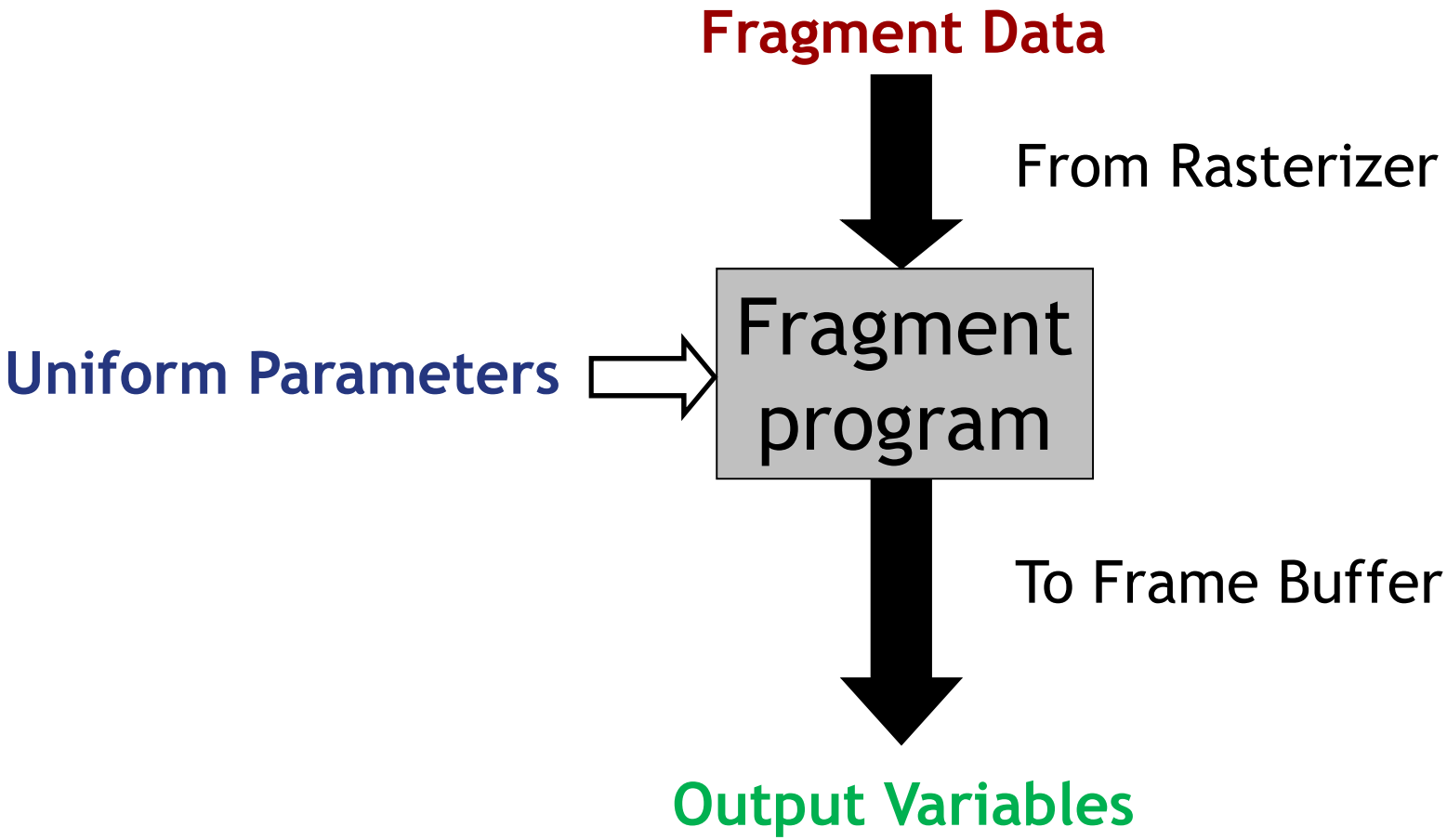
Fragment Programs



Fragment Data

- Changes for each execution of the fragment program
- Fragment data includes:
  - Interpolated standard OpenGL variables for fragment shader, as generated by vertex shader, for example:

```
varying vec4 gl_Color;
varying vec4 gl_TexCoord[];
```

