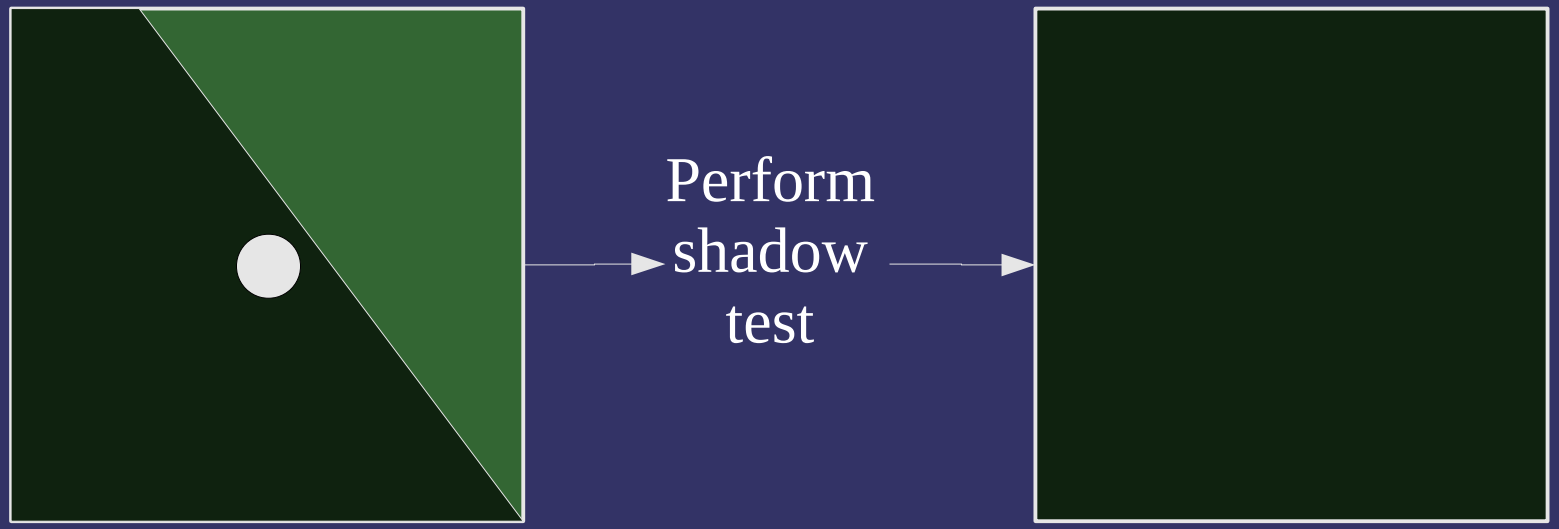
VGP353 – Week 3

- Agenda:
  - Quiz #1
  - More shadow maps:
    - Fixing some aliasing w/percentage closer filtering (PCF)
    - *Plausible* soft shadows w/percentage closer soft shadows (PCSS)

