VGP353 – Week 3

- Agenda:
  - Quiz #1
  - More shadow maps:
    - Percentage closer soft shadows (PCSS)
    - Parallel-split shadow maps (PSSMs)
  - Assignment #2 (shadow maps) started

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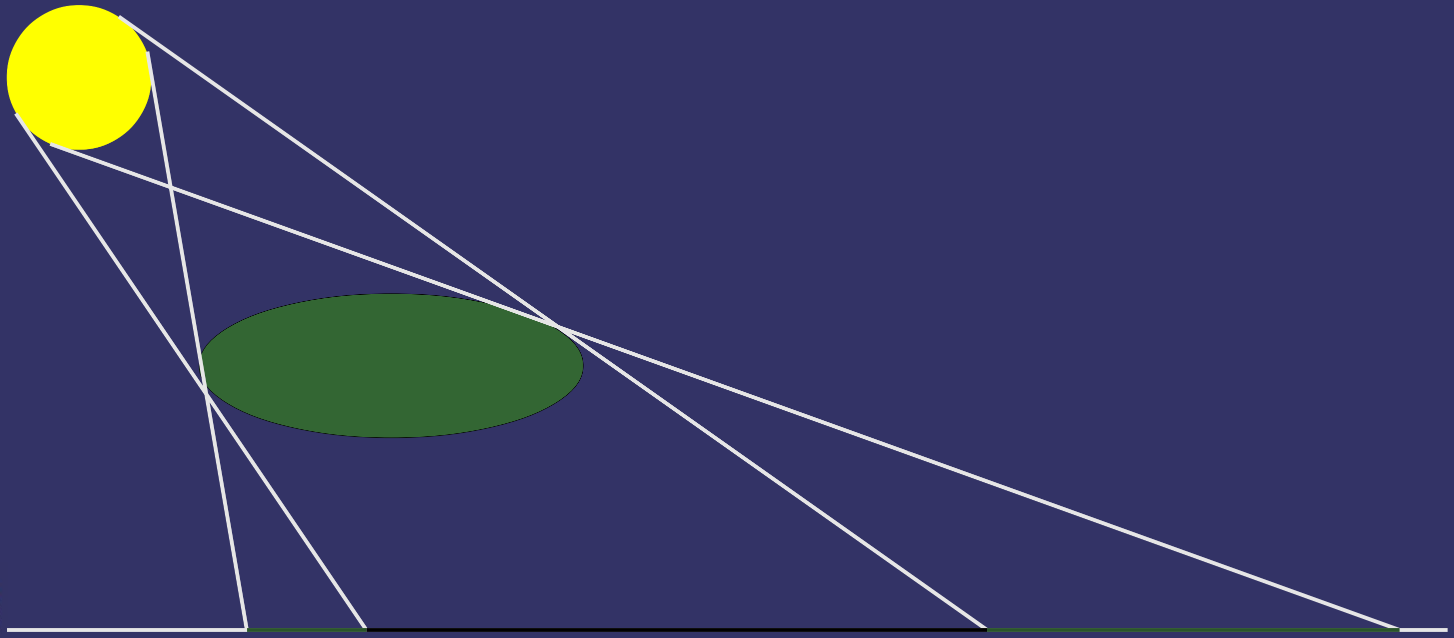
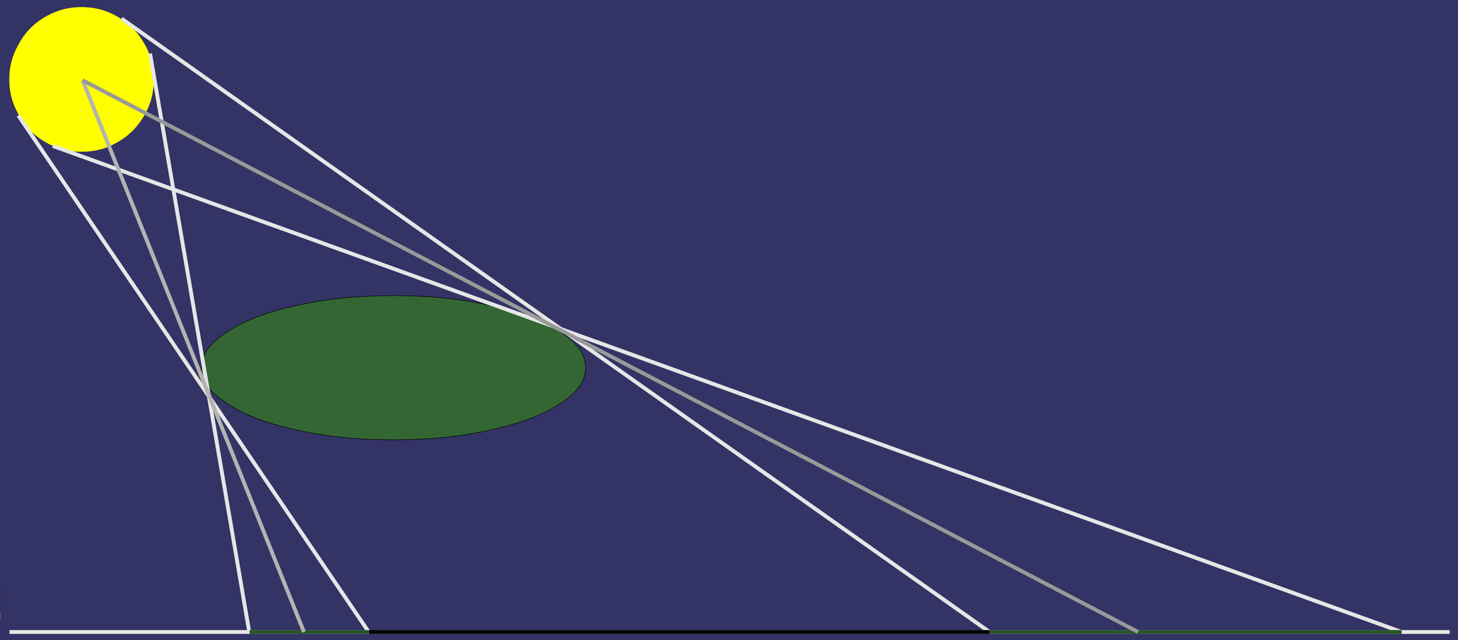
Soft Shadows

