VGP353 – Week 2

- Agenda:
  - Introduce shadow maps
    - Differences / similarities with shadow textures
    - Added benefits
    - Potential problems

Shadow Textures

- Shadow textures have a number of faults:
  - Separate texture for each caster / light pair
  - No self-shadowing
  - Difficulty with casters / receivers that are nearly the same distance from the light
- What is the fundamental limitation at the root of all these problems?

Shadow Textures

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  - Separate texture for each caster / light pair
  - No self-shadowing
  - Difficulty with casters / receivers that are nearly the same distance from the light
- What is the fundamental limitation at the root of all these problems?
  - Each shadow texel is a simple on-or-off. The remaining information must be inferred.

Light Visibility

- Calculating shadows is just like view visibility
  - Along a particular ray, can a point, p, see the light?

    vs.
  - Along a particular ray, which point, p, can the camera see?

Light Visibility

- Several ways to calculate visibility:
  - Geometric – BSP trees, etc.
  - Image-space – Depth buffer, etc.

Light Visibility

- Remember the multi-pass rendering problem:
  - Draw an object
  - Draw the object again, but combine (blend) the new rendering with the old rendering
    - How can we only draw the second pass to pixels where the first pass was visible?

Light Visibility

- Remember the multi-pass rendering problem:
  - Draw an object
  - Draw the object again, but combine (blend) the new rendering with the old rendering
    - How can we only draw the second pass to pixels where the first pass was visible?
    - Change the depth test function to `GL_EQUAL` or `GL_LEQUAL` and take steps to ensure the vertices are transformed in an identical manner.

Light Visibility

- Note the similarity with the shadow texture problem!
  - A pixel is not in shadow if it's the point in space as the point in the shadow map
  - All other pixels along that light ray are occluded and are in shadow

Shadow Maps

- Use the depth buffer from the shadow texture generation pass
  - Compare the distance read from the shadow map to the distance between the object and the light

$$\begin{cases} d_{object} \leq d_{shadow} & \text{Not in shadow} \\ \text{otherwise} & \text{In shadow} \end{cases}$$

  - The color buffer from the shadow texture generation pass is no longer needed

Shadow Textures vs. Shadow Maps

- Shadow texture:
  - Draw either light color or shadow color to a color texture
  - Read light color directly from shadow texture
  - Color fragment based on light color
- Shadow map:
  - Draw distance to nearest object to a depth texture
  - Compare occluder distance to object distance
  - Color fragment based on result of comparison

Shadow Maps

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Shadow Maps

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  - Objects can self-shadow!
  - Near-by objects can shadow each other correctly
- Disadvantages:
  - Aliasing problems
    - Even more than shadow textures
  - More memory usage
  - Omni-directional lights inside the view frustum

Shadow Maps

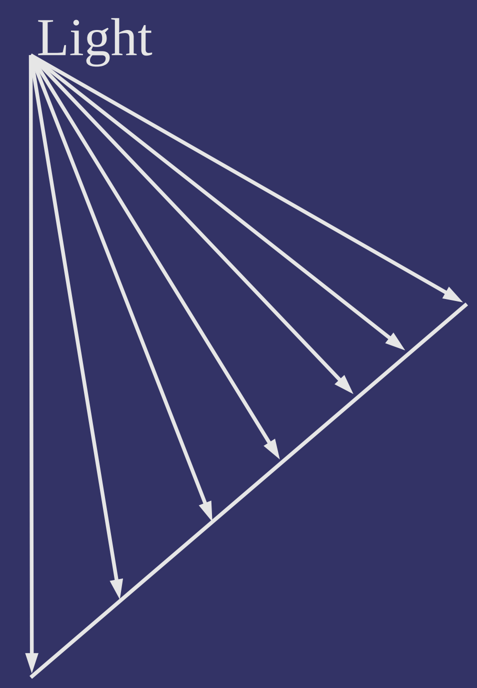
- Algorithm:
  - Group potential casters
  - Calculate frustum that encompasses all objects within a group
  - Render objects using calculated frustum
    - Store depth buffer in a texture (shadow map)
  - Render objects from the camera's PoV with appropriate shadow map
    - Use comparison previously described

