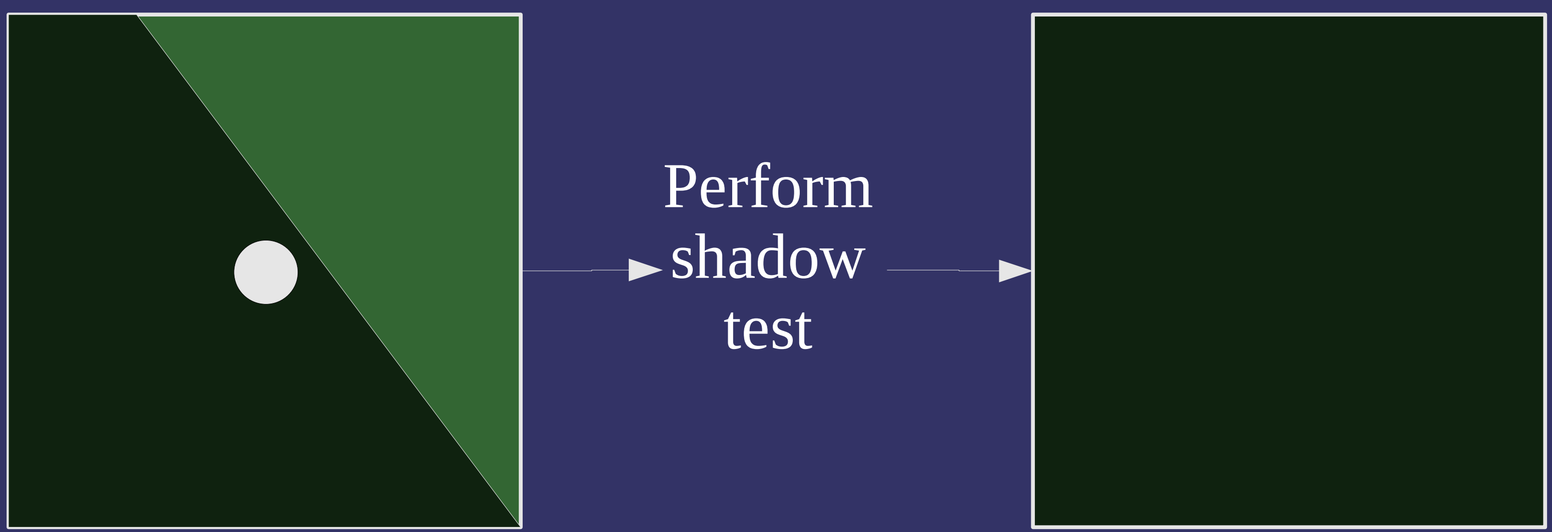
VGP353 – Week 4

- Agenda:
  - Fighting shadow map aliasing
    - Percentage closer filtering (PCF)
    - Perspective shadow maps

22-April-2008

Shadow Map Texture Filtering

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



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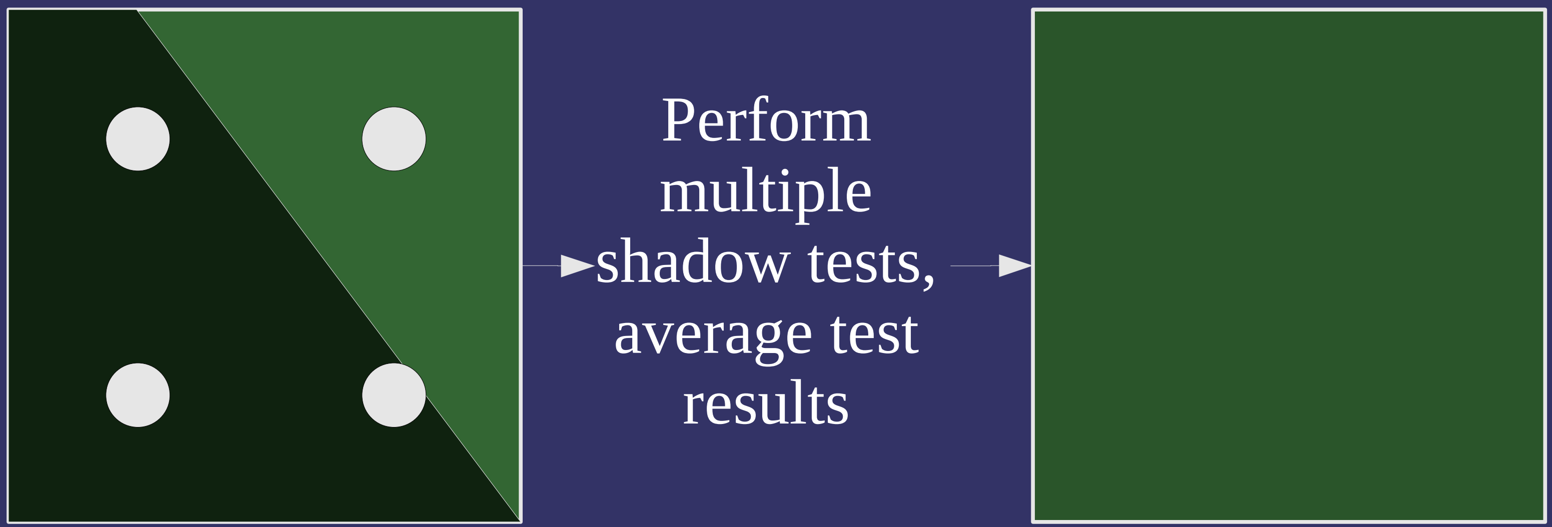
Shadow Map Texture Filtering