  - Interpolated `varying` variables from vertex shader
    - Allows data to be passed from vertex to fragment shader

Uniform Parameters

- Same as in vertex programs

Output Variables

- Pre-defined output variables:
  - `gl_FragColor`
  - `gl_FragDepth`
- OpenGL writes these to the frame buffer
- Result is undefined if you do not set these variables!

Lecture Overview

- Programmable Shaders
  - Vertex Programs
  - Fragment Programs
  - GLSL

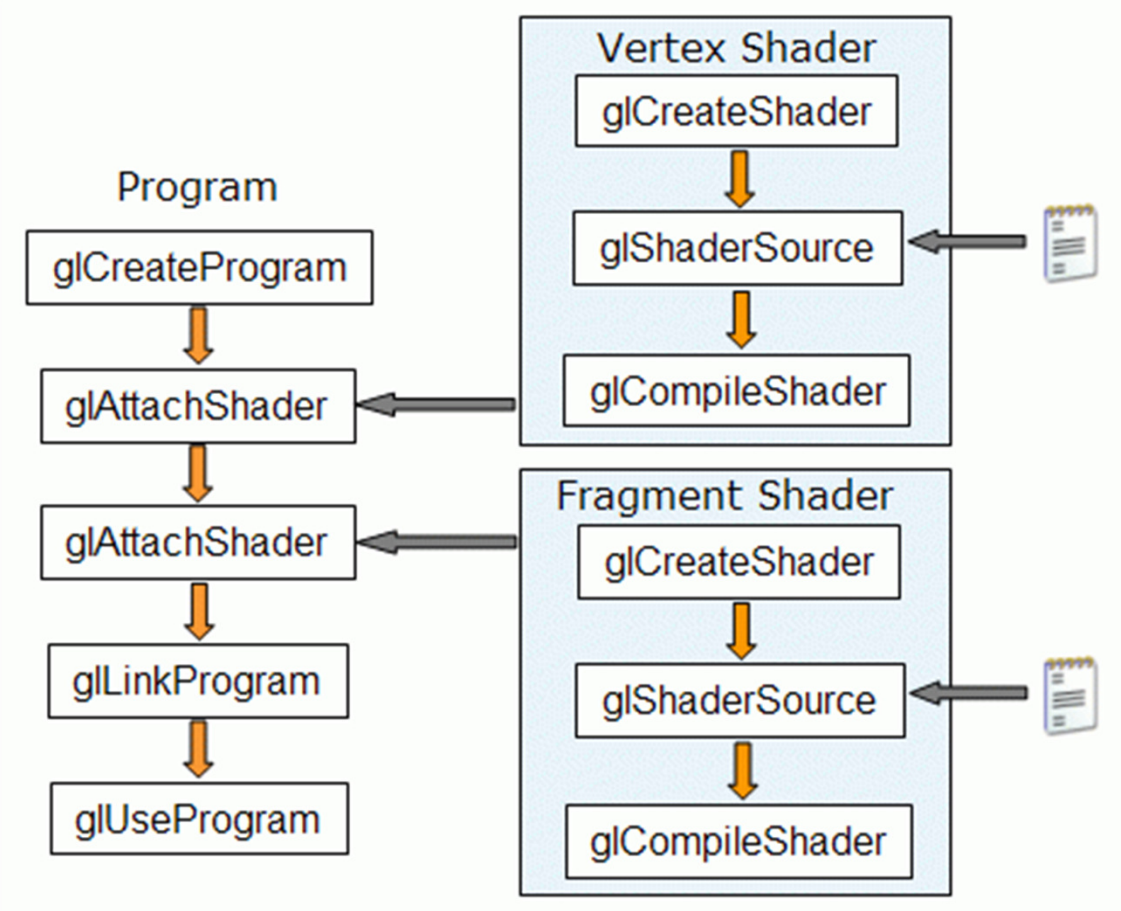
GLSL Main Features

- Similar to C language
- `attribute, uniform, varying` storage classifiers
- Set of predefined variables
  - Access to per-vertex, per-fragment data
  - Access OpenGL state
- Built-in vector data types, vector operations
- No pointers
- No direct access to data or variables in your C++ code