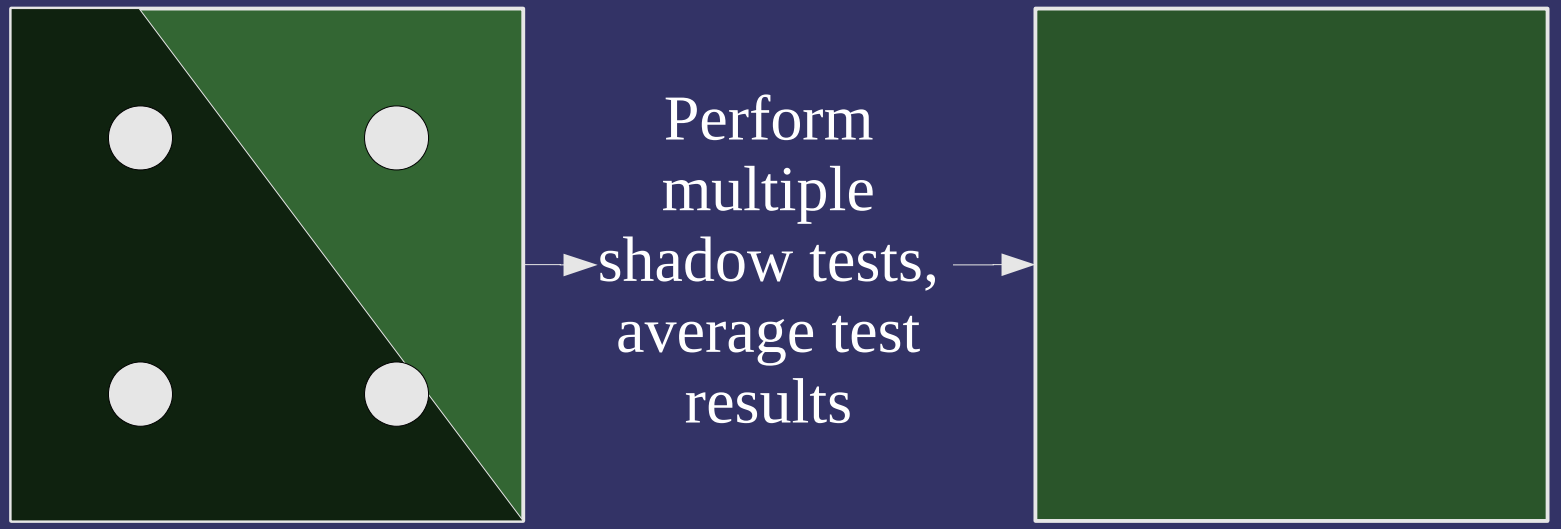
Shadow Map Texture Filtering

- Shadow test samples shadow map once per fragment
  - Results in two possible light levels: fully lit or fully shadowed



Shadow Map Texture Filtering

- Percentage closer filtering (PCF) reads multiple samples, performs one test per sample, averages test results
  - Results in n+1 possible light levels, where n is the number of samples



Shadow Map Texture Filtering

- Straight forward implementation in GLSL:

```
uniform vec2 bias;
uniform sampler2DShadow map;

void main()
{
    vec3 proj = coord.xyz / coord.w;
    vec3 p0 = proj - vec3((0.5 * bias.xy), 0.0);

    float s = texture(map, p0);
    s += texture(map, p0 + vec3(bias.x, 0.0, 0.0));
    s += texture(map, p0 + vec3(0.0, bias.y, 0.0));
    s += texture(map, p0 + vec3(bias.x, bias.y, 0.0));

    shadow /= 4.0;

    ...
}
```

Shadow Map Texture Filtering

- More concise in GLSL 1.30:

```
#version 130
uniform sampler2DShadow map;

void main()
{
    float s = textureProj(map, coord);
    s += textureProjOffset(map, coord, vec2(0, 1));
    s += textureProjOffset(map, coord, vec2(1, 0));
    s += textureProjOffset(map, coord, vec2(1, 1));

    shadow /= 4.0;

    ...
}
```

Shadow Map Texture Filtering

- Even better with GL_ARB_texture_gather
  - But you have to open-code the shadow comparison

```
#version 130
#extension GL_ARB_texture_gather: require

uniform sampler2D map;

void main()
{
    vec4 depth = textureGather(map, coord);
    vec4 s = vec4(lessThan(vec4(gl_FragDepth), depth);

    shadow = dot(s, vec4(0.25));

    ...
}
```

Percentage Closer Filtering

- The good news:
  - Improves quality
  - Larger filter kernels can be used to enable soft shadows
  - Some hardware can do 2x2 PCF nearly for free
    - Just enable `GL_LINEAR` filter on NVIDIA or Intel hardware

Percentage Closer Filtering

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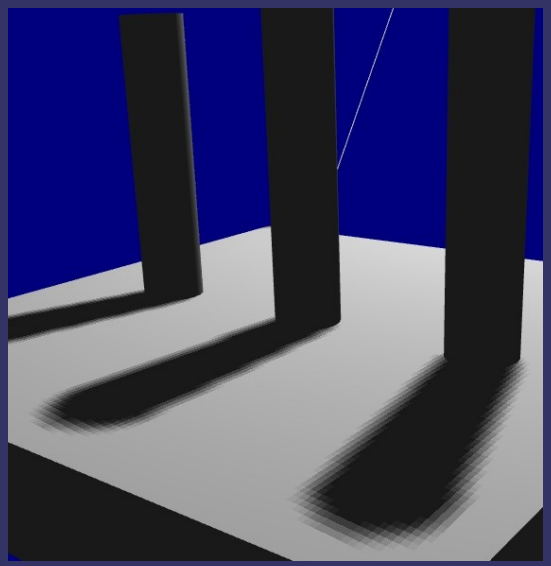
  - Larger filter kernels can be used to enable soft shadows
  - Some hardware can do 2x2 PCF nearly for free
    - Just enable `GL_LINEAR` filter on NVIDIA or Intel hardware
- The bad news:
  - Larger filter kernels are expensive
  - Grid-based sampling has artifacts

