VGP351 – Week 6

- Agenda:
  - Quiz #3
  - Texture mapping, part 1

16-November-2011

What is texture mapping?

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What is texture mapping?

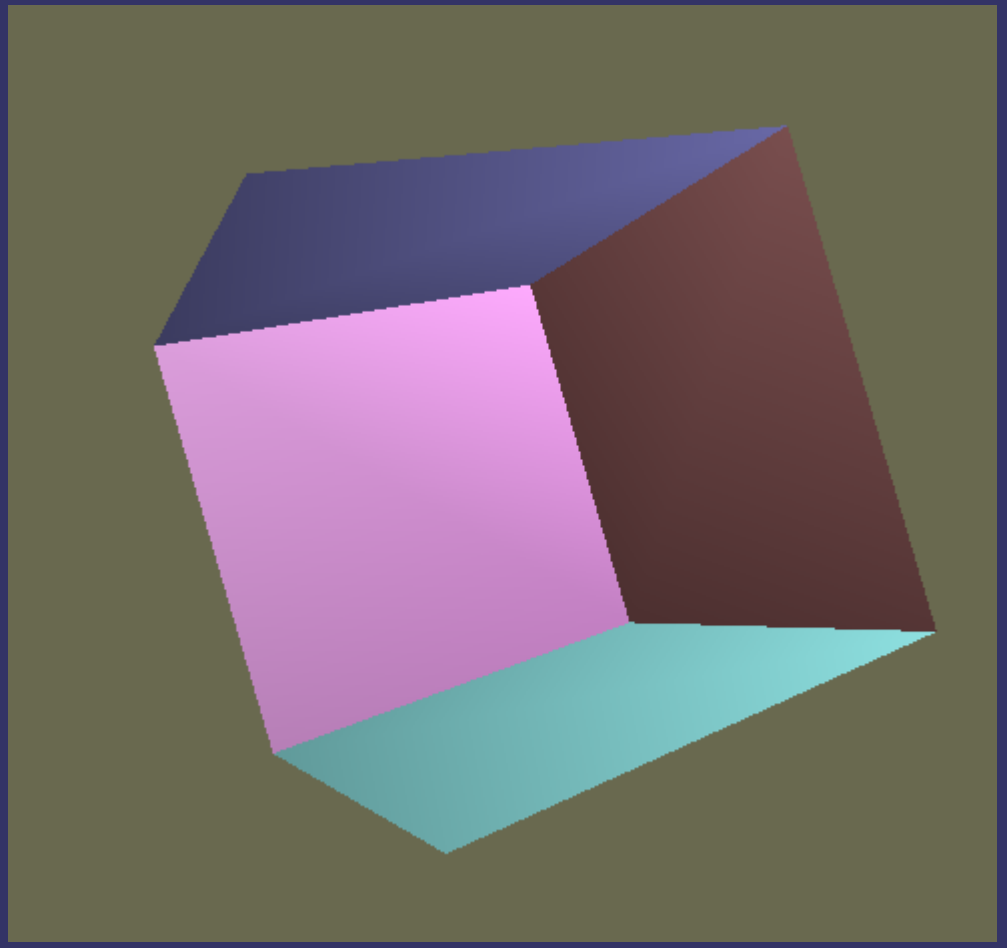
- Classic definition:

  Application of an image to a polygon or 3D model.

Kinds of Images

- Several *dimensionalities* are commonly used:
  - 1D – Usually used as large look-up tables or for color space conversions
  - 2D – Rectangular images...what we usually think of as a texture image
  - 3D (volumetric) – May be used to store voxel type data, volumetric light data, etc.
  - Cubemap (cubic) – 6 square, same-sized textures representing faces of a cube. Often used for environment maps

Texture Mapping



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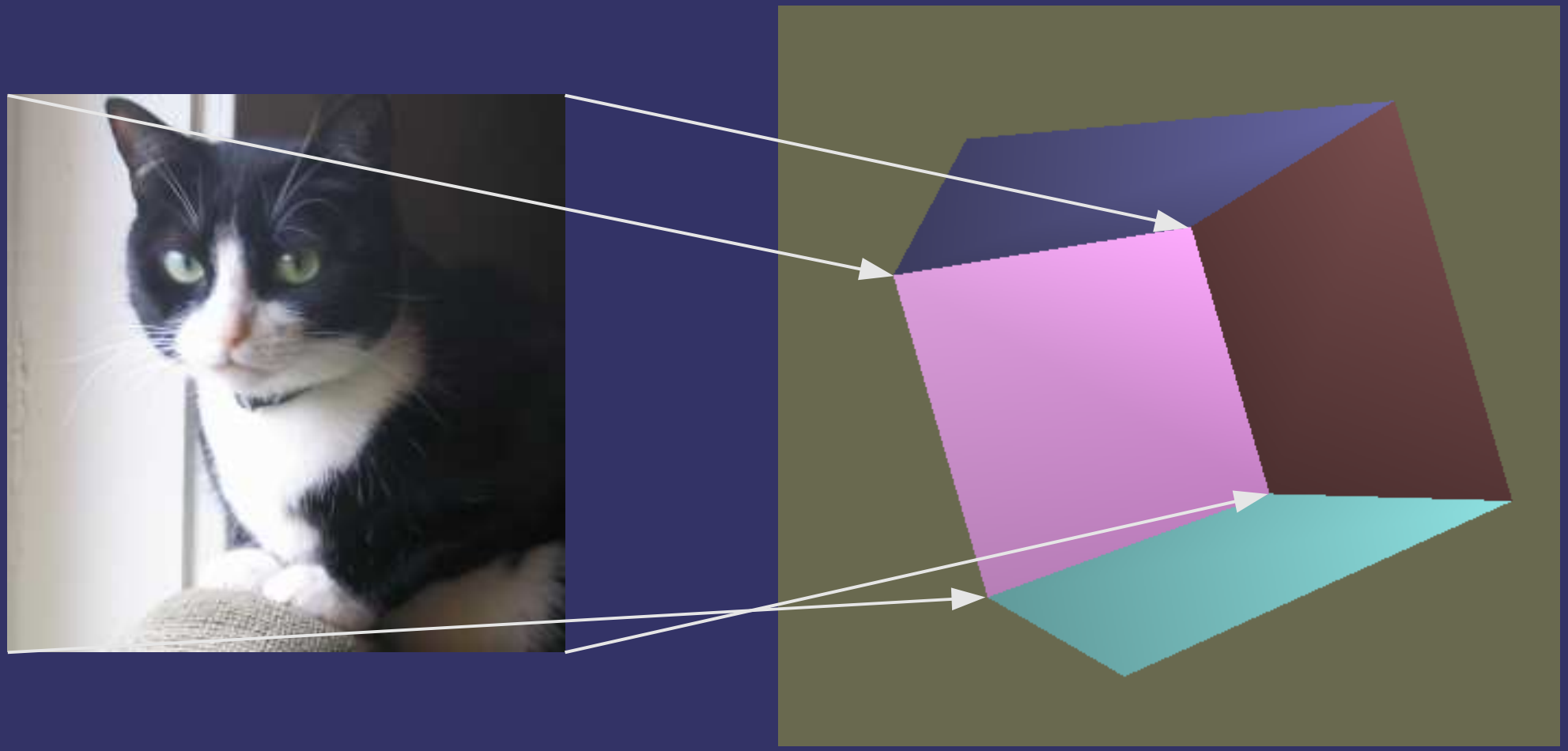
Texture Mapping