- 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



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Soft Shadows

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

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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

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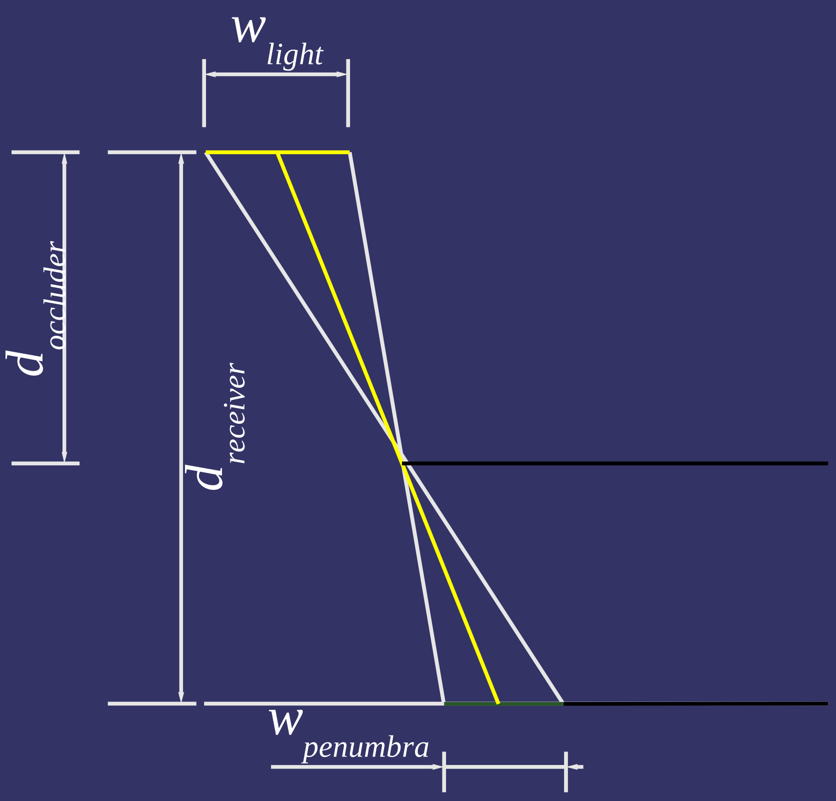
Soft Shadows

- Estimate penumbra size using:

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



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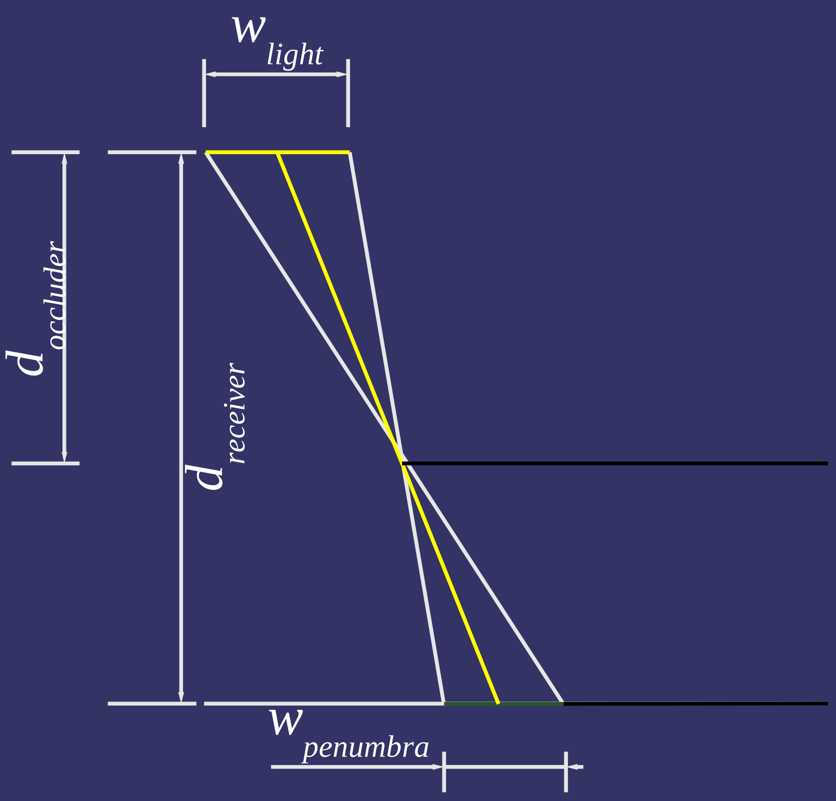
Soft Shadows

- Estimate penumbra size using:

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

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



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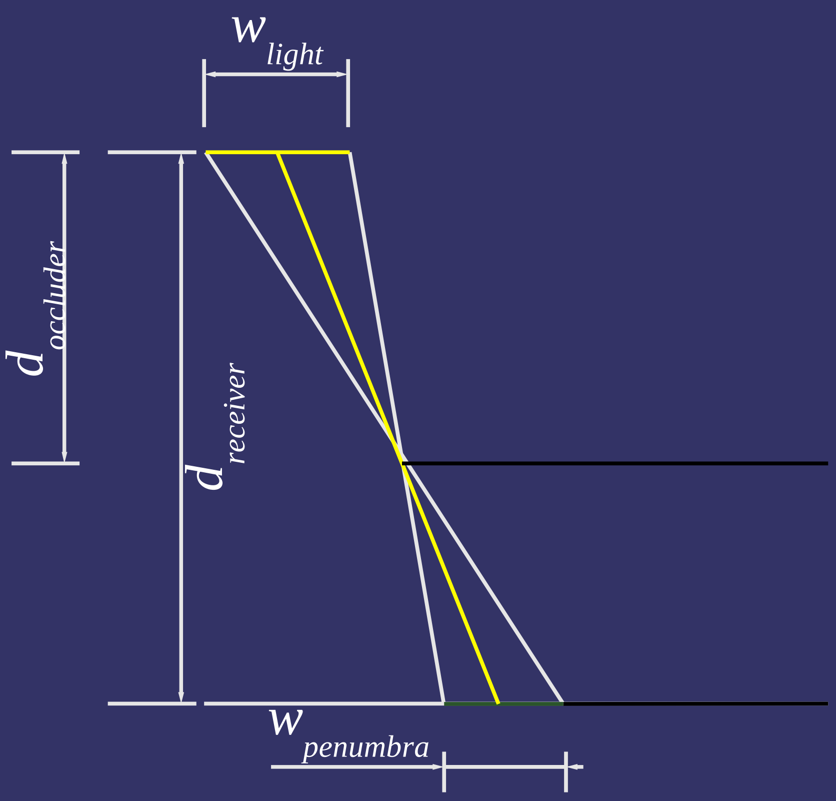
Soft Shadows

- Estimate penumbra size using:

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

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



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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

