# Texture Coordinates

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Textbook Chapter 15

Some slides courtesy of M. Kim, KAIST

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## Today

- Reminders:
  - Assignment 3 due today
  - Midterm 2 coming soon (March 21)
- Assignment 4 introduction
- Cube maps
- Projector maps

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- Assignment 4 demo



## C[3] Survey

- How far along are you with Assignment 3
  a) Not started
  b) Can run template code
  c) Finished at least one part
  d) Finished all fully specified parts (1,2,3)
  e) Finished everything

## $C^3$ Survey

- Assignment 4 will be out soon (tomorrow). It is very useful for understanding texture mapping and studying for midterm 2 on March 21. When should we make Assignment 4 due?
  a) March 19 (2 working days before midterm)
     + makes sure you finish assignment before midterm
     - many of you have lots going on in the next 2 wks
  b) March 25 (2 working days after midterm)
     - some may procrastinate on assignment and hence lose learning opportunity for midterm
     + gives you more time, but … CAVEAT: don't complain that you didn't do the assignment later! Please do at least parts 1-3 before midterm

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## $C^3$ Review: Texture mapping

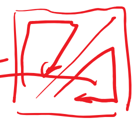
- In which part of the pipeline can you access textures?
  a) In the vertex shader
  b) In the fragment shader
  c) Both of the above
  d) None of the above

## $C^3$ Exercise: Texture mapping

- If the following picture corresponds to the texture coordinates:

```
static GLfloat sqTex[12] = {
        0, 0,
        1, 1,
        1, 0,

        0, 0,
        0, 1,
        1, 1
    };
```



(0,1) (1,1)

(0,0) (1,0)

which picture corresponds to the following?

```
static GLfloat sqTex[12] = {
    0, 0,
    1, 1,
    1, 0,

    0, 0,
    1, 0,
    1, 1
};
```

a)

b)

c)

(d) None of these. It's an error

## More on Texture Coordinates

- Part 1 uses the texture coordinates supplied with the model, generated using a 3rd party program (3DS Max). Similar functions available in Blender, Maya, and other modeling software.
- Legacy OpenGL had a function (glTexGen) to do this, removed from current versions
- In production, coordinates designed with model (or "painted" on 3D model)
- The next two parts show how useful texture coordinates can often be computed in shaders

## Environment cube maps

- Textures can also be used to model the environment in the distance around the object being rendered.
- In this case, we typically use 6 square textures representing the faces of a large cube surrounding the scene.

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## Environment cube maps

- Each texture pixel represents the color as seen along one direction in the environment.
- This is called a *cube map*. GLSL provides a cube-texture data type, samplerCube specifically for this purpose.

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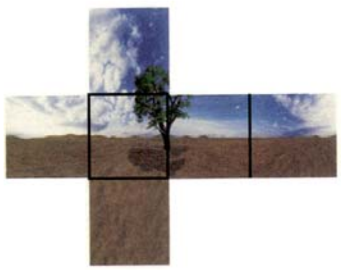
## Environment cube maps

- During the shading of a point, we can treat the material at that point as a perfect mirror and fetch the environment data from the appropriate incoming direction.



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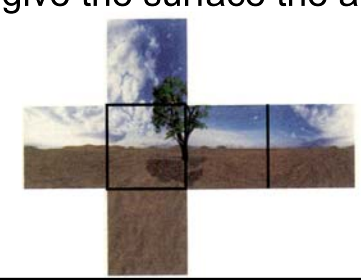
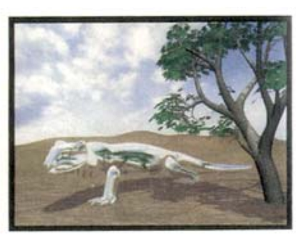
## Environment map shader

- We calculated $B(\vec{v})$ in a previous lecture.
- This bounced vector will point points towards the environment direction, which would be observed in a mirrored surface.
- By looking up the cube map, using this direction, we give the surface the appearance of a mirror.





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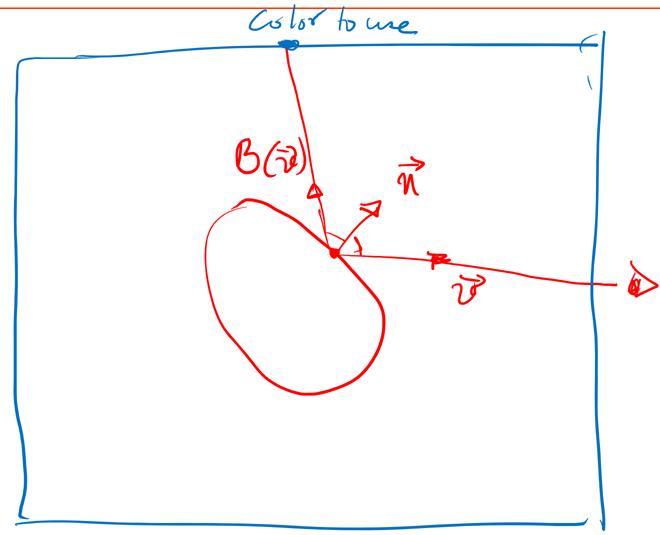
## Geometry of Cube Mapping






## Environment map shader

- Fragment shader

```
#version 330
uniform samplerCube uTexUnit0;
in vec3 vNormal;
in vec4 vPosition;
out vec4 fragColor;

vec3 reflect(vec3 w, vec3 n){
  return n*(dot(w,n)*2.0) - w; // bounce vector
}

void main() {
  vec3 normal = normalize(vNormal);
  vec3 reflected = reflect(normalize(vec3(-vPosition)), normal);
  vec4 texColor0 = textureCube(uTexUnit0, reflected);
  fragColor = vec4(texColor0.r, texColor0.g, texColor0.b, 1.0);;
}
```

From book.
Can also use built in GLSL reflect( )

Note: $B(\vec{w}) = reflect(-\vec{w})$

## Environment map shader

- -vPosition represents the view vector $\vec{v}$
- textureCube is a special GLSL function that takes a direction vector and returns the color stored at this direction in the cube texture map.
- Here we assume eye-coordinates, but frame changes may be needed.