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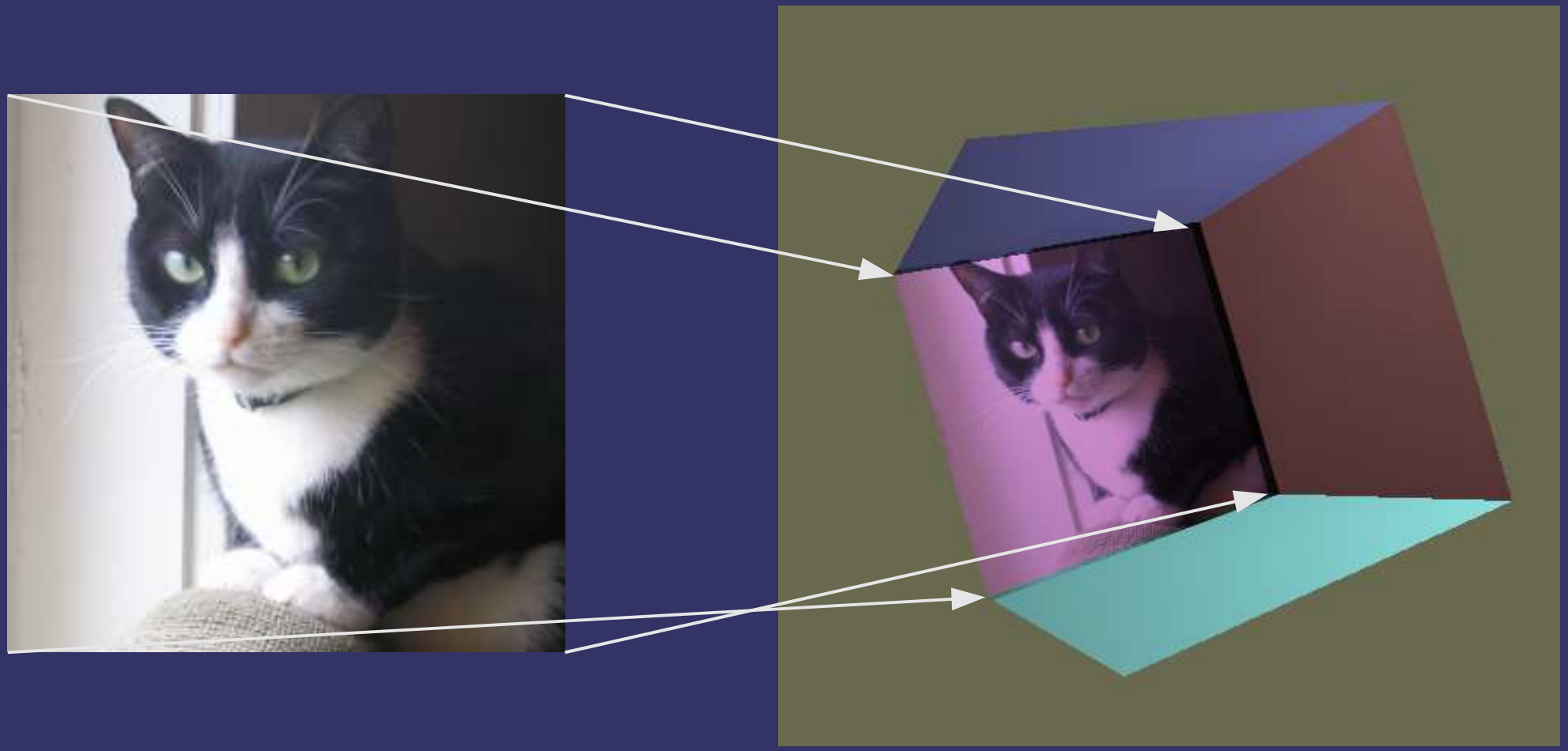
Texture Mapping



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Texture Mapping

- Where does the *mapping* come from?
  - Numerous types of projections
    - Spherical
    - Cylindrical
    - Planar
  - Reflections
  - “Hand” edited coordinates