Grid-Based Sampling

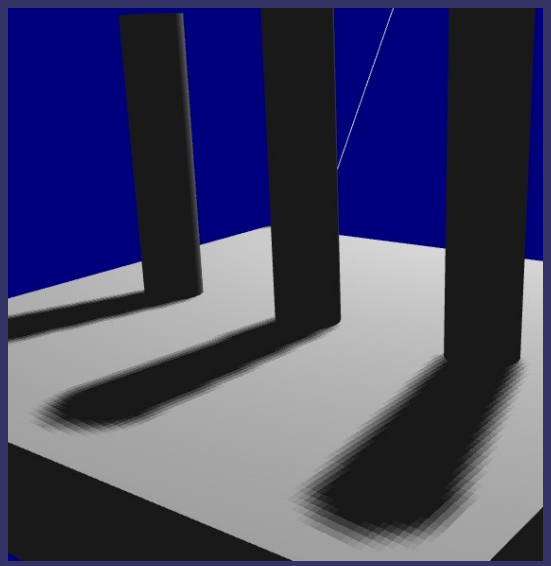
- Grid-based sampling artifacts have regular shape and are easily noticed by the eye

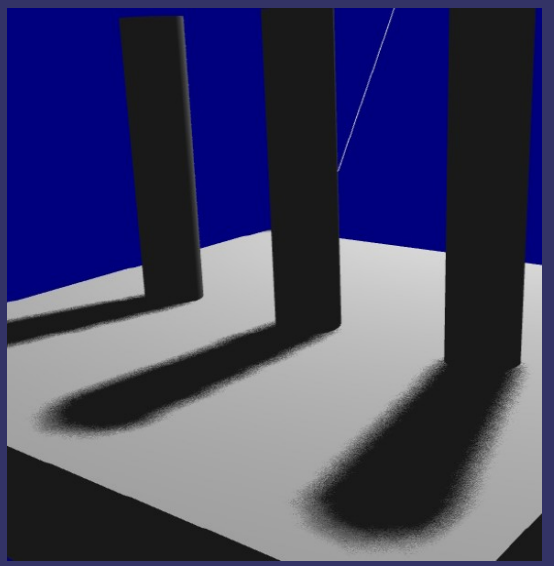


Images from http://ati.amd.com/developer/SIGGRAPH05/ShadingCourse_ATI.pdf

Grid-Based Sampling

- Grid-based sampling artifacts have regular shape and are easily noticed by the eye
- Irregular sample patterns are more easily accepted by the eye
  - Can even use fewer samples in the same size area

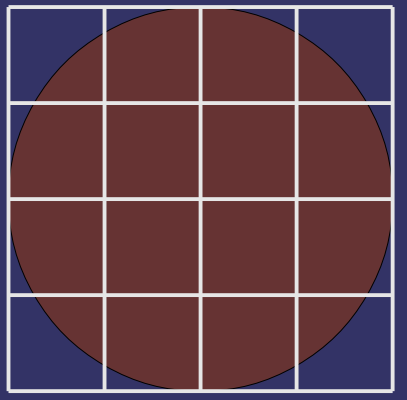




Images from http://ati.amd.com/developer/SIGGRAPH05/ShadingCourse_ATI.pdf

Irregular Sampling

- Select filter area



Irregular Sampling

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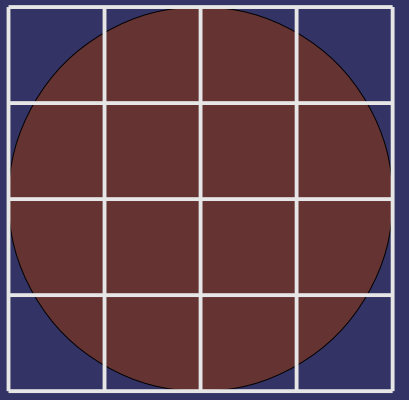
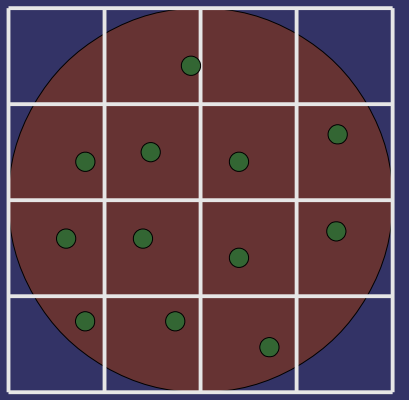