Example: Treat normals as colors

```
// Vertex Shader
varying vec4 color;

void main()
{
  // Treat the normal (x, y, z) values as (r, g, b) color
components.
  color = vec4(clamp(abs((gl_Normal + 1.0) * 0.5), 0.0, 1.0),
1.0);

  gl_Position = ftransform();
}

// Fragment Shader
varying vec4 color;

void main()
{
  gl_FragColor = color;
}
```

Creating Shaders in OpenGL



Source: Gabriel Zachmann, Clausthal University

Video

- OpenGL and GLSL Demo 2
  - http://www.youtube.com/watch?v=cQ8P16X0Op8

Tutorials and Documentation

- OpenGL and GLSL specifications
  - http://www.opengl.org/documentation/specs/
- GLSL tutorials
  - http://www.lighthouse3d.com/opengl/glsl/
  - http://www.clockworkcoders.com/oglsl/tutorials.html
- OpenGL Programming Guide (Red Book)
- OpenGL Shading Language (Orange Book)
- OpenGL 4.4 API Reference Card
  - http://www.khronos.org/files/opengl44-quick-reference-card.pdf

Lecture Overview

- Texture Mapping
  - Overview
  - Wrapping
  - Texture coordinates
  - Anti-aliasing

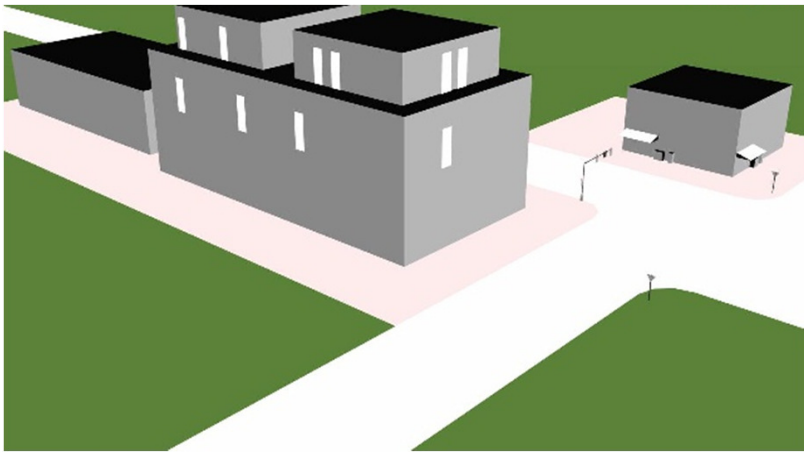
Large Triangles

Pros:

- Often sufficient for simple geometry
- Fast to render

Cons:

- Per vertex colors look boring and computer-generated

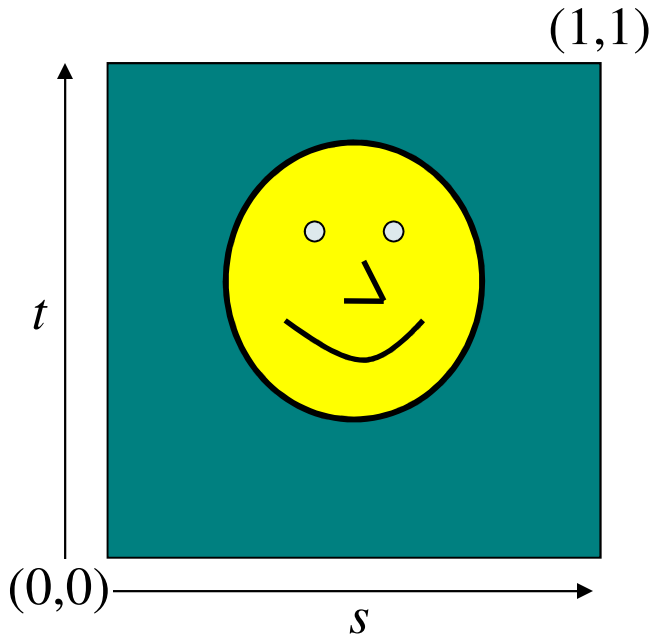


Texture Mapping

- Map textures (images) onto surface polygons
- Same triangle count, much more realistic appearance

Texture Mapping

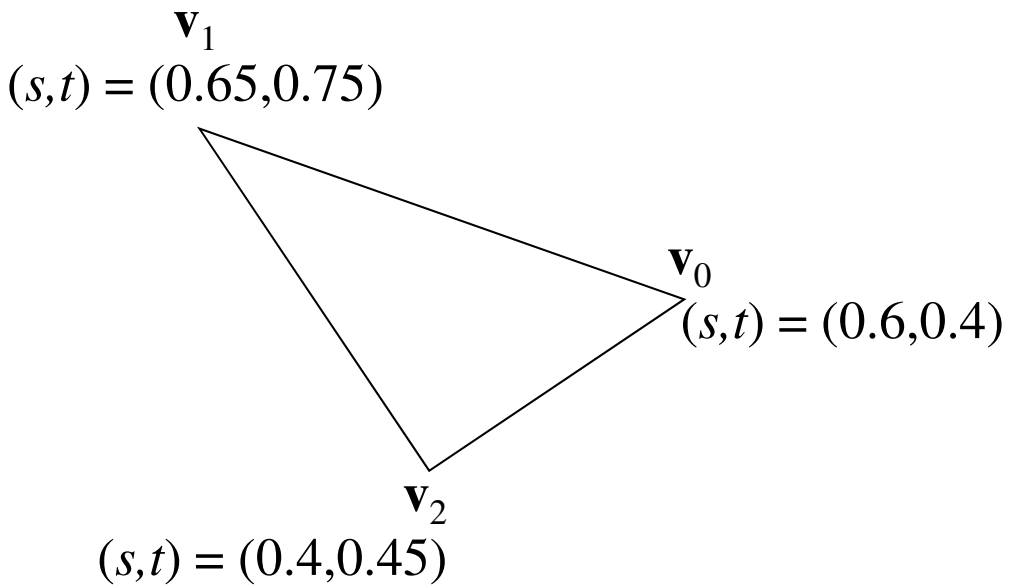
- Goal: map locations in texture to locations on 3D geometry
- Texture coordinate space
  - Texture pixels (texels) have texture coordinates (s,t)
- Convention
  - Bottom left corner of texture is at $(s,t) = (0,0)$
  - Top right corner is at $(s,t) = (1,1)$