Cylindrical Mapping

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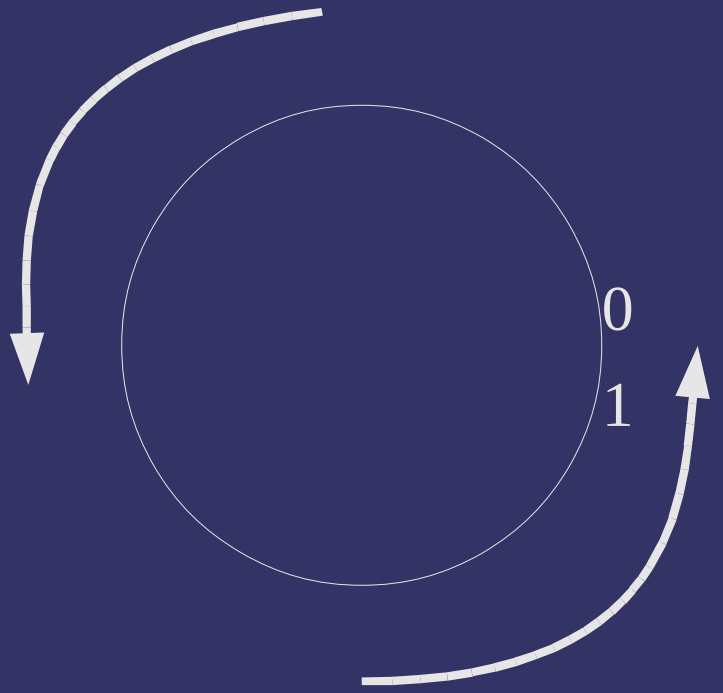
Cylindrical Mapping

1, 0 1, 1

0, 0 1, 0



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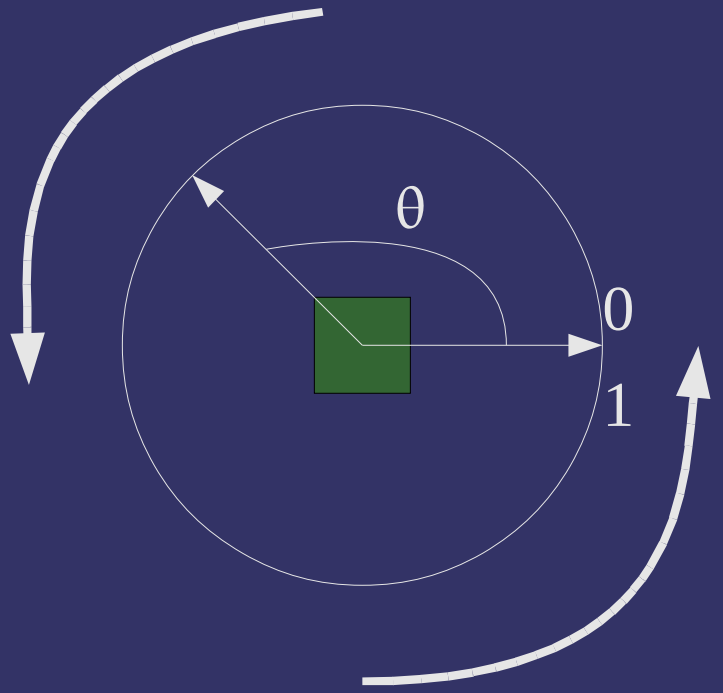
Cylindrical Mapping

1, 0 1, 1

0, 0 1, 0



$u = \theta / 2\pi$

$v = y$

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Cylindrical Mapping

```
vec2 cylinder_map(vec3 position)
{
    vec2 tc;

    tc.s = atan(position.x, position.z) / (2.0 * PI);
    tc.t = position.y;
    return tc;
}
```

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Explicit Texture Coordinates

- Most commonly, texture coordinates are generated by the 3D modeling package
  - These coordinates are stored in the model file, and supplied, by you, to OpenGL

Explicit Texture Coordinates

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  - These coordinates are stored in the model file, and supplied, by you, to OpenGL
  - Coordinates are supplied using vertex shader attributes

Point Sprites

- Special mode for rendering points that automatically generates useful texture coordinates
  - Upper left of point gets (0, 0, 0, 0) and lower right gets (1, 1, 0, 0)
  - Enable in GL with:

```
glEnable(GL_POINT_SPRITE);
```

    - Adds the fragment shader varying `gl_PointCoord`
  - `GL_NV_point_sprite` adds some other controls

Coordinate Interpolation

- Linear interpolation:

$$u_\alpha = (1-\alpha)u_0 + \alpha u_1$$

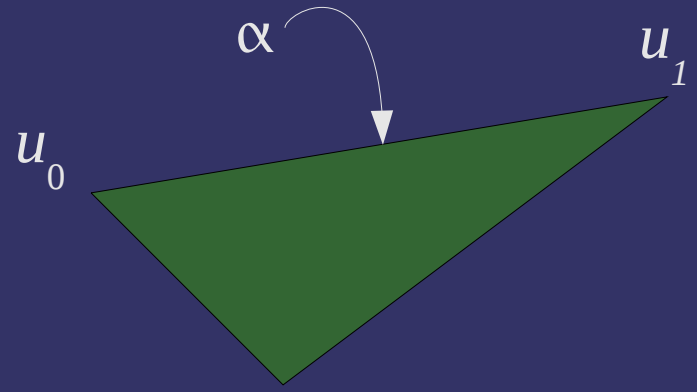

Image from http://wwwx.cs.unc.edu/~sud/courses/236/a6/

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Coordinate Interpolation

- Linear interpolation:

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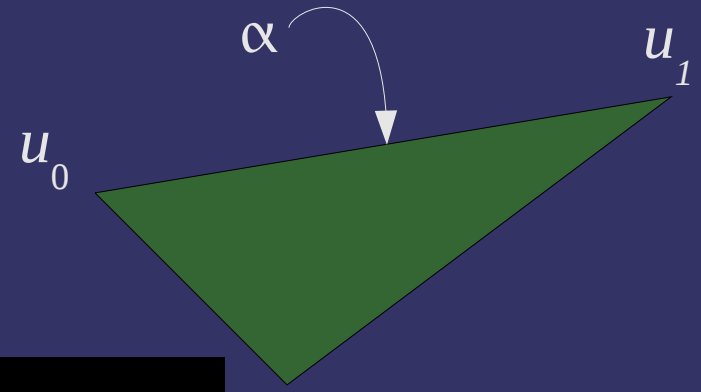