- Select random sample locations within area



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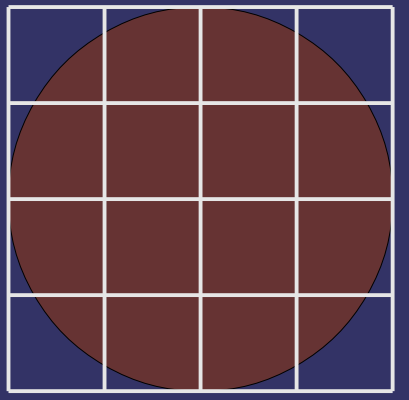

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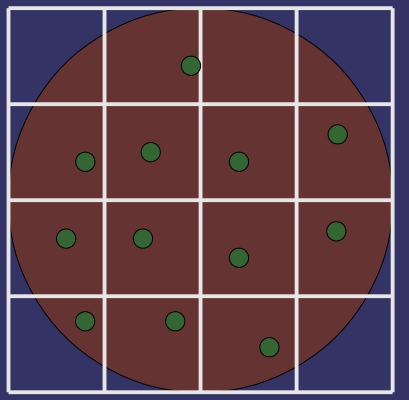
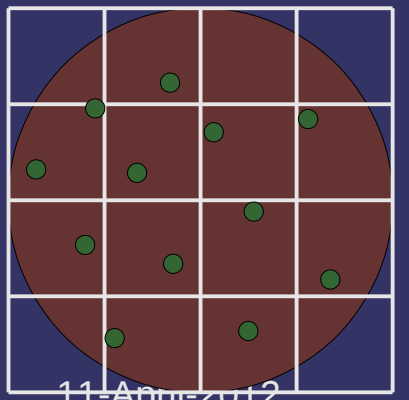


- Randomly rotate sample locations
  - Rotation based on screen location



Irregular Sampling

```
uniform vec2 sample_locations[12];
uniform mat2x2 sample_rotations[7];

float pcf_shadow_filter(sampler2DShadow map, vec4 coord)
{
    // Select rotation matrix based on pixel location
    int k = int(mod(gl_FragPosition.x + gl_FragPosition.y, 7.0));
    vec3 proj = coord.xyz / coord.w;
    float sum = 0.0;

    for (int i = 0; i < sample_locations.length(); i++) {
         vec2 offset = sample_rotations[k] * sample_locations[i]
         sum += texture(map, proj + vec3(offset, 0.0));
    }

    return sum / float(sample_locations.length());
}
```

Filter Cost

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  - Nyquist–Shannon sampling theorem tells us that areas with only low-frequency information need fewer samples than areas with high-frequency information