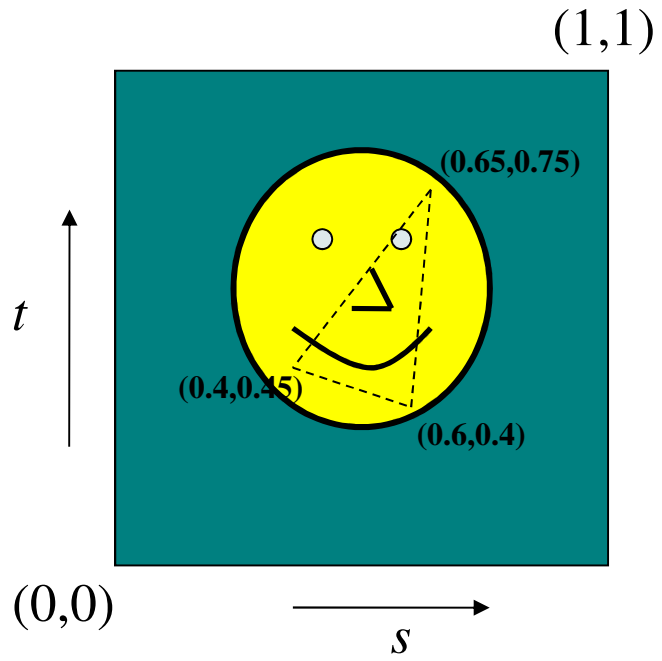
Texture coordinates

Texture Mapping

- Store 2D texture coordinates s,t with each triangle vertex



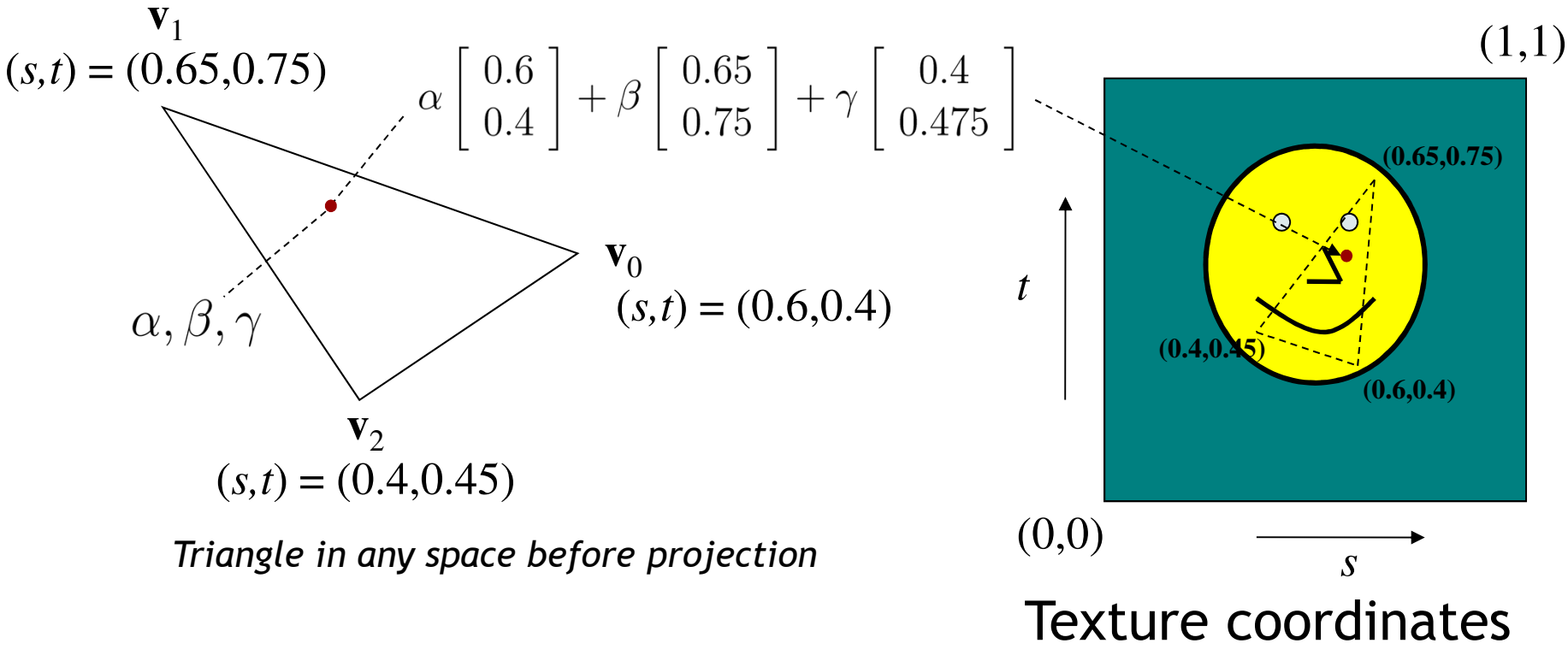
Triangle in any space before projection



Texture coordinates

Texture Mapping

- Each point on triangle has barycentric coordinates α, β, γ
- Barycentric coordinates interpolate texture coordinates
- Done automatically on GPU