Shadow Map Problems

- Four big problems with shadow maps:
  - Sampling differences between shadow map rendering and reading...the dreaded “shadow acne”
  - Aliasing
  - Lack of depth precision
  - Omni-directional lights inside the view frustum

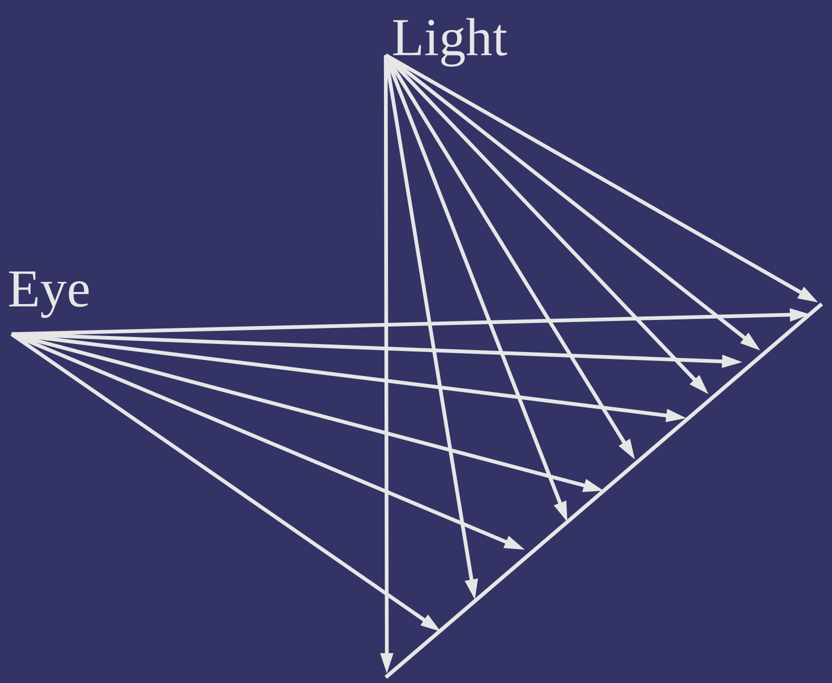
Shadow Acne

- Light and camera sample object at different positions
  - Drawing from the light's PoV samples one set of positions



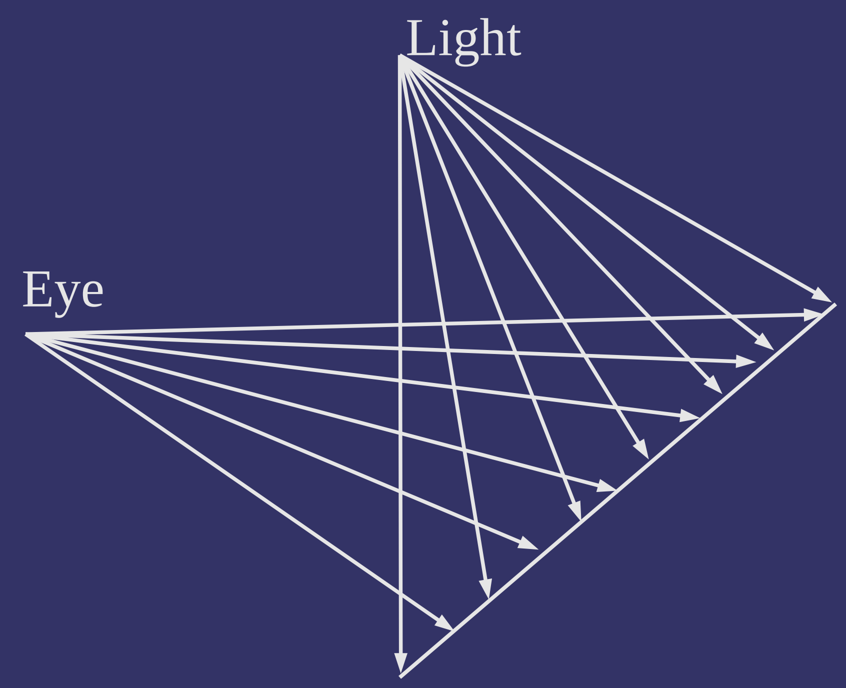
Shadow Acne

- Light and camera sample object at different positions
  - Drawing from the light's PoV samples one set of positions
  - Drawing from the camera's PoV samples a different set of positions