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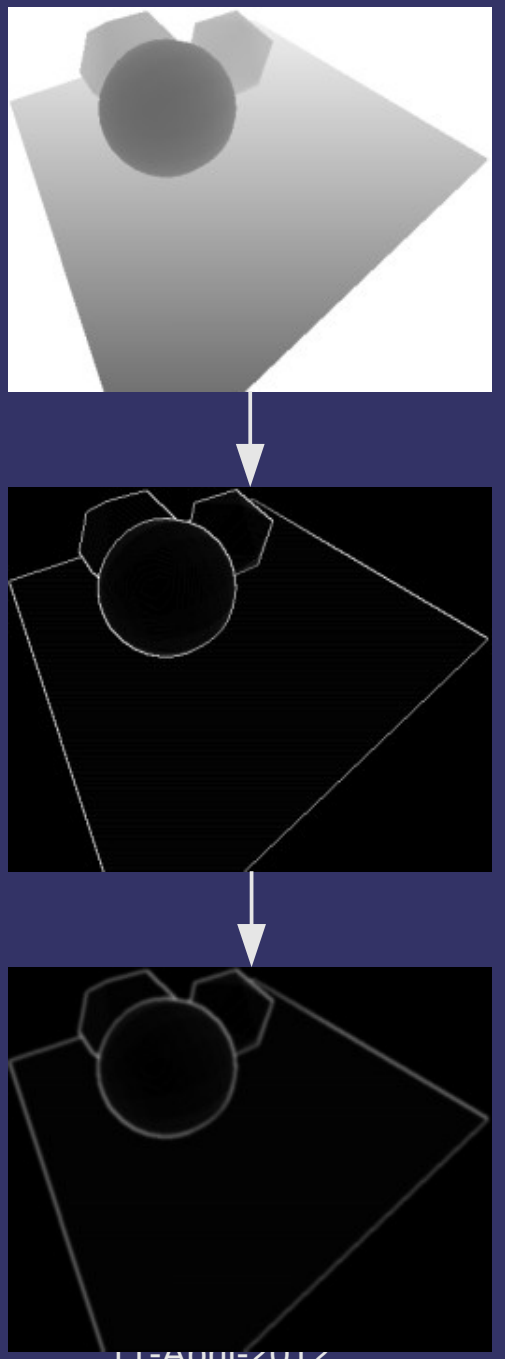
- 12 or 16 samples per fragment is expensive
  - In most of the final image, expensive sampling is unnecessary
  - Nyquist–Shannon sampling theorem tells us that areas with only low-frequency information need fewer samples than areas with high-frequency information
    - The only high-frequency information is near the shadow boundaries!

Shadow Boundary Map

- Find boundaries in shadow map using edge detection filter
  - The edges in the map are the regions where the expensive filter should be applied
- Blur edge map using a blur kernel equal in size to the shadow map sample filter
  - This increases the area where the expensive filter will be applied and ensures that it will be applied everywhere that it needs to be



Shadow Boundary Map

- Use the shadow boundary map to determine whether to use one or many shadow samples

```
if (textureProj(boundary_map, proj) > 0.0)
    shadow = pcf_shadow_filter(shadow_map, proj);
else
    shadow = textureProj(shadow_map, proj)
```

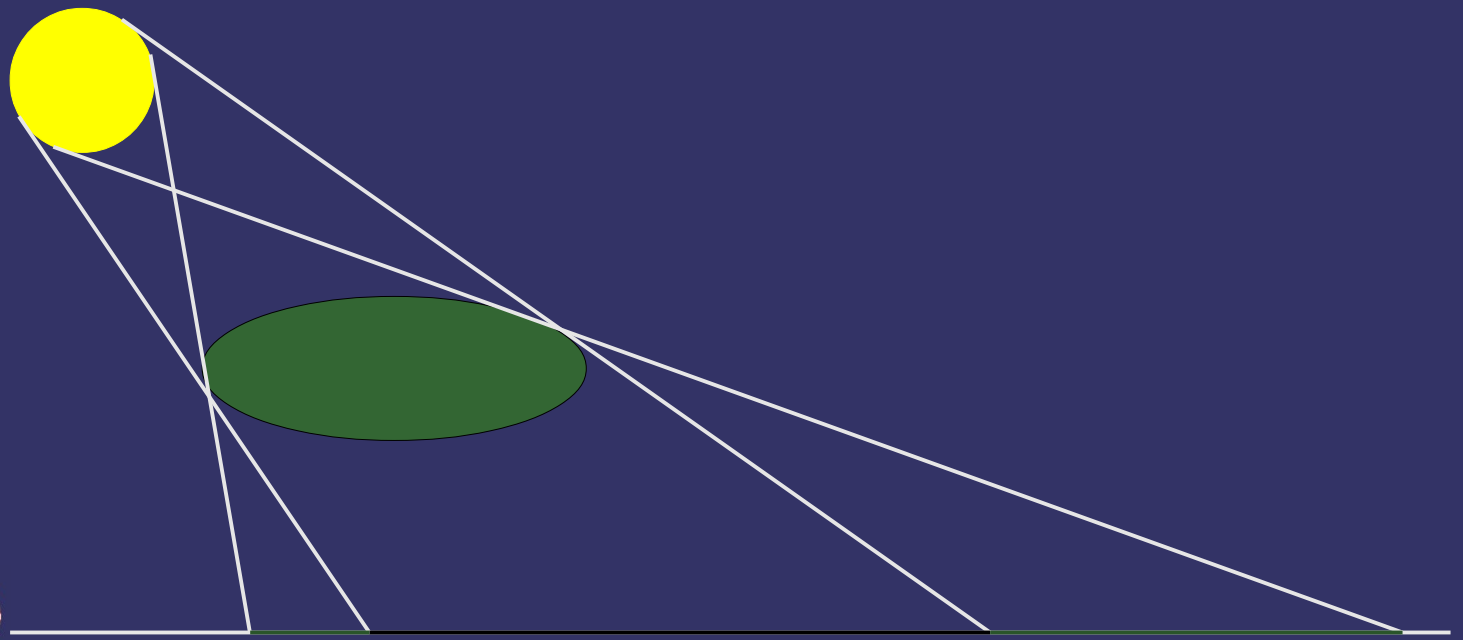
  - On hardware that support dynamic flow control, this can be a *big* win
    - DFC is a required part of DX 9.0c Shader Model 3.0
      - Geforce6 and later
      - Radeon X1xxx (R500) and later
      - Intel GMA X3000 (G965) and later