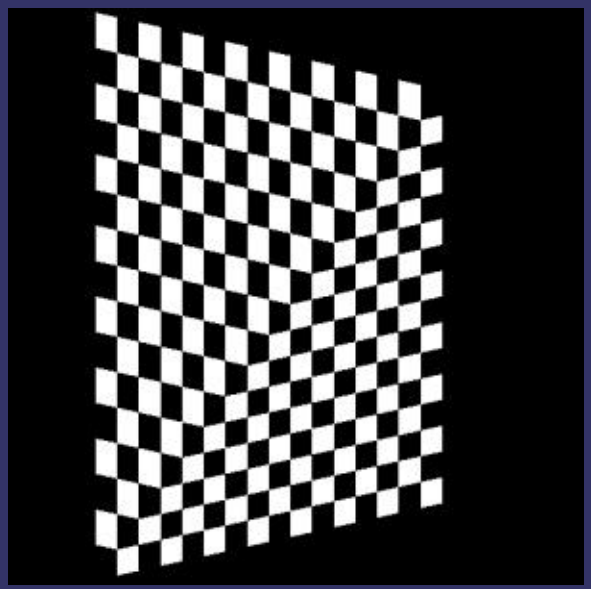

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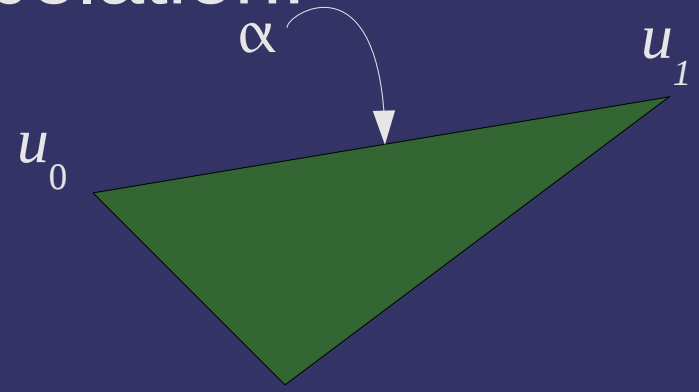
Coordinate Interpolation

- Perspective correct interpolation:

$$u_\alpha = \frac{(1-\alpha)\frac{u_0}{z_0} + \alpha\frac{u_1}{z_1}}{(1-\alpha)\frac{1}{z_0} + \alpha\frac{1}{z_1}}$$



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Coordinate Interpolation

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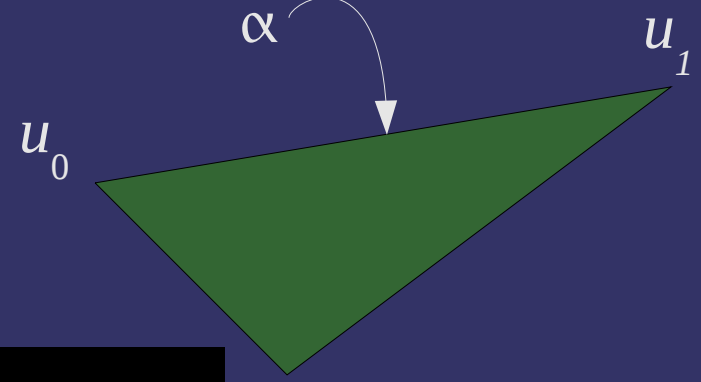

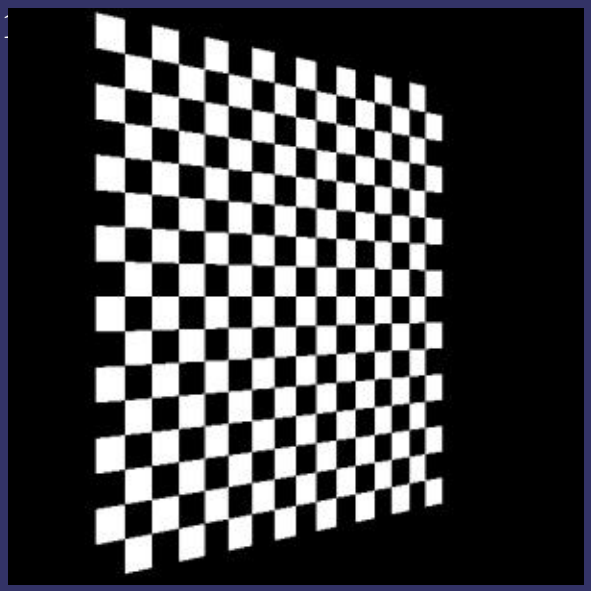

Image from http://wwwx.cs.unc.edu/~sud/courses/236/a6/

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Coordinate Interpolation

- Controllable via interpolation qualifiers

```
#version 130
in vec4 uses_perspective;
noperspective in vec2 uses_linear;
flat in vec3 flat_shaded;
```

  - For `flat`, the value from the last vertex in the primitive is used.

Creating Textures

- In OpenGL, textures are named objects

```
void glGenTextures(GLsizei n,
                   GLuint *textures);

void glDeleteTextures(GLsizei n,
                      const GLuint *textures);
```

- “Bind” a texture for use:

```
void glBindTexture(GLenum target,
                   GLuint texture);
```

  - `target` selects the dimensionality
  - Binding creates the object, but it still has no storage

Creating Textures

- Texture targets:
  - `GL_TEXTURE_1D` – 1D texture
  - `GL_TEXTURE_2D` – 2D texture
  - `GL_TEXTURE_3D` – 3D textures
  - `GL_TEXTURE_RECTANGLE_ARB` – Special kind of 2D texture
  - `GL_TEXTURE_CUBE_MAP` – Cubic texture
    - There are other cubic texture targets. We'll discuss those next week with environment mapping

Creating Textures

- Storage is created and *optionally* initialized with:

```
void glTexImage1D(GLenum target, GLint level,
    GLint internalFormat, GLsizei width,
    GLint border, GLenum format, GLenum type,
    const GLvoid *pixels);
```

  - Variations for 2D and 3D textures also exist
  - 1D textures do not exist in OpenGL ES
- Storage is updated with:

```
void glTexSubImage1D(GLenum target,
    GLint level, GLint xoffset, GLsizei width,
    GLenum format, GLenum type,
    const GLvoid *pixels);
```