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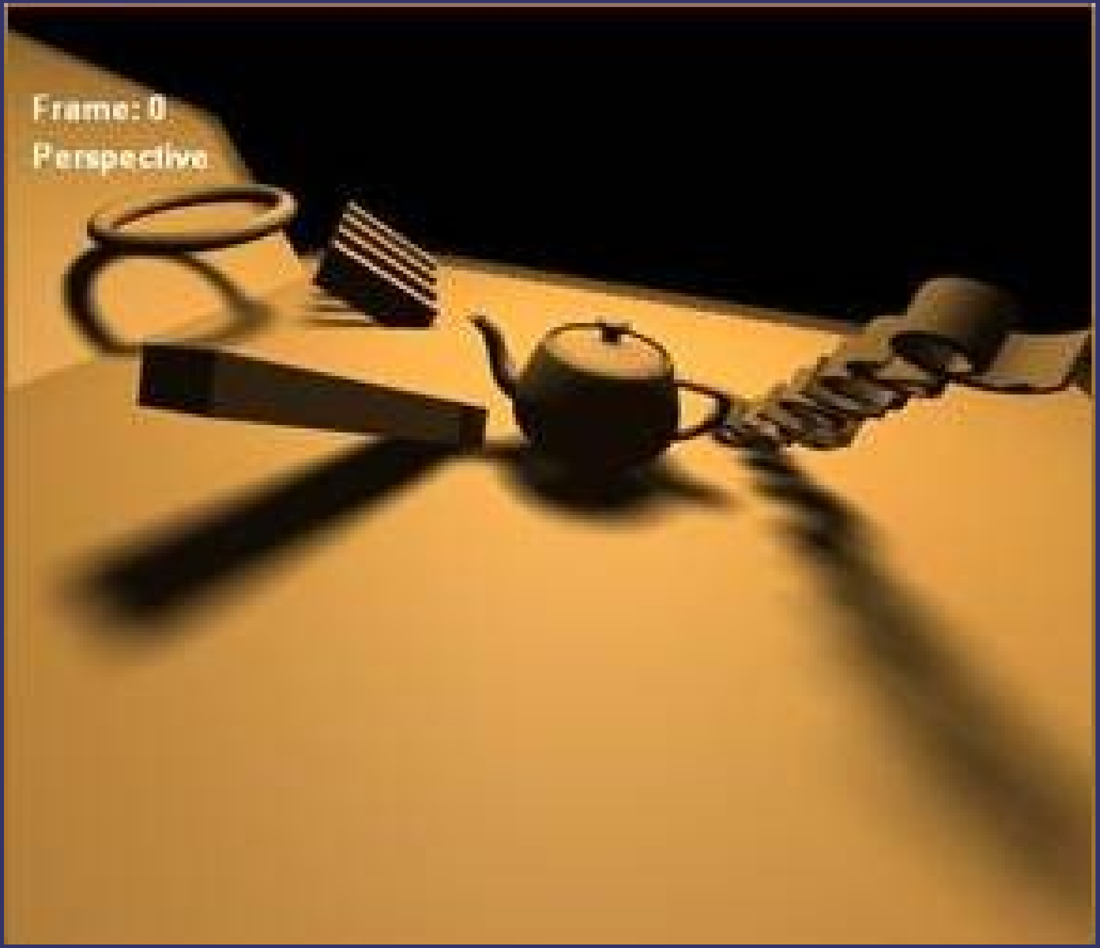
Soft Shadows

- 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

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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
  - As r_s increases, each texel covers more of the surface
  - 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
  - As r_i increases, each pixel covers more of the surface
  - The projected size of a surface at distance r_i is approximately:

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

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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 $d > d_i$