References

Sander, P. and Isidoro, J. *Explicit Early-Z Culling and Dynamic Flow Control on Graphics Hardware*. ATI Corporation, 2005, accessed 20 April 2008; available from http://ati.amd.com/developer/techpapers.html

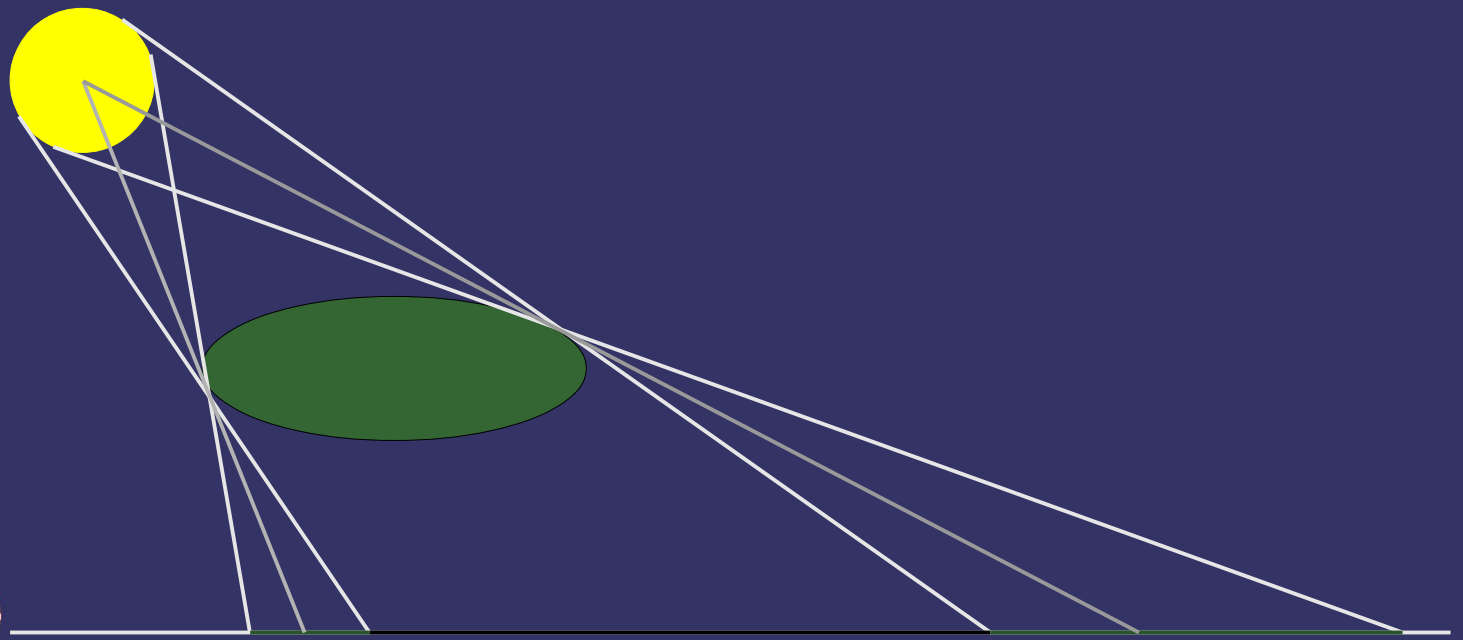
Soft Shadows

- Real lights have area
  - Since the light has area, there are regions where only a portion of the light is occluded...this is the penumbra