- 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 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);

    vec4 shadow = shadow2D(map, p0);
    shadow += shadow2D(map, p0 + vec3(bias.x, 0.0, 0.0));
    shadow += shadow2D(map, p0 + vec3(0.0, bias.y, 0.0));
    shadow += shadow2D(map, p0 + vec3(bias.x, bias.y, 0.0));

    shadow /= 4.0;

    ...
}
```

Percentage Closer Filtering

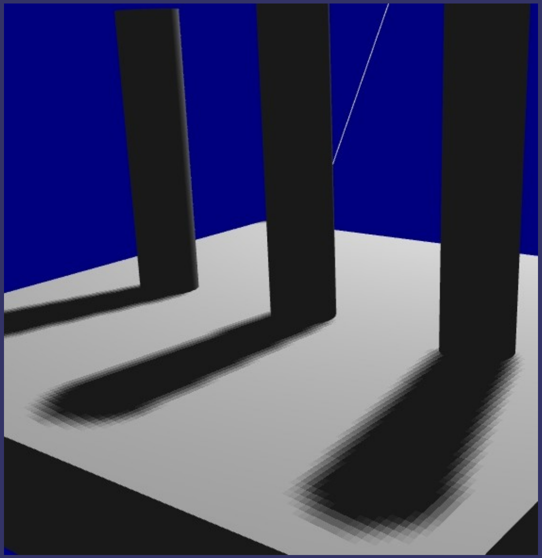
- The good news:
  - Improves quality
  - Larger filter kernels can be used to enable soft shadows
  - Some hardware can do 2x2 PCF nearly for free
    - Just enable `GL_LINEAR` filter on Nvidia hardware

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 hardware
- The bad news:
  - Larger filter kernels are expensive
  - Grid-based sampling has artifacts

Grid-Based Sampling

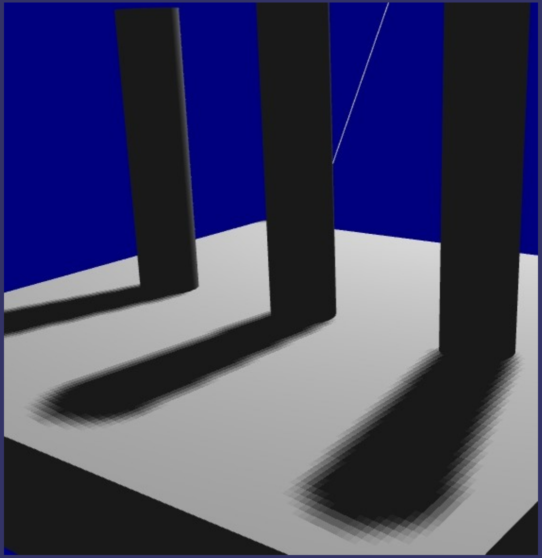
- Grid-based sampling artifacts have regular shape and are easily noticed by the eye

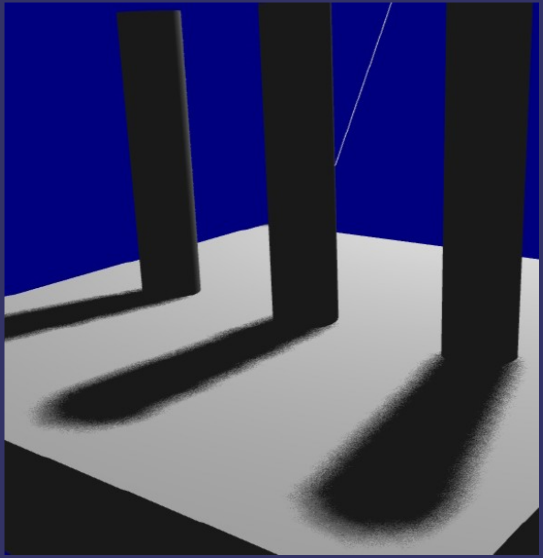


Images from http://ati.amd.com/developer/SIGGRAPH05/ShadingCourse_ATI.pdf