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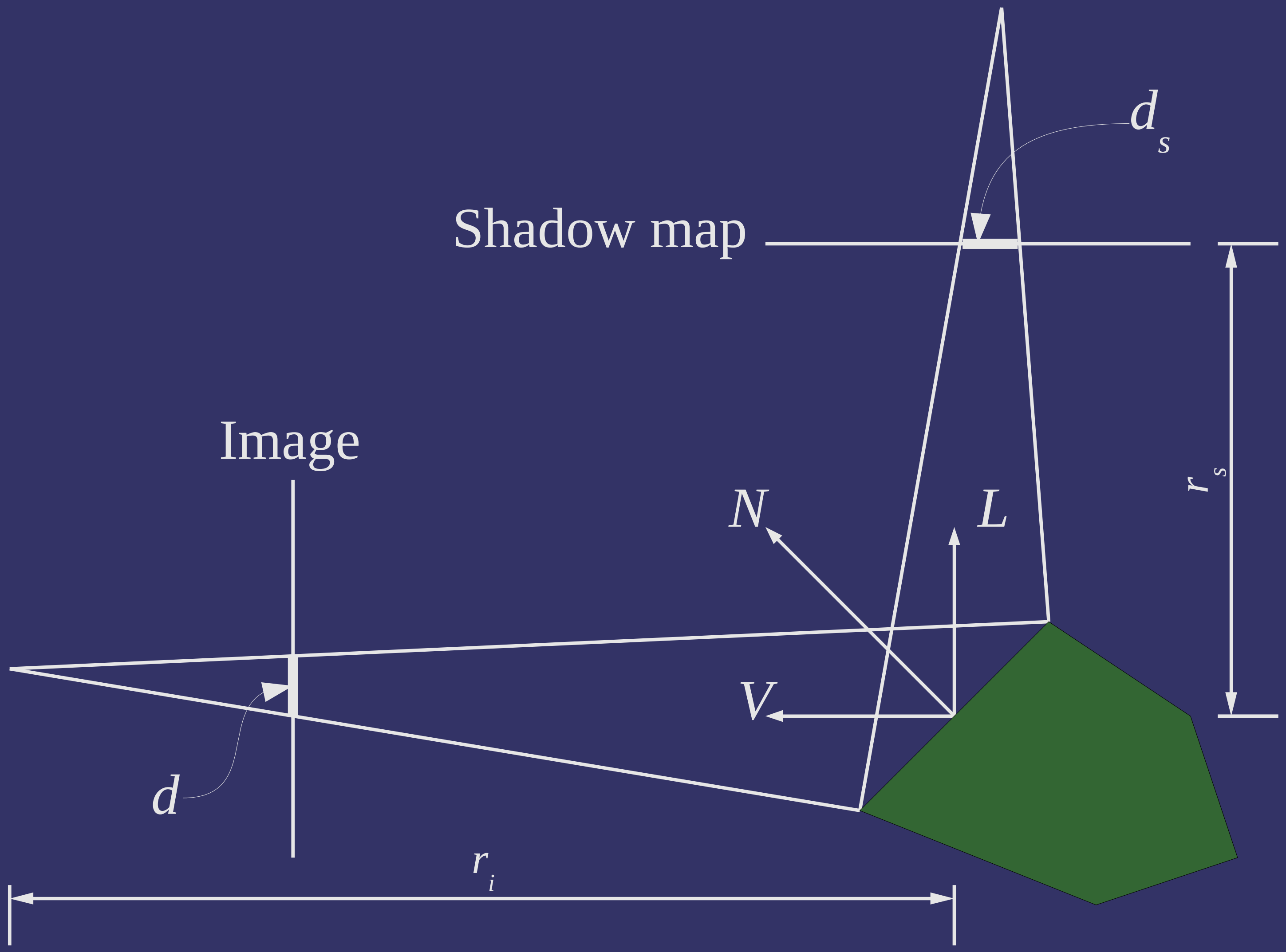
Shadow Map Aliasing



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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 $d > d_i$
  - Matches intuition:
    - 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!

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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!

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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

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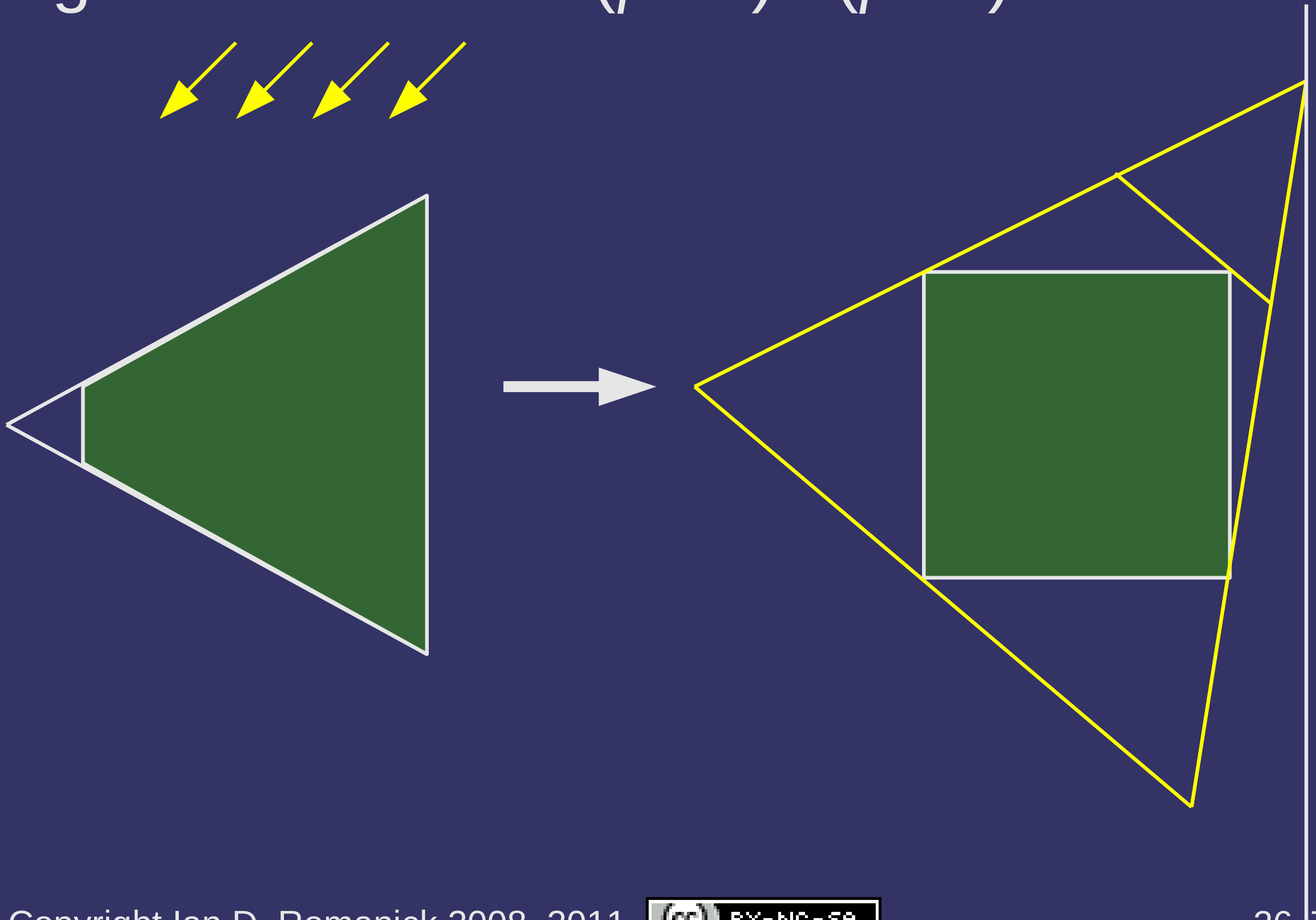
Perspective Shadow Maps