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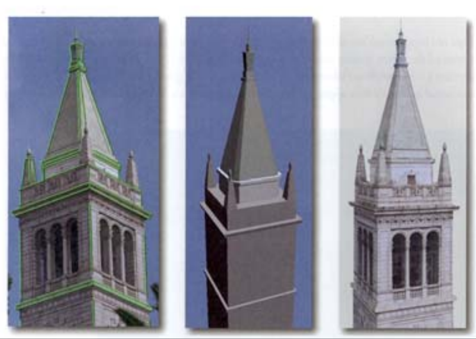
## Projector texture mapping

- There are times when we wish to glue our texture onto our triangles using a *projector* model, instead of the affine gluing model.
- For example, we may wish to simulate a slide projector illuminating some triangles in space.



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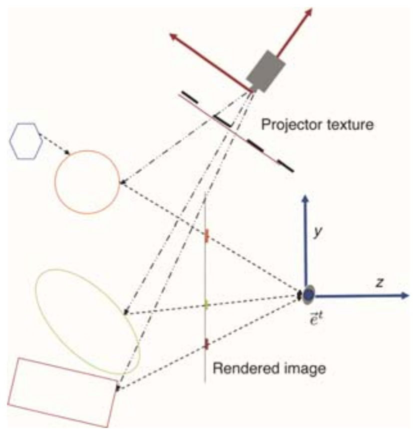
## Geometry of Projector Textures

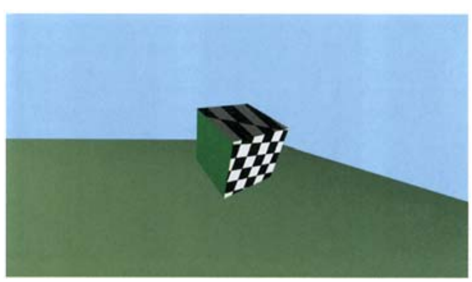





## Projector texture mapping

- The slide projector is modeled using 4 by 4, modelview and projection matrices, $M_s$ and $P_s$

$$\begin{bmatrix} x_t w_t \\ y_t w_t \\ - \\ w_t \end{bmatrix} = P_s M_s \begin{bmatrix} x_o \\ y_o \\ z_o \\ 1 \end{bmatrix}$$



## Projector texture mapping

- With the texture coordinates defined as
  $$x_t = \frac{x_t w_t}{w_t} \text{ and } y_t = \frac{y_t w_t}{w_t}$$
- To color a point on a triangle with object coordinates $[x_o, y_o, z_o, 1]^t$ , we fetch the texture data stored at location $[x_t, y_t]^t$

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## Projector texture mapping

- The three quantities $x_t w_t$, $y_t w_t$ and $w_t$ are all affine functions of $(x_o, y_o, z_o)$ . Thus these quantities will be properly interpolated over a triangle when implemented as varying variables.
- In the fragment shader, we need to divide by $w_t$ to obtain the actual texture coordinates.
- When doing projector texture mapping, we do not need to pass any texture coordinates as attribute variables to our vertex shader.

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## Projector texture mapping

- We simply use the object coordinates already available to us.
- We do need to pass in, using uniform variables, the necessary projector matrices.

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## Projector texture mapping

- Projector vertex shader

```
#version 330

uniform mat4 uModelViewMatrix;
uniform mat4 uProjMatrix;

uniform mat4 uSProjMatrix;
uniform mat4 uSModelViewMatrix;

in vec4 aVertex;
out vec4 vTexCoord;

void main(){
  vTexCoord = uSProjMatrix * uSModelViewMatrix * aVertex;
  gl_Position = uProjMatrix * uModelViewMatrix * aVertex;
}
```

Vertex shader generates texture coordinates! But not normalized

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## Projector texture mapping

- Projector fragment shader

```
#version 330

uniform sampler2D vTexUnit0;

in vec4 aTexCoord;
out vec4 fragColor;

void main(){
  vec2 tex2;
  tex2.x = vTexCoord.x/vTexCoord.w;
  tex2.y = vTexCoord.y/vTexCoord.w;
  vec4 texColor0 = texture2D(vTexUnit0, tex2);
  fragCoor = texColor0;
}
```

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## Projector texture mapping

- Conveniently, OpenGL even gives us a special call texture2DProj(vTexUnit0, pTexCoord), that actually does the divide for us.
- Inconveniently, when designing our slide projector matrix uSProjMatrix, we have to deal with the fact that the canonical texture image domain in OpenGL is the unit square, whose lower left and upper right corners have coordinates $[0,0]^t$ and $[1,1]^t$ used for the display window.

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