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

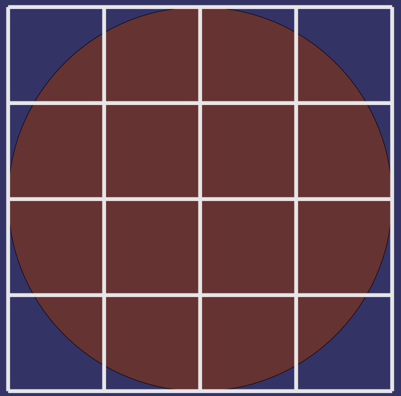




Images from http://ati.amd.com/developer/SIGGRAPH05/ShadingCourse_ATI.pdf

Irregular Sampling

- Select filter area



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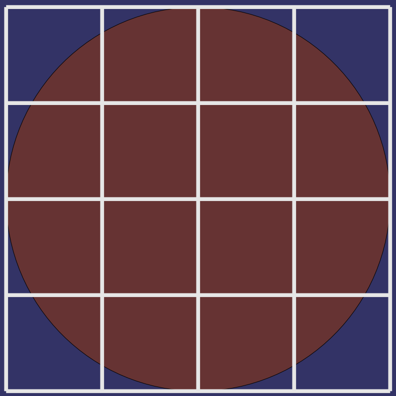
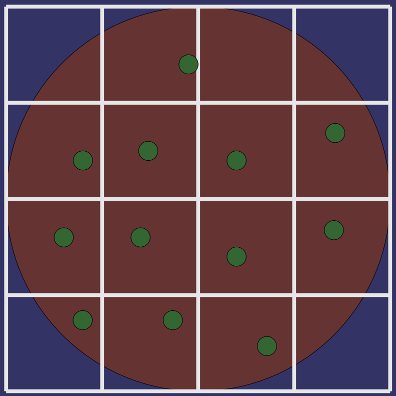
Irregular Sampling

- Select filter area



- Select random sample locations within area



Irregular Sampling

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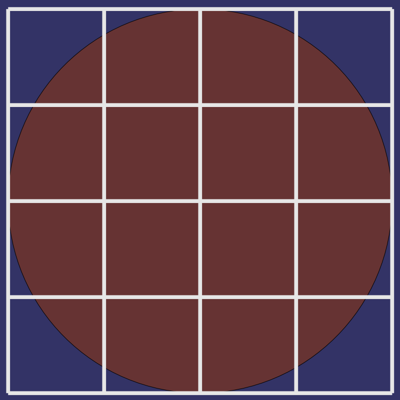

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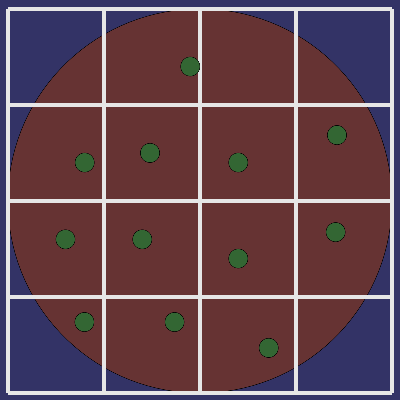
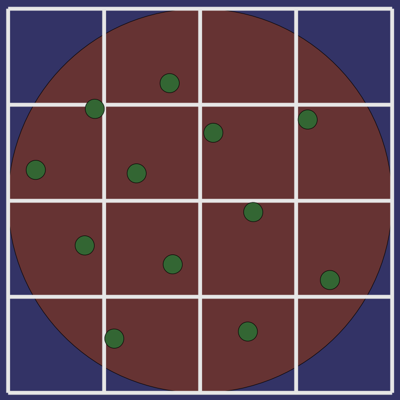


- Randomly rotate sample locations
  - Rotation based on screen location



Filter Cost

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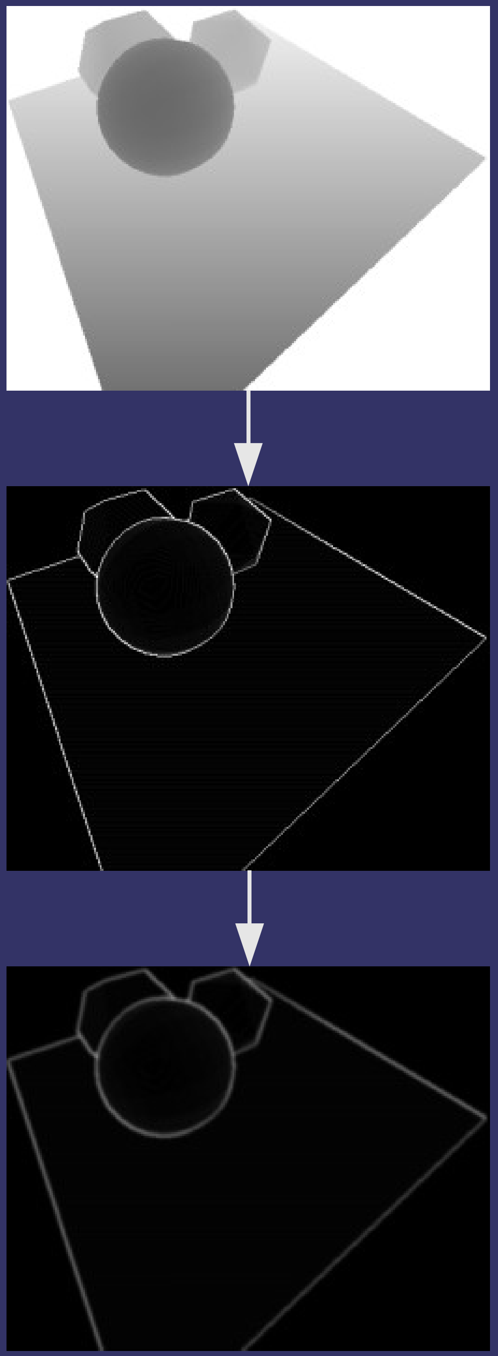
Filter Cost

- 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



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Shadow Boundary Map

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