Creating Textures

- `format` and `type` describe the source data
  - `format` can be one of: `GL_RED`, `GL_GREEN`, `GL_BLUE`, `GL_ALPHA`, `GL_RGB`, `GL_BGR`, `GL_RGBA`, `GL_BGRA`, `GL_LUMINANCE`, and `GL_LUMINANCE_ALPHA`
    - The last two are removed in OpenGL 3.1
  - With OpenGL 3.0 or `GL_ARB_texture_rg`, `format` can also be one of `GL_RG` or `GL_RED`

Creating Textures

- `format` and `type` describe the source data
  - `type` can be any of the basic type enums (e.g., `GL_UNSIGNED_BYTE`)
  - `type` can be one of the "packed" types:
    `GL_UNSIGNED_SHORT_5_6_5`,
    `GL_UNSIGNED_SHORT_4_4_4_4`,
    `GL_UNSIGNED_SHORT_5_5_5_1`,
    `GL_UNSIGNED_INT_8_8_8_8`
    - There are also `_REV` versions that reverse the ordering of the components
  - A few other uncommon types have been omitted

Creating Textures

- `internalFormat` describes how the texture should be stored
  - `GL_ALPHA`, `GL_ALPHA4`, `GL_ALPHA8`, `GL_ALPHA12`, `GL_ALPHA16`, `GL_LUMINANCE`, `GL_LUMINANCE4`, `GL_LUMINANCE8`, `GL_LUMINANCE12`, `GL_LUMINANCE16`, `GL_LUMINANCE_ALPHA`, `GL_LUMINANCE4_ALPHA4`, `GL_LUMINANCE6_ALPHA2`, `GL_LUMINANCE8_ALPHA8`, `GL_LUMINANCE12_ALPHA4`, `GL_LUMINANCE12_ALPHA12`, `GL_LUMINANCE16_ALPHA16`, `GL_INTENSITY`, `GL_INTENSITY4`, `GL_INTENSITY8`, `GL_INTENSITY12`, `GL_INTENSITY16`, `GL_RGB`, `GL_R3_G3_B2`, `GL_RGB4`, `GL_RGB5`, `GL_RGB8`, `GL_RGB10`, `GL_RGB12`, `GL_RGB16`, `GL_RGBA`, `GL_RGBA2`, `GL_RGBA4`, `GL_RGB5_A1`, `GL_RGBA8`, `GL_RGB10_A2`, `GL_RGBA12`, or `GL_RGBA16`

Creating Textures

- Storage is created and initialized from framebuffer data with:

```
void glCopyTexImage1D(GLenum target,
    GLint level, GLenum internalformat,
    GLint x, GLint y, GLsizei width,
    GLint border);
```

- Storage is updates from framebuffer data with:

```
void glCopyTexSubImage1D(GLenum target,
    GLint level, GLint xoffset,
    GLint x, GLint y, GLsizei width);
```

Texture Units

- A texture unit is the piece of hardware that accesses a texture image
- Many OpenGL texture operations are per-object, but some are per-unit
  - Select the unit with:

```
void glActiveTexture(GLenum texture);
```

Enum is `GL_TEXTURE`*n*, where *n* is unit number

Texture Units

- A texture unit is the piece of hardware that accesses a texture image
- Many OpenGL texture operations are per-object, but some are per-unit
  - Select the unit with:

```
void glActiveTexture(GLenum texture);
```

- Use this API to set per-unit texture objects as well!

Texture Parameters

- Set texture object parameters with:

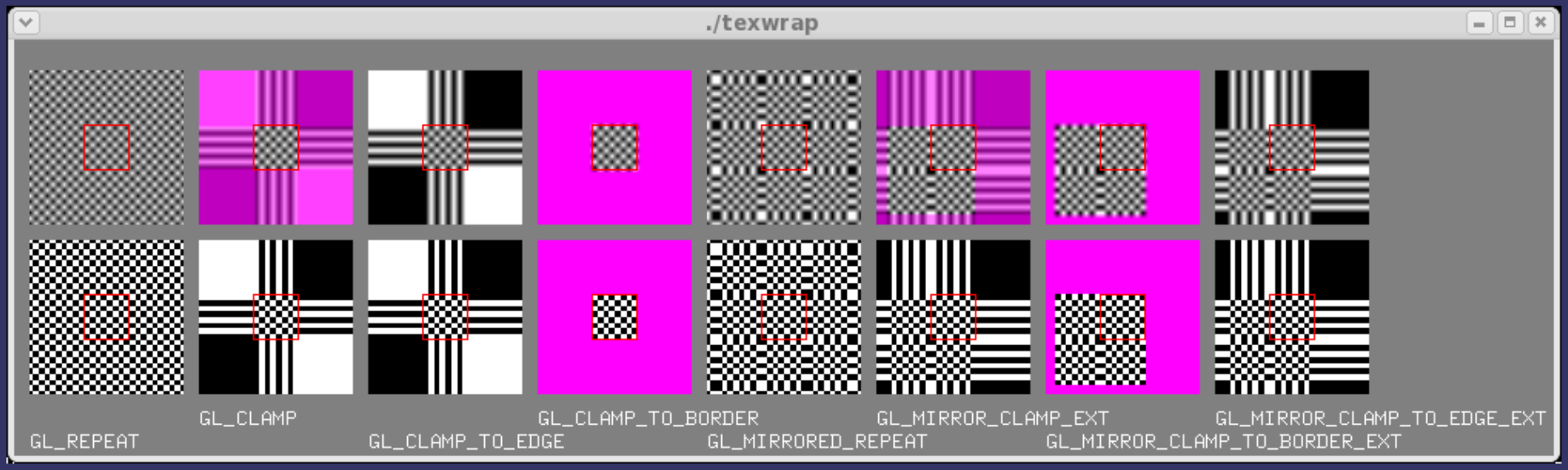
```
void glTexParameteri(GLenum target,
    GLenum pname, GLint param);

void glTexParameteriv(GLenum target,
    GLenum pname, const GLint *params);
```

Texture Wrapping

- Texture images have coordinates on the range [0, 1]
  - What happens if the requested texel coordinate is outside that range?