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



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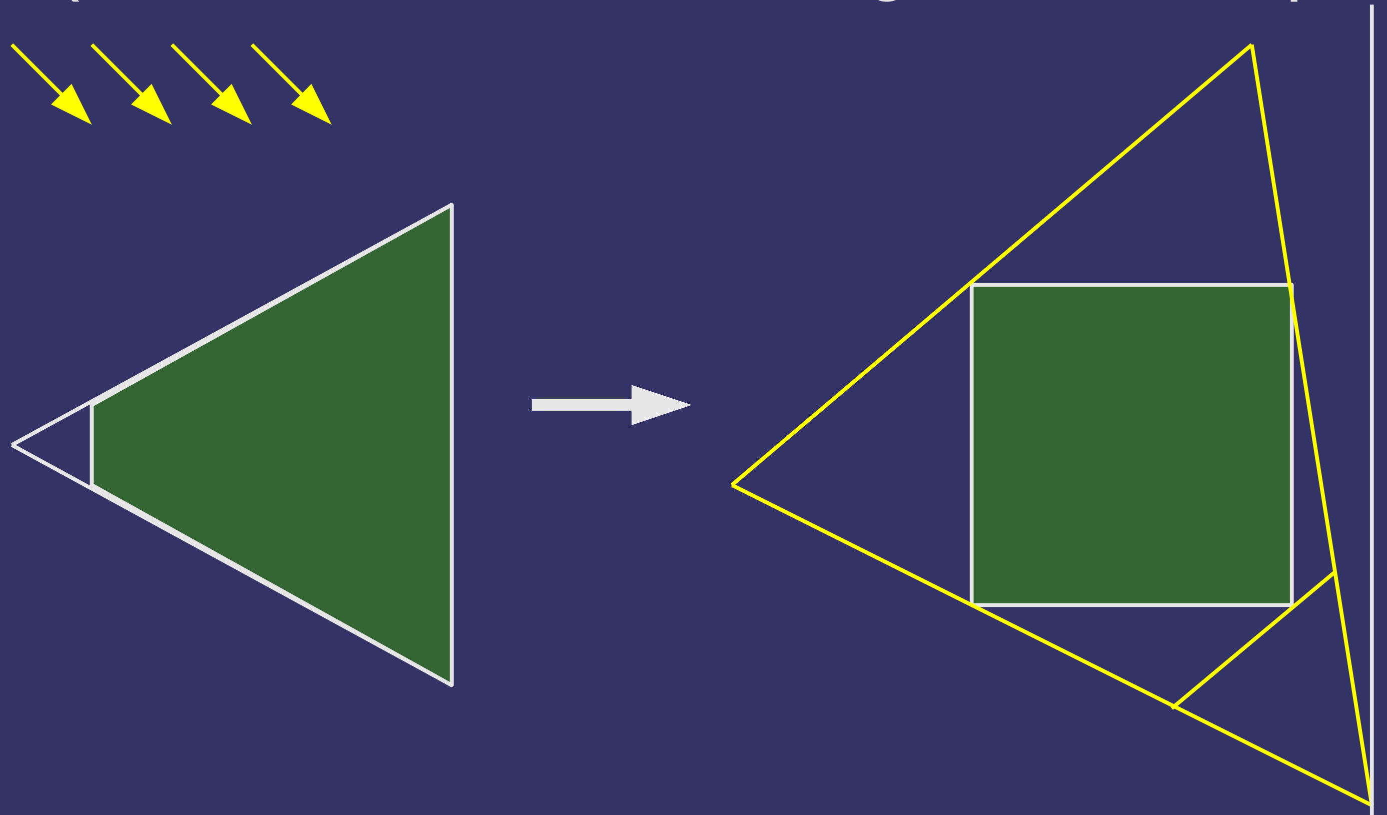
Perspective Shadow Maps