```
if (texture2DProj(boundary_map, proj) > 0.0) {
    shadow = pcf_shadow_filter(shadow_map, proj);
} else {
    shadow = shadow2DProj(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

Break

Shadow Map Aliasing

- A shadow map texel represents an area $d_s \times d_s$
  - d_s is the reciprocal of the shadow map resolution
  - As shadow map resolution increases, d_s decreases
  - The projected size of a surface at distance r_s is approximately:

$$\frac{d_s r_s}{N \cdot L}$$

Shadow Map Aliasing

- An image pixel represents an area $d_i \times d_i$
  - d_i is the reciprocal of the image resolution
  - As image resolution increases, d_i decreases
  - The projected size of a surface at distance r_i is approximately:

$$\frac{d_i r_i}{N \cdot V}$$

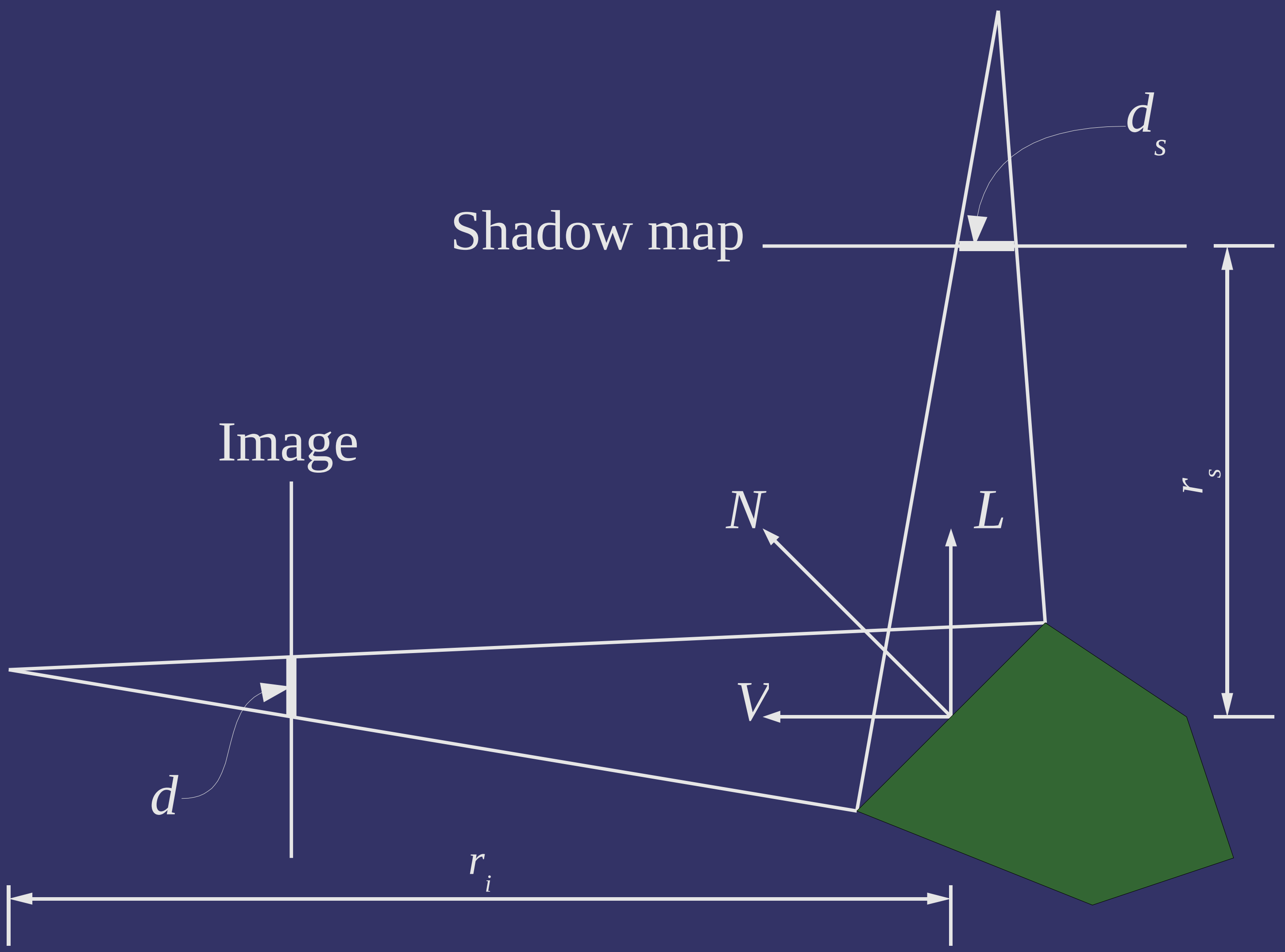
Shadow Map Aliasing

- The size of the projection of the shadow texel in the final image is:

$$d = d_s \frac{r_s}{r_i} \frac{N \cdot V}{N \cdot L}$$

  - Aliasing occurs when $d > d_i$

Shadow Map Aliasing



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Shadow Map Aliasing

- The size of the projection of the shadow texel in the final image is:

$$d = d_s \frac{r_s}{r_i} \frac{N \cdot V}{N \cdot L}$$

  - Aliasing occurs when $d > d_i$
  - Intuitively, if the shadow area is small in the shadow map, but large in the final image, there will be aliasing

Shadow Map Aliasing

$$d_s \frac{r_s}{r_i} \frac{N \cdot V}{N \cdot L}$$

Large when light rays are nearly tangent to surface geometry, but surface geometry faces towards the viewer

- This is called *projection aliasing*
- Dependent on orientation of scene geometry
- Can change even when light and viewer are stationary
- Difficult to fix!

Shadow Map Aliasing

$$d_s \frac{r_s}{r_i} \frac{N \cdot V}{N \cdot L}$$

Occurs when the view is close to individual texels of the shadow map

- This is called *perspective aliasing*
- Occurs if the shadow map is too small (i.e., d_s is large)
- Can only increase shadow map size so much!
- Also occurs if $r_s \gg r_i$

Large when light rays are nearly tangent to surface geometry, but surface geometry faces towards the viewer