Texture Wrapping



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Texture Wrapping

- Texture images have coordinates in [0, 1]
  - What happens if the requested texel coordinate is outside that range?
  - It depends on the wrap mode!
- Wrap mode is set independently for each axis
- 8 possible modes
  - Not all implementations support all 8
  - OpenGL 1.5 and later only require 5
  - OpenGL 3.1 and later remove `GL_CLAMP`
  - OpenGL ES 2.0 only has `GL_CLAMP_TO_EDGE`, `GL_REPEAT`, and `GL_MIRRORED_REPEAT`

Texture Wrapping

- Select the wrap mode with `glTexParameter`:

```
glTexParameteri(GL_TEXTURE_2D,
                GL_TEXTURE_WRAP_S,
                GL_CLAMP_TO_BORDER);
glTexParameteri(GL_TEXTURE_2D,
                GL_TEXTURE_WRAP_T,
                GL_REPEAT);
```

Texture Wrapping

- GL_CLAMP, GL_CLAMP_TO_BORDER, and the mirrored versions use a texture “border” color

```
const GLfloat color[4] = {
    0.0, 1.0, 0.0, 1.0
};

glTexParameterfv(GL_TEXTURE_2D,
                 GL_TEXTURE_BORDER_COLOR,
                 color);
```

Samplers

- In GLSL, textures are accessed through special data types called *samplers*
  - There is a sample type for each texture target: `sampler1D`, `sampler2D`, `samplerRect`, `sampler3D`, and `samplerCube`
  - Samplers are uniforms
    - Set the sampler uniform to the number of the texture *unit*

```
sampler_loc = glGetUniformLocation(prog, “tex”);
...
glUniform1i(sampler_loc, 1);
```

Texture Sample Functions

- Textures are accessed using special GLSL functions
  - There is a many variations of these functions
  - The function name must match the sampler type
  - See the GLSL quick reference

http://www.khronos.org/files/opengl-quick-reference-card.pdf

Connecting Textures to Samplers

Texture A

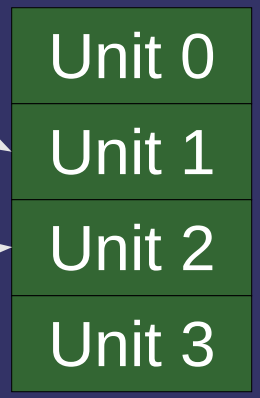
Texture B

Texture C

Texture D

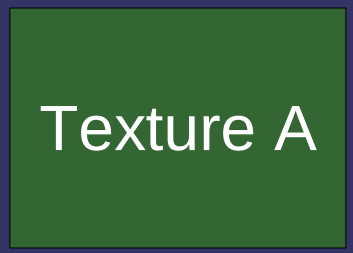
Connect texture with texture unit:

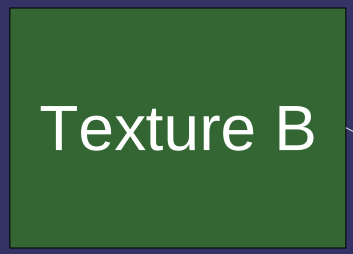
```
glGenTextures(1, &tex_b); glGenTextures(1, &tex_c);
…
glActiveTexture(GL_TEXTURE1);
glBindTexture(GL_TEXTURE_2D, tex_b);
glActiveTexture(GL_TEXTURE2);
glBindTexture(GL_TEXTURE_2D, tex_c);
```

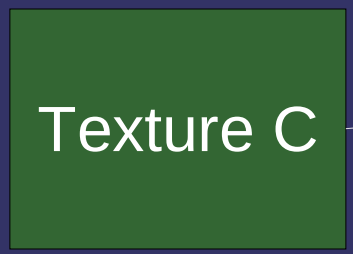


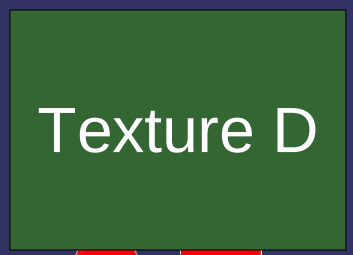

```
#version 130
uniform sampler2D tex;
in vec2 coord;
out vec4 color;

void main()
{
  color = texture(tex, cord);
}
```

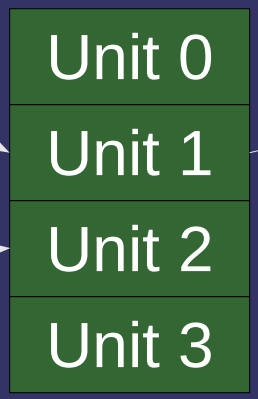
Connecting Textures to Samplers









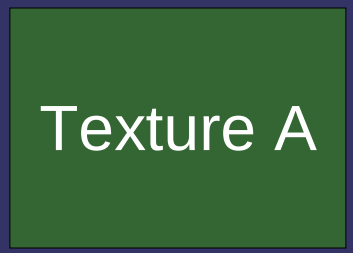


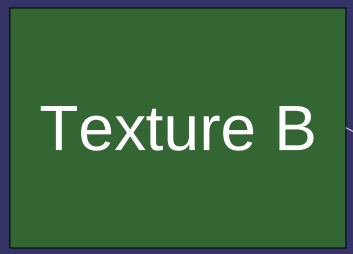

```
#version 130
uniform sampler2D tex;
in vec2 coord;
out vec4 color;

void main()
{
  color = texture(tex, cord);
}
```

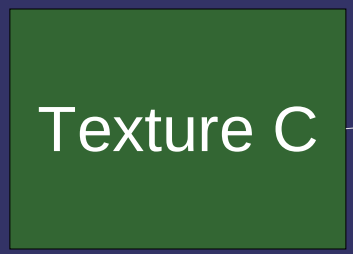
Connect texture unit with sampler:

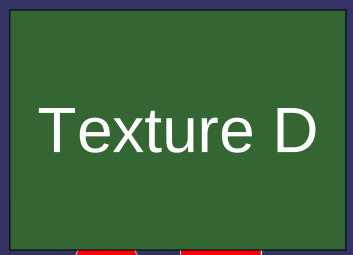
```
tex_loc = glGetUniformLocation(prog, “tex”);
…
glUniform1i(tex_loc, 1);
```