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



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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

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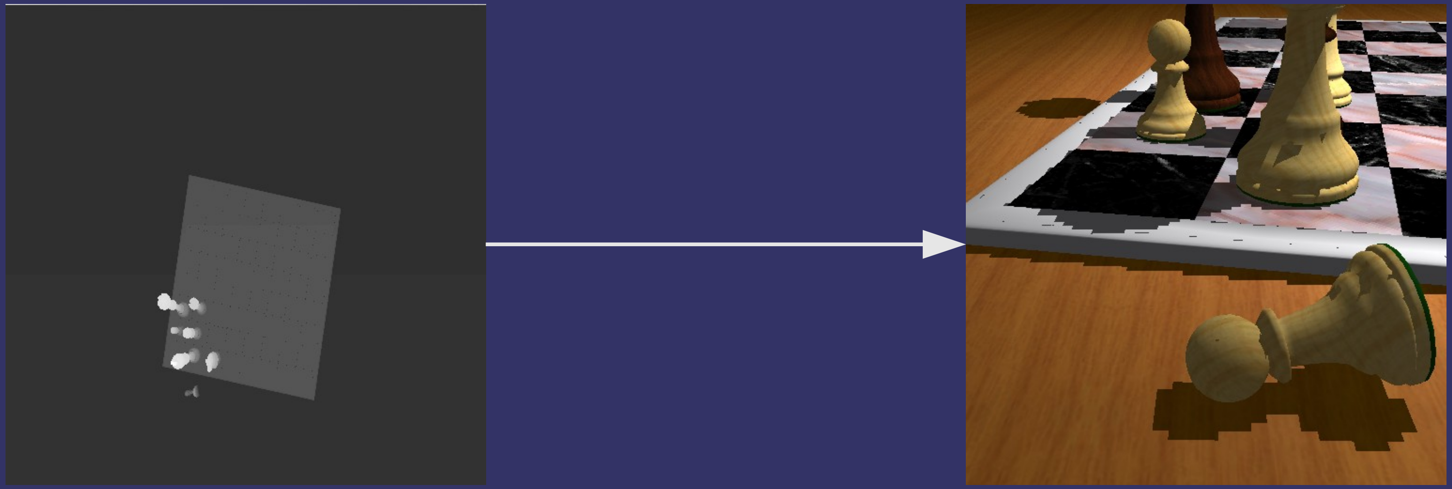
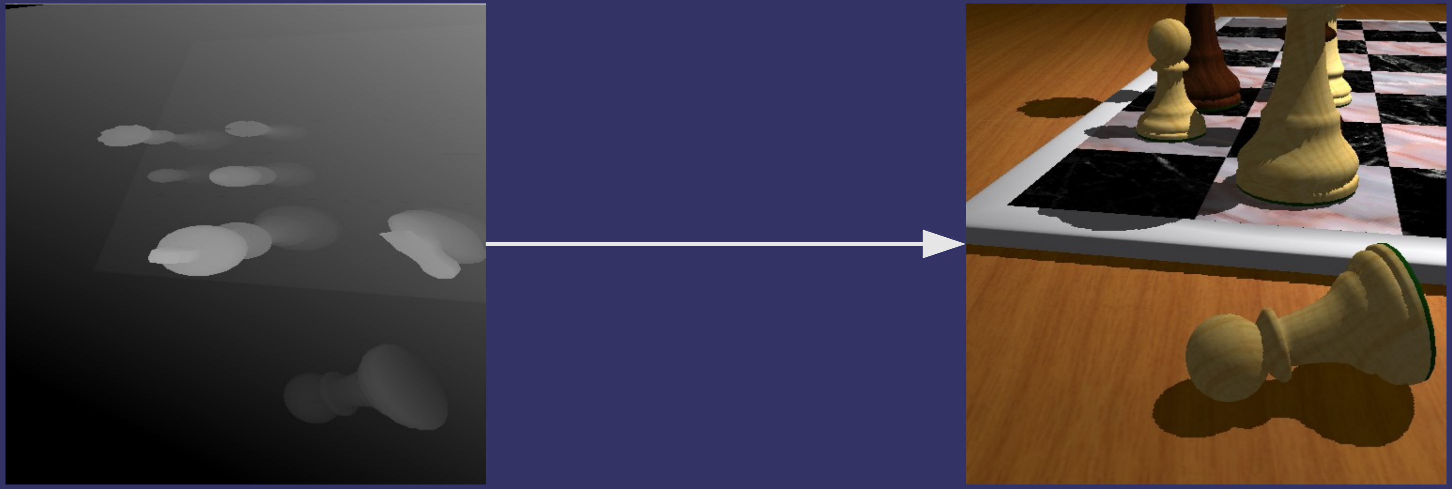
Perspective Shadow Map