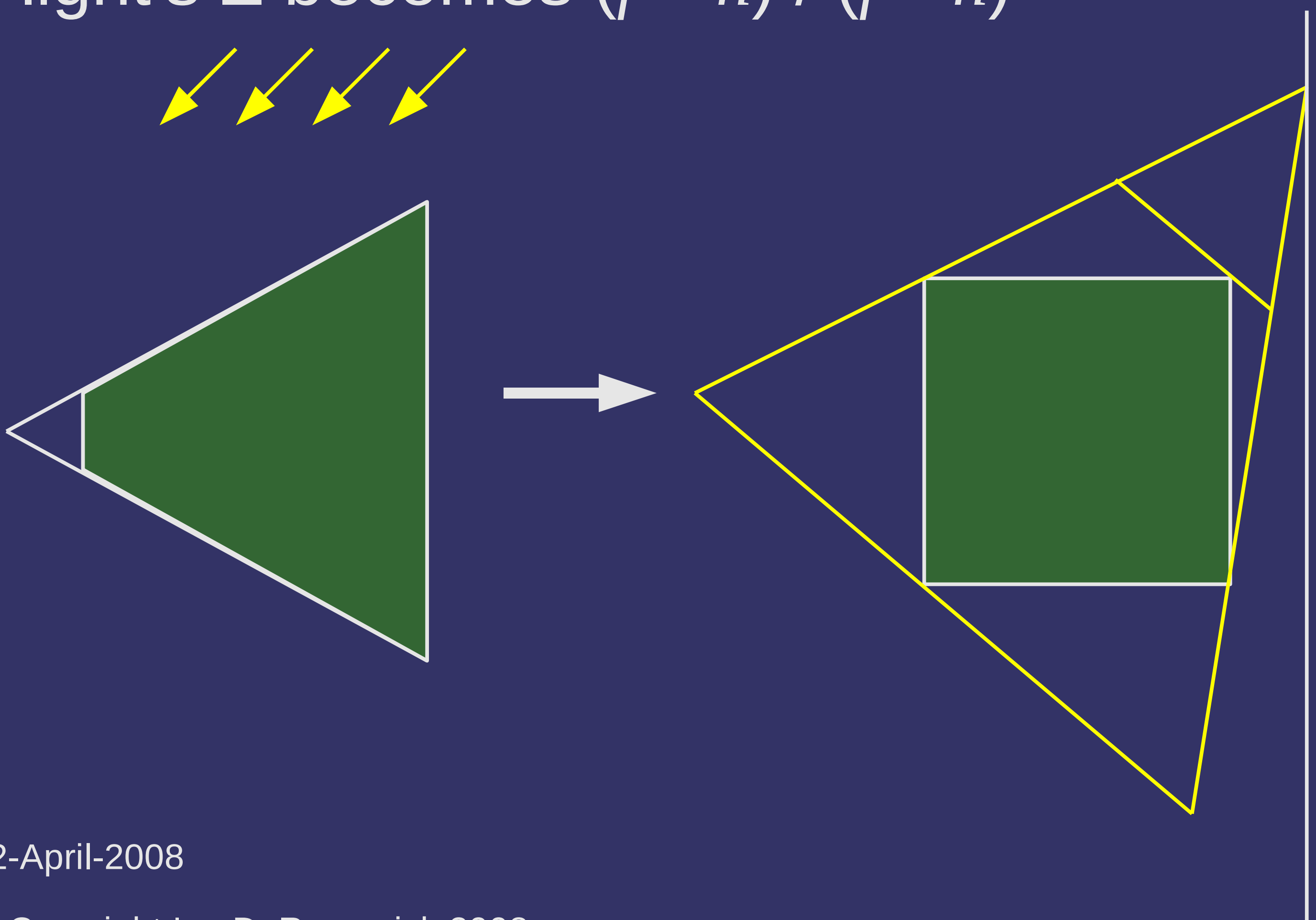
- This is called *projection aliasing*
- Dependent on orientation of scene geometry
- Can change even when light and viewer are stationary
- Difficult to fix!