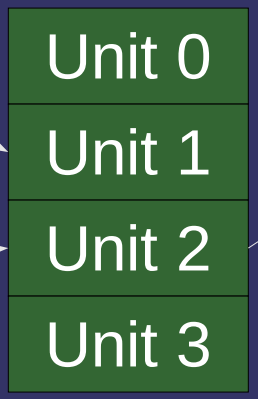
Connecting Textures to Samplers









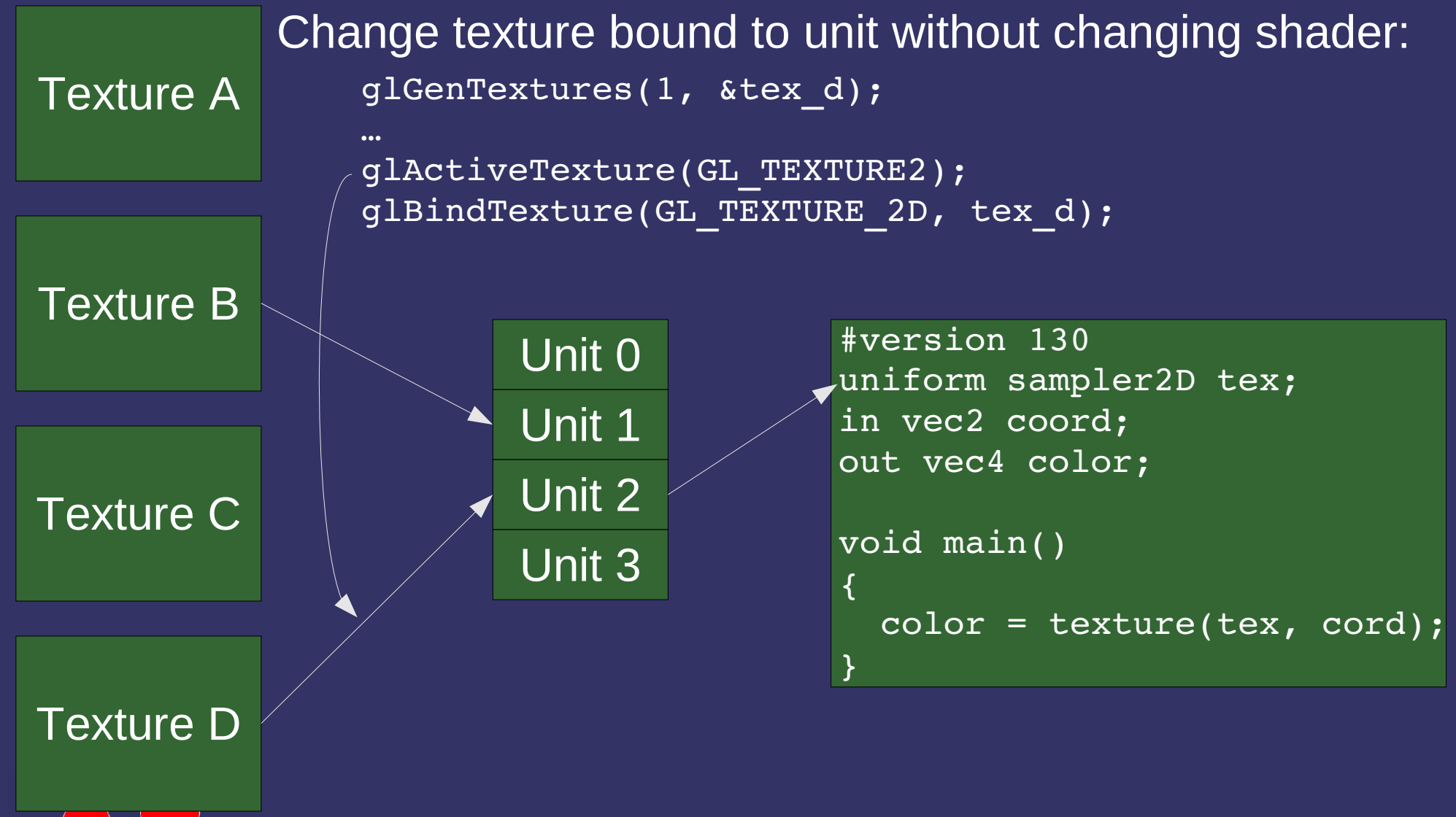



```
#version 130
uniform sampler2D tex;
in vec2 coord;
out vec4 color;

void main()
{
  color = texture(tex, cord);
}
```

Connect different texture unit with sampler:

```
tex_loc = glGetUniformLocation(prog, “tex”);
…
glUniform1i(tex_loc, 2);
```

Connecting Textures to Samplers



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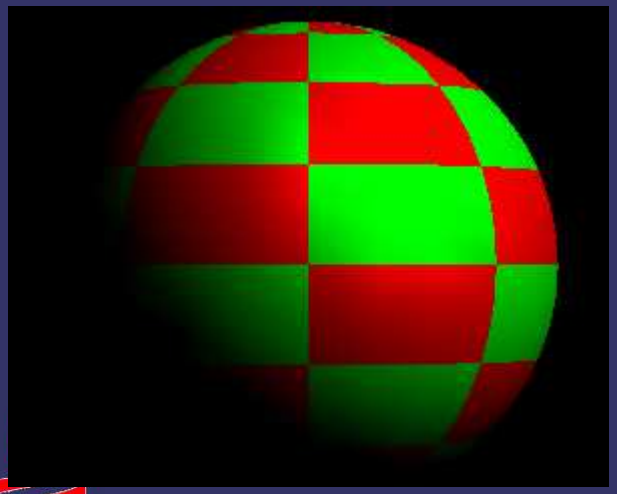
Specular Lighting

- We perform lighting in the vertex shader and texturing in the fragment shader
  - VS passes a single color to FS, and FS combines it with the texture color
  - Why is this wrong?