Soft Shadows

- Real lights have area
  - Since the light has area, there are regions where only a portion of the light is occluded...this is the penumbra
  - Shadow maps represent part of the penumbra as umbra and part as unoccluded



Soft Shadows

- Size of penumbra region varies with:
  - Size of light
  - Distance between occluder and light
  - Distance between occluder and receiver

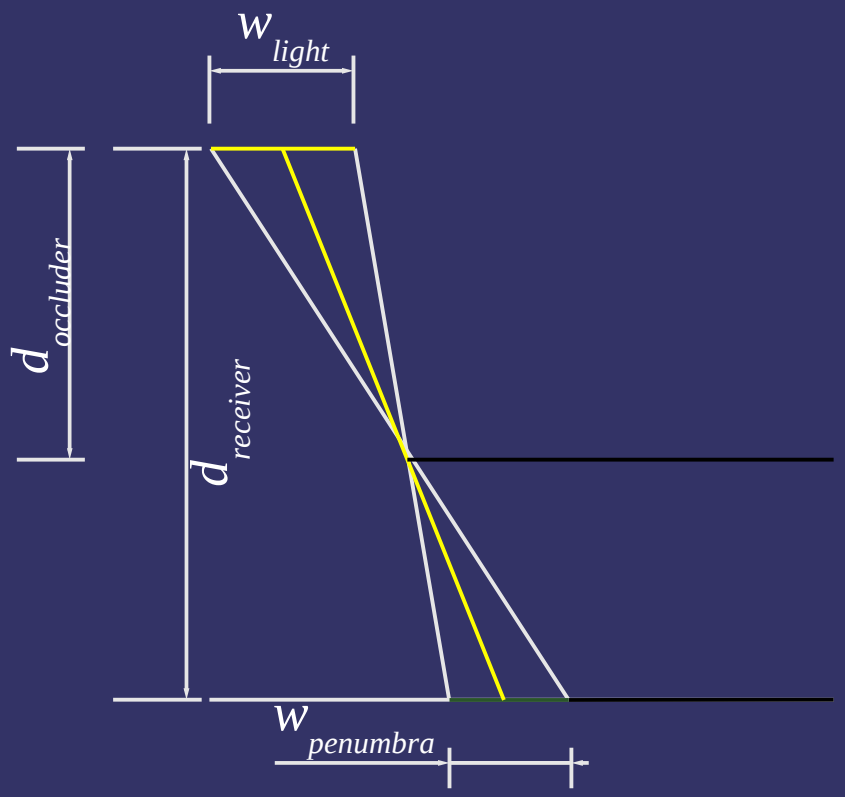
Soft Shadows

- Size of penumbra region varies with:
  - Size of light
  - Distance between occluder and light
  - Distance between occluder and receiver
- Using this information to perform *correct* light visibility calculations is hard
  - Make some simplifying assumptions!
  - Assume that all occluders, receivers, and lights are both flat and parallel to each other

Soft Shadows

- Estimate penumbra size using:

$$w_{penumbra} = \frac{(d_{receiver} - d_{occluder}) \times w_{light}}{d_{occluder}}$$