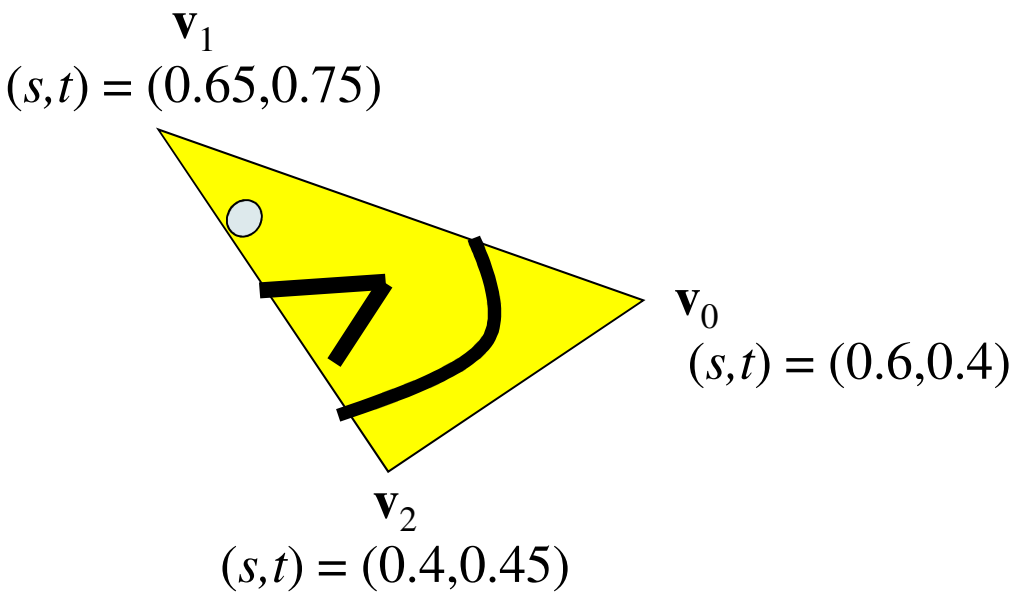


Triangle in any space before projection

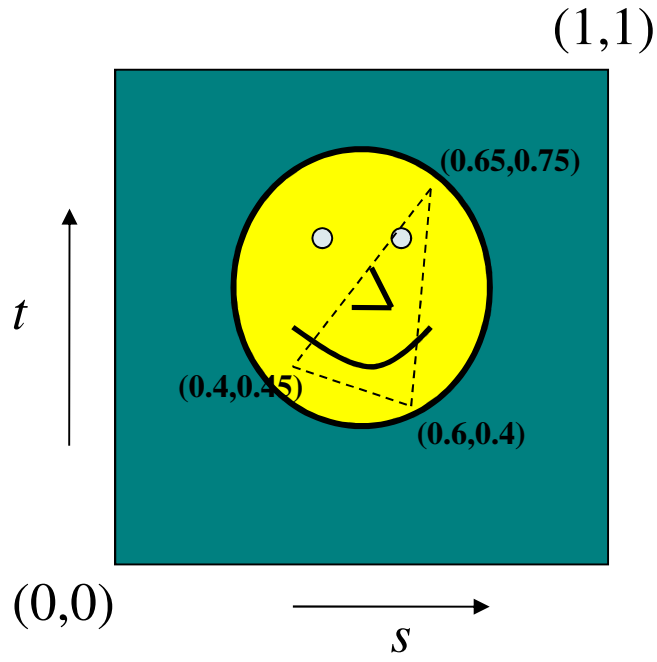
Texture coordinates

Texture Mapping

- Each point on triangle gets color from its corresponding point in texture

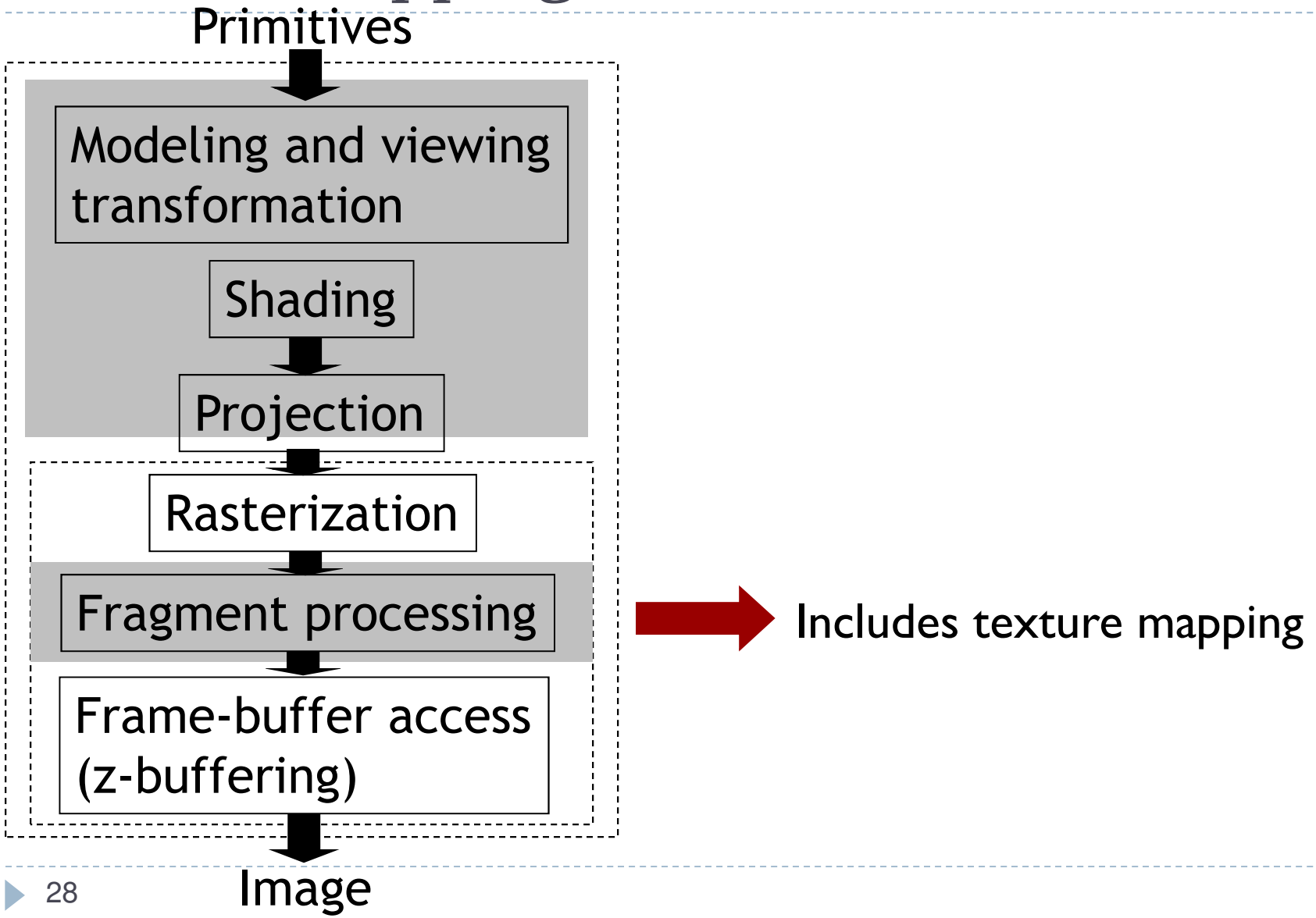


Triangle in any space before projection



Texture coordinates

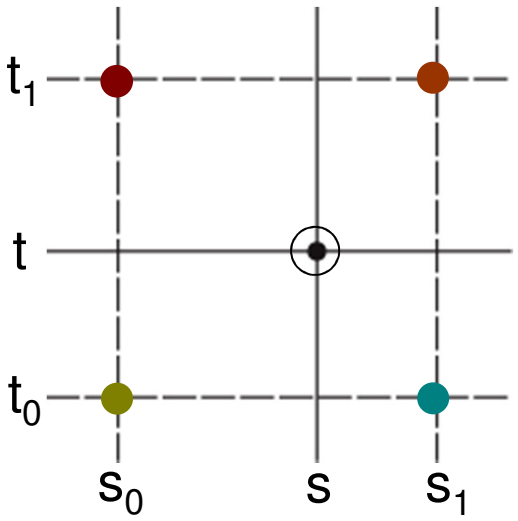
Texture Mapping