Perspective Shadow Maps

- If the problem stems from the relationship between the camera frustum and light frustum, then the solution make take both frusta into account
  - Perform shadow map calculations in post-projection camera space *instead of* world space
  - The projection remaps the frustum volume to a cube, this cube is then sampled to create the shadow map
    - Applying this to the world before applying the light's view effectively changes the “shape” of the light

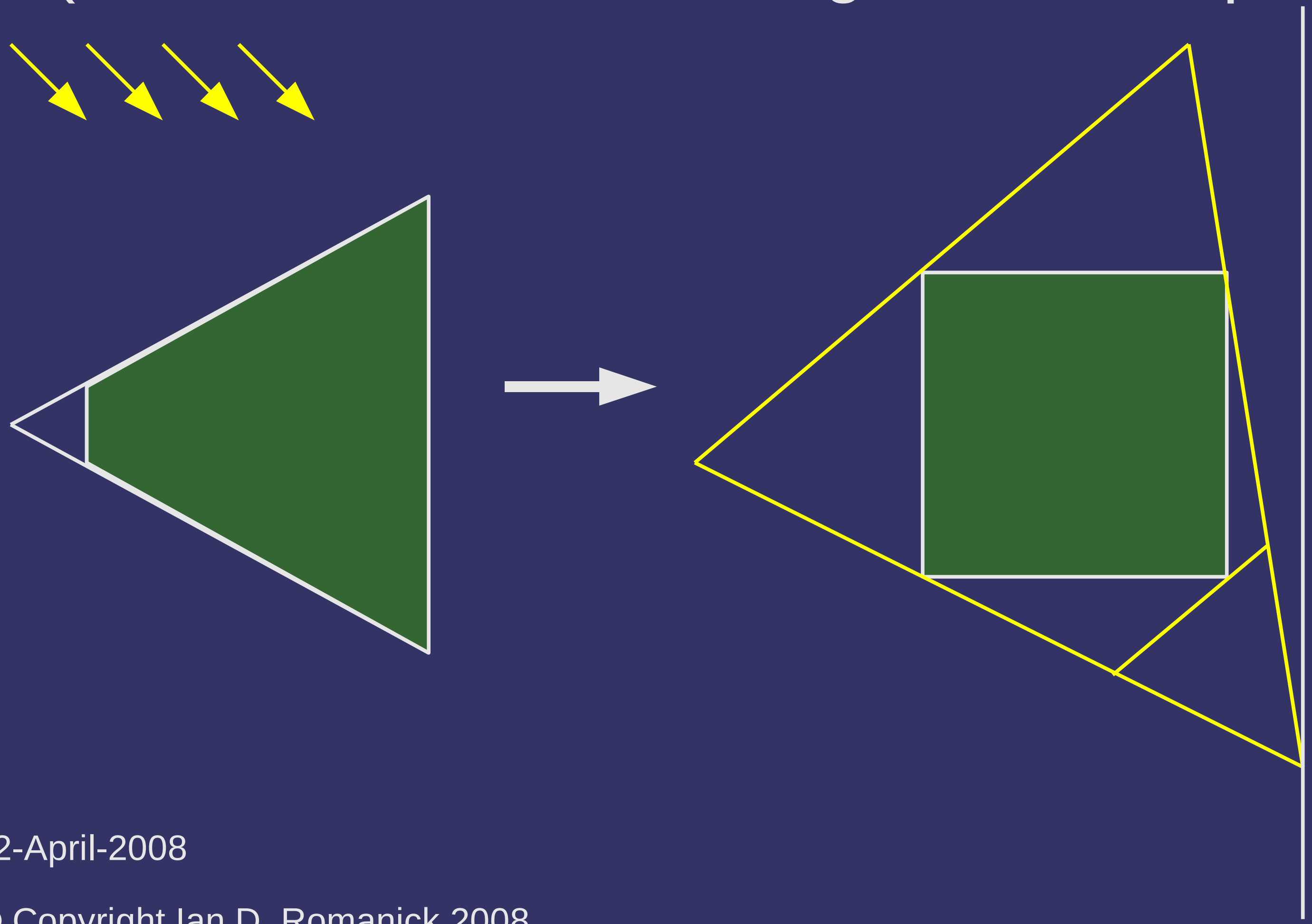
Perspective Shadow Maps

- Directional lights become point lights “on the infinity plane”
  - The light's Z becomes $(f + n) / (f - n)$



Perspective Shadow Maps

- Directional front-lights become inverted
  - Reverse the order of the usual depth and shadow tests (i.e., less-than becomes greater-or-equal)