Soft Shadows

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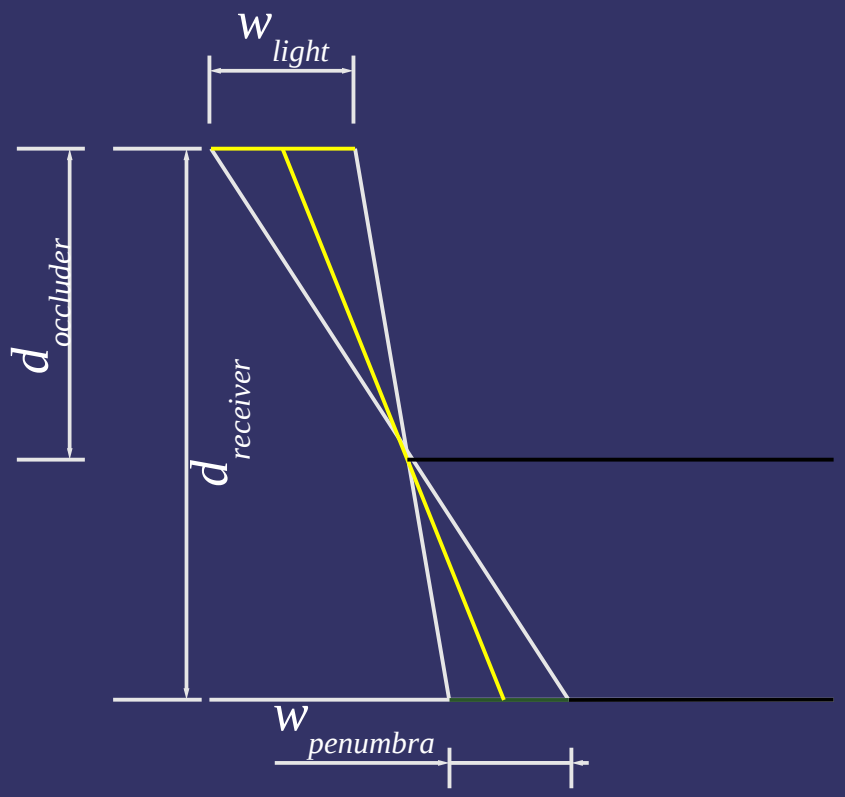
- How do we determine $d_{occluder}$?



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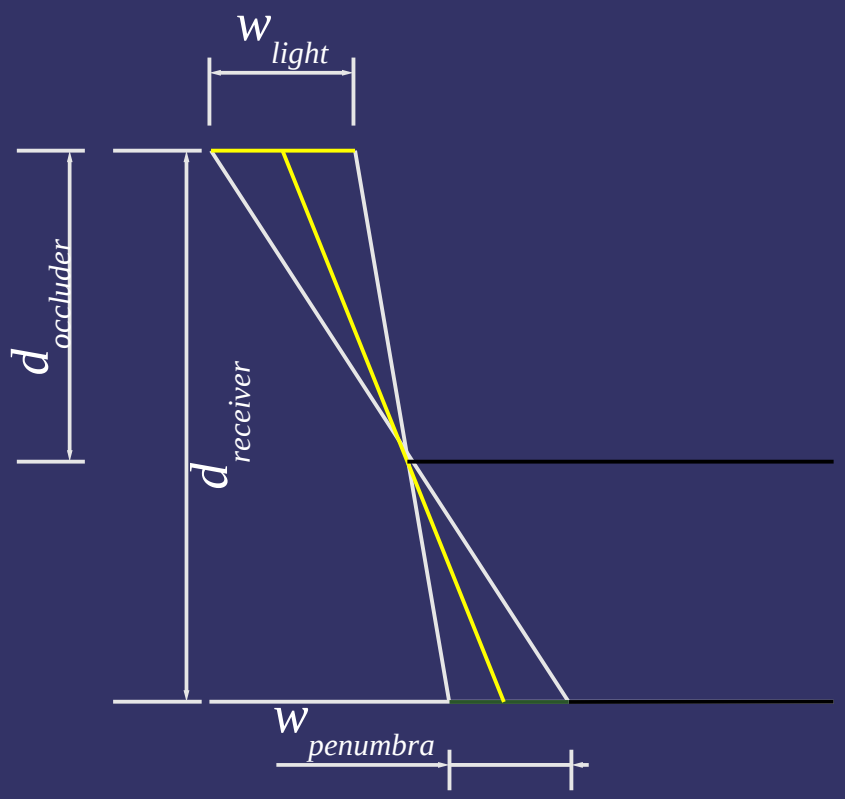

- How do we determine $d_{occluder}$?
  - Search the shadow map for possible occluders

Soft Shadows

- Examine a region around the point in the shadow map
  - Select region size based on light size and rendering budget
  - Sample values and *average* all depths less than the current fragment
    - Very similar to percentage closer filter (PCF)
- Use resulting average as $d_{occluder}$
  - $w_{penumbra}$ is the width of the PCF filter area

Soft Shadows

- Demo

Original image from
http://developer.nvidia.com/object/gdc_2005_presentations.html

References

Randima Fernando. *Percentage-Closer Soft Shadows.* 2005. Game Developer's Conference. http://developer.download.nvidia.com/shaderlibrary/docs/shadow_PCSS.pdf

Next week...

- Shadow volumes

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