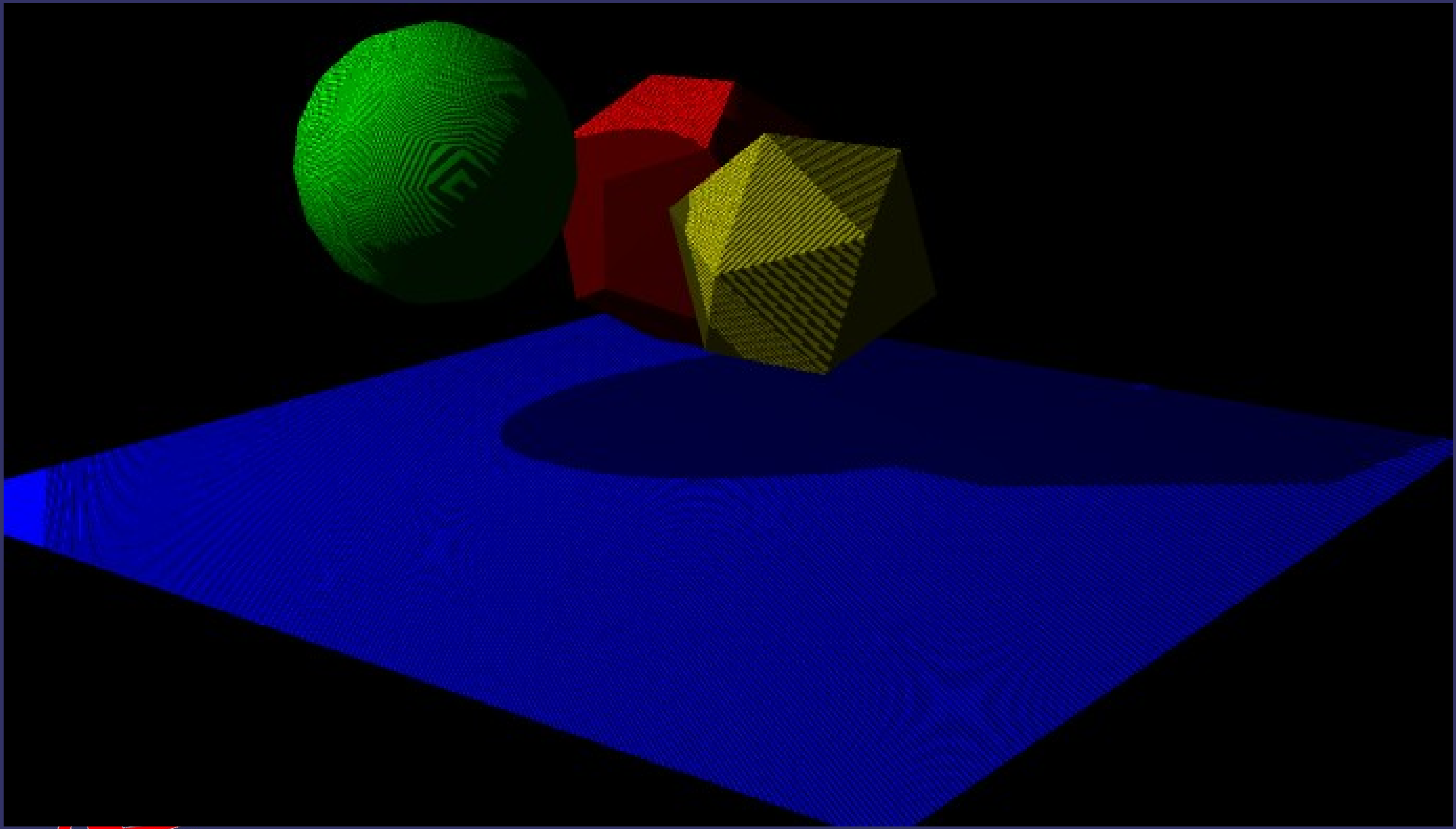


Shadow Acne

- Light and camera sample object at different positions
  - Drawing from the light's PoV samples one set of positions
  - Drawing from the camera's PoV samples a different set of positions
  - Result: incorrect values are used to determine if a surface shadows itself