Specular Lighting

```
uniform sampler2D tex;    // sampler set by C code

varying vec2 tex_coord;   // texture coordinate from
                          // vertex shader

varying vec3 lit_color;   // per-vertex lighting from
                          // vertex shader

void main(void)
{
    gl_FragColor = lit_color
        * texture2D(tex, tex_coord);
}
```

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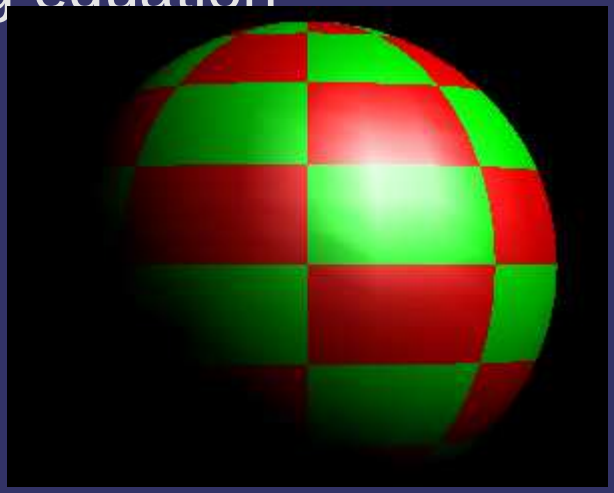
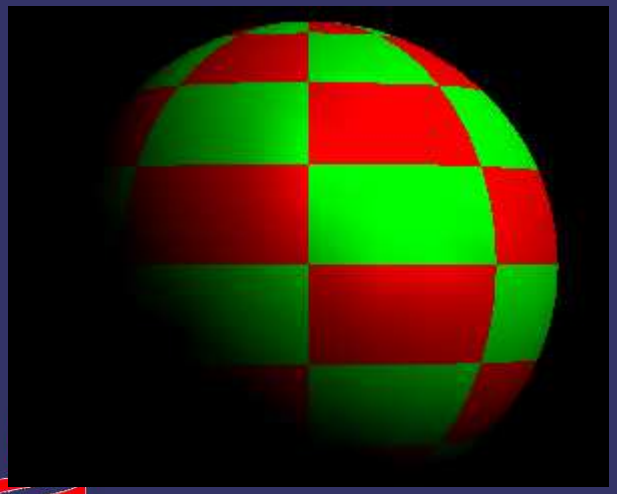
Specular Lighting

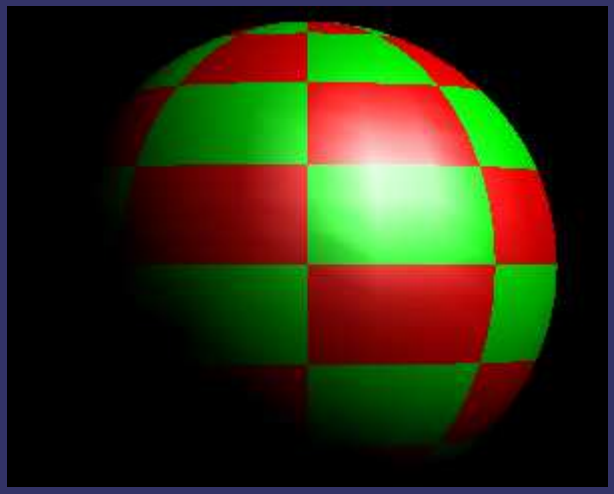
- We perform lighting in the vertex shader and texturing in the fragment shader
  - VS passes a single color to FS, and FS combines it with the texture color
  - Why is this wrong?
  - Texture color is typically a diffuse property
    - It usually supplies C_d in the lighting equation



Specular Lighting

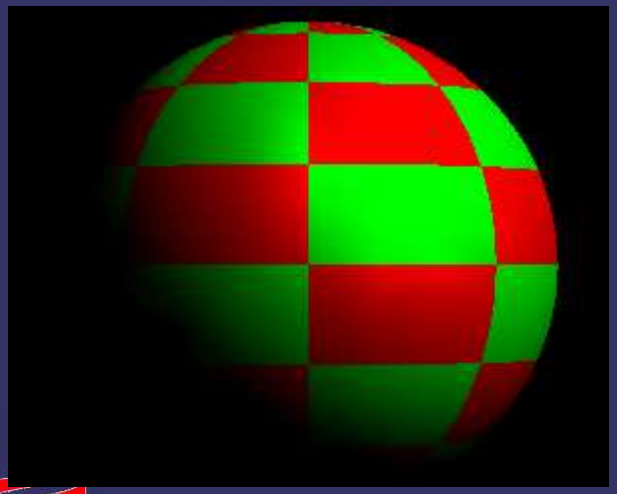
- How can we fix this?

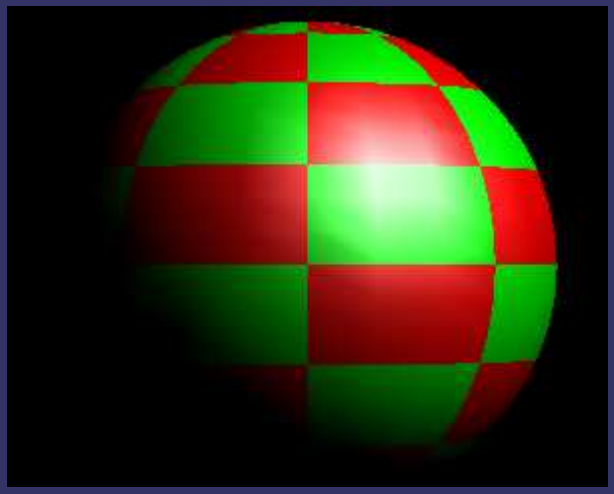




Specular Lighting

- How can we fix this?
  - Perform lighting per-pixel in the fragment shader
  - Send diffuse color and specular color *separately* from the vertex shader to the fragment shader





Specular Lighting

```
uniform sampler2D tex;    // sampler set by C code

varying vec2 tex_coord;   // texture coordinate from
                          // vertex shader

varying vec3 diff_color; // per-vertex diffuse lighting
                          // from vertex shader

varying vec3 spec_color; // per-vertex specular
                          // lighting from vertex shader

void main(void)
{
    gl_FragColor = spec_color
        + (diff_color * texture2D(tex, tex_coord));
}
```

Next week...

- More texture mapping
  - Sampling and filtering

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