Texture Look-Up

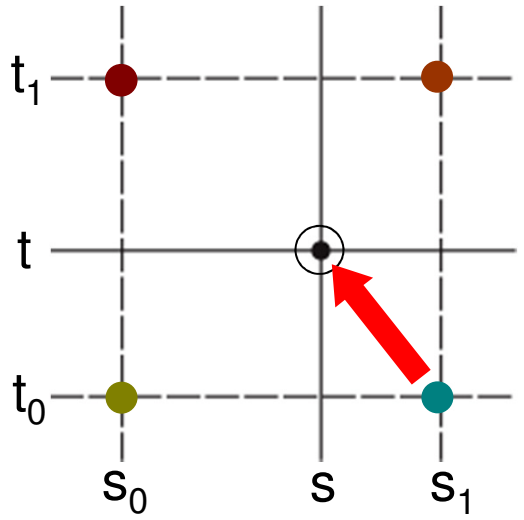
- Given interpolated texture coordinates (s, t) at current pixel
- Closest four texels in texture space are at

  (s_0,t_0), (s_1,t_0), (s_0,t_1), (s_1,t_1)
- How to compute pixel color?



Nearest-Neighbor Interpolation

- Use color of closest texel



- Simple, but low quality and aliasing

Bilinear Interpolation

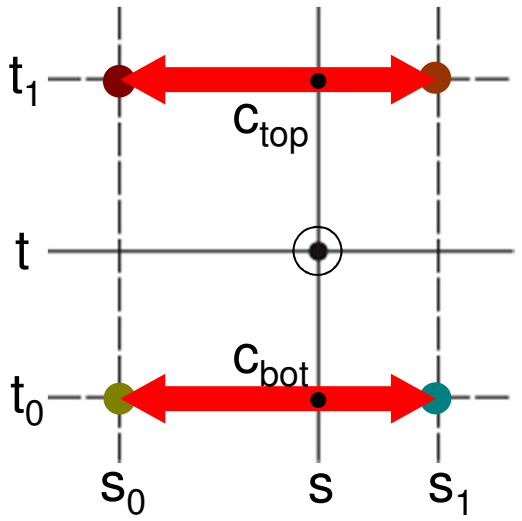
1. Linear interpolation horizontally:

   Ratio in s direction r_s:

$$r_s = \frac{s - s_0}{s_1 - s_0}$$

$c_{top} = tex(s_0,t_1)\ (1-r_s) + tex(s_1,t_1)\ r_s$

$c_{bot} = tex(s_0, t_0)\ (1-r_s) + tex(s_1,t_0)\ r_s$



Bilinear Interpolation

2. Linear interpolation vertically

Ratio in t direction r_t:

$$r_t = \frac{t - t_0}{t_1 - t_0}$$

$c = c_{bot} (1 - r_t) + c_{top} r_t$