Shadow Acne



Shadow Acne

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Shadow Acne

- Two common solutions:
  - Render back faces to shadow map
    - Front faces aren't drawn to shadow map, so they won't self-shadow
    - Back faces aren't lit: depth comparison result is irrelevant

Shadow Acne

- Two common solutions:
  - Use polygon offset
    - Bias fragment depth by small factor to ensure $d_{shadow} \geq d_{object}$

```
glPolygonOffset(1.1f, 1.0f);
```

    - Very tricky to get right! Movie fx companies spend *lots* of time tweaking every frame to eliminate artifacts[1]

[1] G. King, “Shadow Mapping Algorithms.” NVIDIA. 2004.
ftp://download.nvidia.com/developer/presentations/2004/GPU_Jackpot/Shadow_Mapping.pdf

Shadow Acne

- Two common solutions:
  - Render back faces to shadow map
    - Front faces aren't drawn to shadow map, so they won't self-shadow
    - Back faces aren't lit: depth comparison result is irrelevant
    - Can still have acne when normal map causes a polygon facing away from the light to be lit

Shadow Map Aliasing

- Several sources of aliasing in shadow maps
  - Must use nearest-neighbor sampling
    - Bilinear or mipmap sampling would average depth values together for use in comparison
  - Depth maps are typically small, so fine details may get lost
    - Shadows from thin objects (telephone wires, chain link fence, etc.) may disappear
    - Small gaps between objects may fill-in
  - Objects distant from light may be too small in shadow map
    - If the object's shadow is near the camera, it will appear very blocky