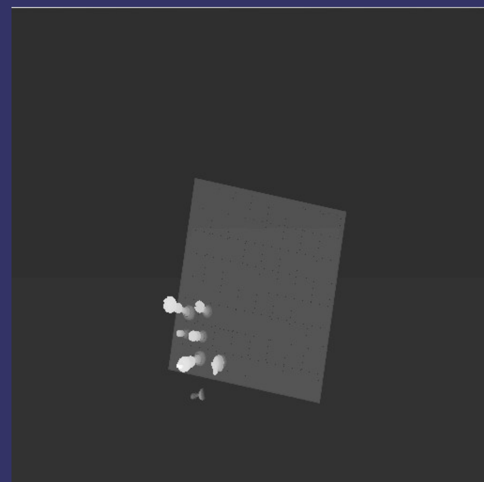


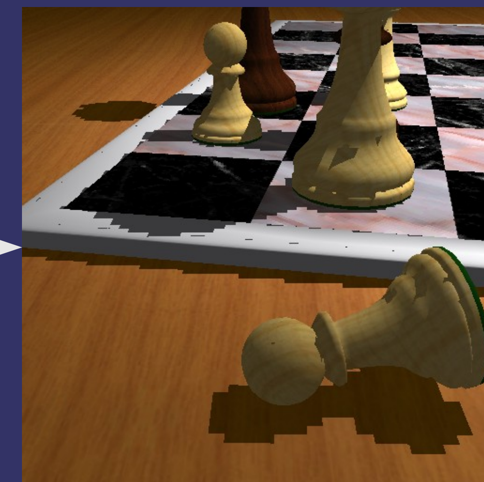
Perspective Shadow Maps

- Directional lights have other quirks
  - The more parallel the light and view direction, the lower the quality
    - A directional light pointing in the exact opposite direction of the view direction degrades back to the classic shadow map case
  - Casters behind the viewer (i.e., negative Z) are inverted and projected past the far plane
    - Several methods to handle this special case
  - Point lights have similar issues

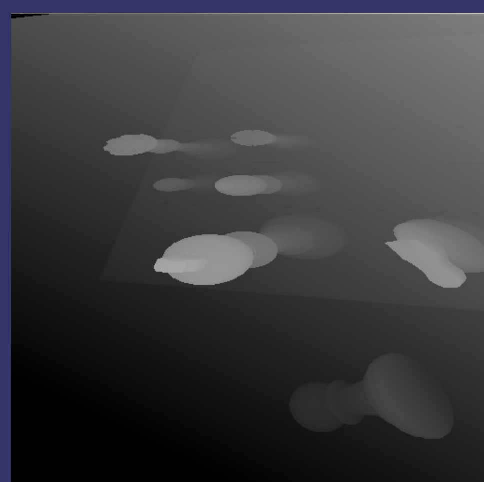
Perspective Shadow Map

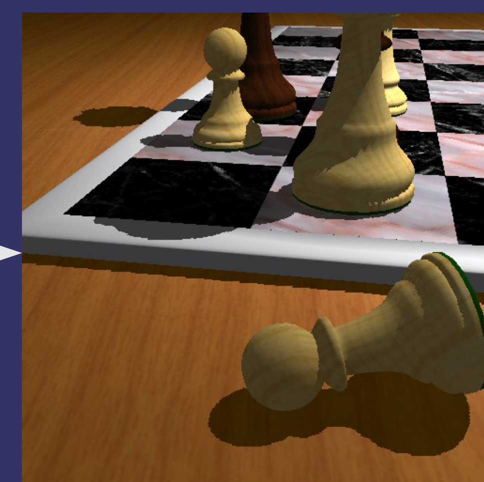
Standard
shadow map





Perspective
shadow map





Images from http://www-sop.inria.fr/reves/publications/data/2002/SD02/index.gb.html

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Perspective Shadow Maps

- Advantages:
  - Improves quality for many common cases
  - Easy to implement for directional light sources
- Disadvantages:
  - Shadow maps are view dependent, and must be regenerated when the camera moves (instead of just when the light or objects move)
  - Dual perspective transforms exaggerate shadow acne
  - As the viewer moves, the quality of the shadow map changes...even if the rest of the scene is static
    - For *most* games, this is the deal breaker

References

Stamminger, M. and Drettakis, G. 2002. Perspective shadow maps. In *Proceedings of the 29th Annual Conference on Computer Graphics and interactive Techniques* (San Antonio, Texas, July 23 - 26, 2002). SIGGRAPH '02. ACM, New York, NY, 557-562. http://www-sop.inria.fr/reves/publications/data/2002/SD02/index.gb.html

Next week...

- End of shadow maps
  - Percentage closer soft shadows
  - Parallel split shadow maps
- Quiz #2
  - Week 3 and week 4 material
- Assignments:
  - Programming assignment #2 due
  - Programming assignment #3 begins
  - First reading presentation!

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