Shadow Map Precision

- Every Z-buffer has potential precision problems

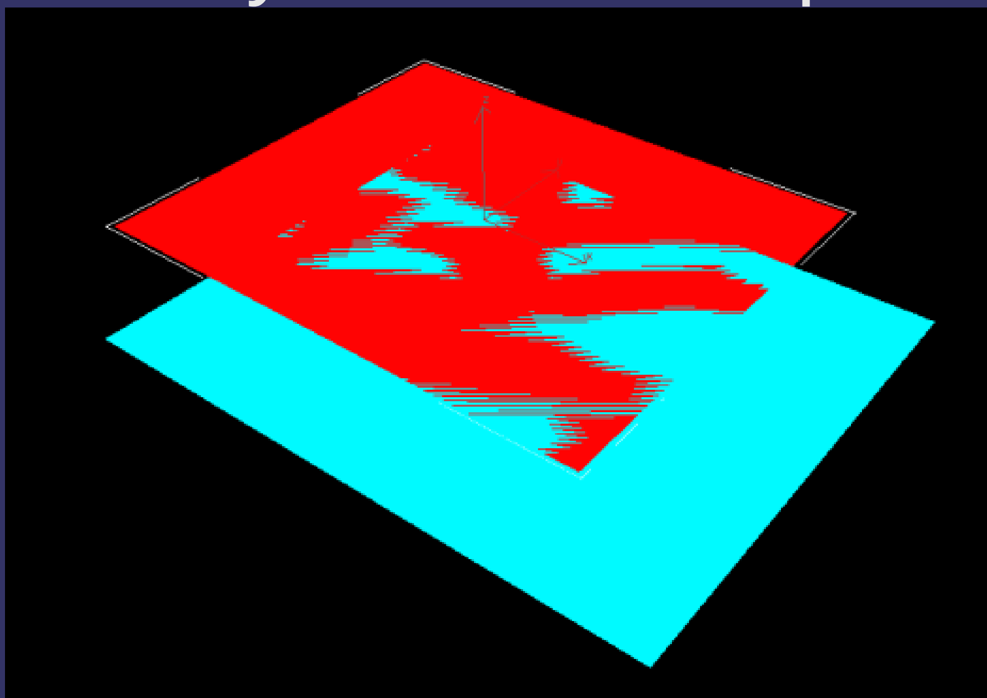
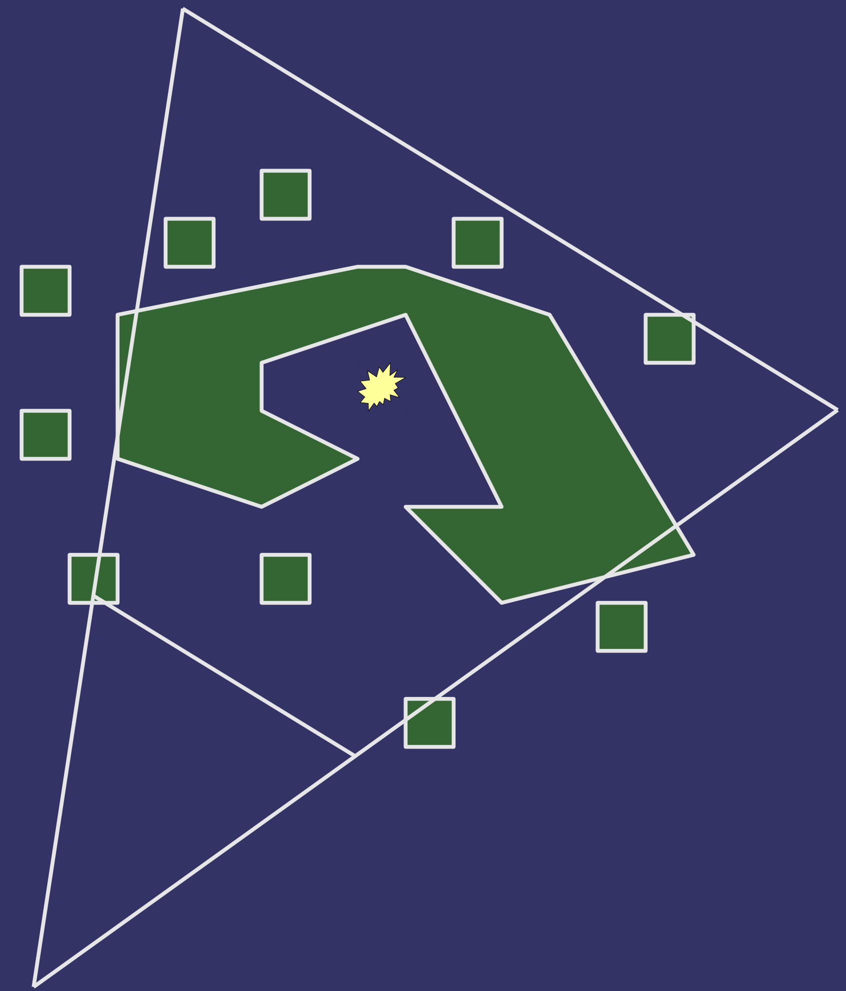


Image from http://en.wikipedia.org/wiki/Z-fighting

  - Objects distant from near-plane get fewer significant bits to store depth
    - May not be noticeable far from the near plane
  - Due to viewing differences, lack of Z precision far from *light's* near-plane may result in artifacts close to *camera's* near-plane

Omni-directional Lights

- Consider this scene...
  - What frustum do we pick for the light and the large object?
  - We'd need a 360° field-of-view!



Shadow Maps in GLSL

- New sampler types:
  - `sampler1DShadow`
  - `sampler2DShadow`
  - `sampler2DRectShadow`

Shadow Maps in GLSL

- New sampler functions:

```
vec4 shadow2D(sampler2DShadow, vec3)
vec4 shadow2DProj(sampler2DShadow, vec4)
```

  – 3rd component of texture coordinate is the distance used for comparison
  – There are also `1D` and `2DRect` versions
  – Value returned depends on comparison mode and `GL_DEPTH_TEXTURE_MODE` setting of texture unit

– As with projective textures, use shadow sampler types and functions instead of doing comparisons by hand

Shadow Maps in GLSL

- OpenGL 3.0 and GLSL 1.30 change things:
  - `GL_DEPTH_TEXTURE_MODE` is deprecated
    - You don't want it.
    - It's removed completely in 3.1
  - GLSL texture functions change name and return type:

```
float texture(sampler2DShadow, vec3)
float textureProj(sampler2DShadow, vec4)
```

- - `1D` and `2DRect` versions get similar changes

Shadow Maps in GLSL

- For GLSL 1.20 and earlier:
  - Leave `GL_DEPTH_TEXTURE_MODE` in the default state
    - `GL_LUMINANCE`
  - Wrap 1.20 API to look like 1.30 API:

```
float texture(sampler2DShadow s, vec3 c)
{
    return shadow2D(s, c).x;
}
```

Shadow Maps in GLSL

- Each texture has a depth comparison mode
  - Mode is set by calling `glTexParameteri` with *name* of `GL_TEXTURE_COMPARE_FUNC`
  - Sets mode used for comparison in `sampler[12]D` functions
  - Comparison mode is one of the “usual” `GL_LEQUAL`, etc. modes.
- Sampler function returns 1.0 if the test passes or 0.0 if the test fails

Depth Textures

- Store single component, normalized value used for depth (shadow) comparisons
  - Use one of three internal formats:
    - `GL_DEPTH_COMPONENT16`
    - `GL_DEPTH_COMPONENT24`
    - `GL_DEPTH_COMPONENT32`
  - Only format that can be used with GLSL shadow samplers
    - Can be also use with non-shadow samplers as a luminance, intensity, or alpha texture

Depth Textures

- Create just like any other texture:

```
glBindTexture(GL_TEXTURE_2D, my_shadow_tex);
glTexImage2D(GL_TEXTURE_2D, 0, GL_DEPTH_COMPONENT24,
             0, 0, width, height, GL_DEPTH_COMPONENT,
             GL_UNSIGNED_INT, NULL);
```

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             GL_UNSIGNED_INT, NULL);
```

- To use as false-color texture:

```
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_COMPARE_MODE,
                GL_NONE);
```

  - Color returned is `vec4(d, d, d, 1)`

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glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_COMPARE_MODE,
                GL_NONE);
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  - Color returned is `vec4(d, d, d, 1)`

- To use as a shadow map:

```
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_COMPARE_MODE,
                GL_COMPARE_R_TO_TEXTURE);
```

Depth Textures

- Set comparison function similarly:

```
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_COMPARE_FUNC,
                GL_LESS);
```

  - In OpenGL 1.4 only `GL_LEQUAL` and `GL_GEQUAL` were available
  - In OpenGL $\geq$ 1.5 all 8 functions are available

Depth Textures and FBOs

- Attach the depth-component texture to the depth attachment:

```
glFramebufferTexture2D(GL_FRAMEBUFFER,
                       GL_DEPTH_ATTACHMENT,
                       GL_TEXTURE_2D, tex, 0);
```

  - If there are no mipmaps (likely), as usual, be sure to set non-mipmap minification mode
  - If there is no color output (likely), be sure to disable all color buffer access:

```
glDrawBuffer(GL_NONE);
glReadBuffer(GL_NONE);
```

Next week...

- Advanced shadow map techniques
  - Quiz #1
  - Assignment #1, part 2... due *next week*
  - Read:

W. Reeves, D. Salesin, and R. Cook, "Rendering Antialiased Shadows with Depth Maps." In Proceedings of SIGGRAPH ’87. 1987. http://graphics.pixar.com/ShadowMaps/

R. Fernando, "Percentage-Closer Soft Shadows." In Proceedings of SIGGRAPH 2005. 2005. http://developer.nvidia.com/object/siggraph_2005_presentations.html

  - Reducing shadow map aliasing
  - Percentage closer soft shadows (PCSS)
  - Depth range optimizations

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