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

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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

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Perspective Shadow Maps

- Some significant problems:
  - Shadow map *quality* is view-dependent
  - Several special cases that must be handled depending on light direction / position
  - Difficulties handling shadow casters behind the camera
- Introduced some good ideas:
  - Re-parameterizing the scene based on the camera / light frusta
  - Quantitatively determining when aliasing will occur

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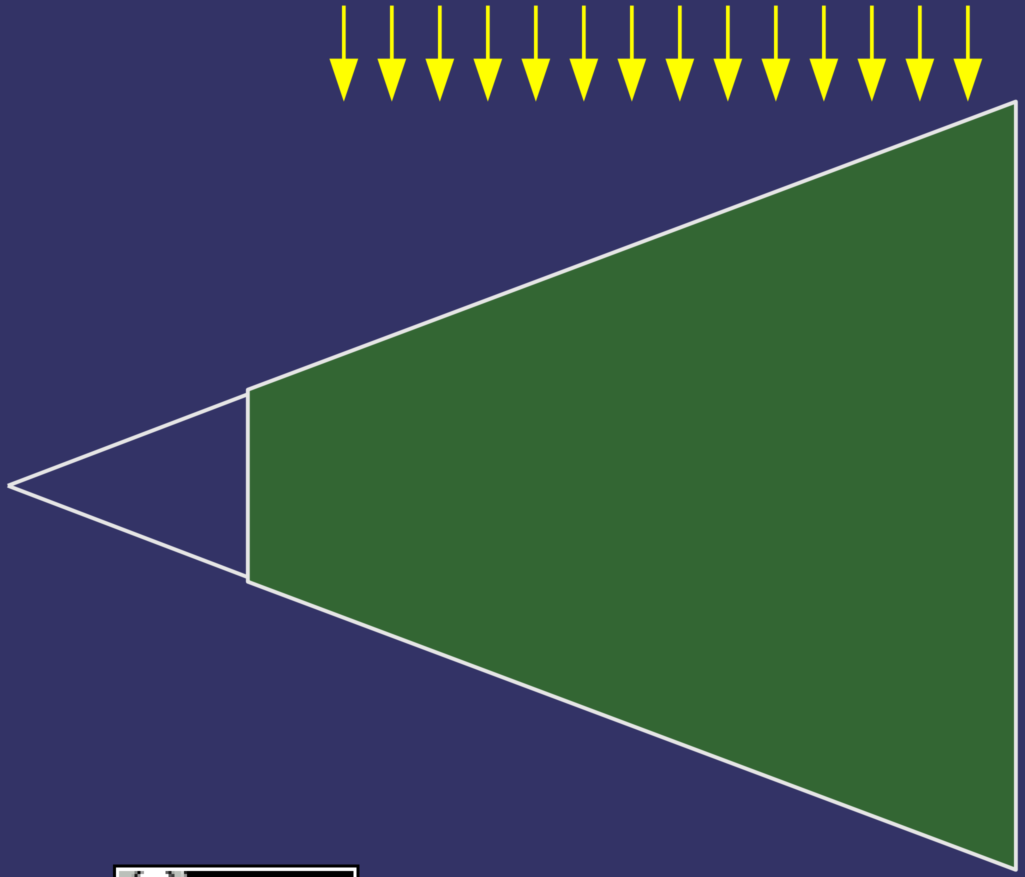
Parallel-Split Shadow Maps

- PSSMs solve most of these problems



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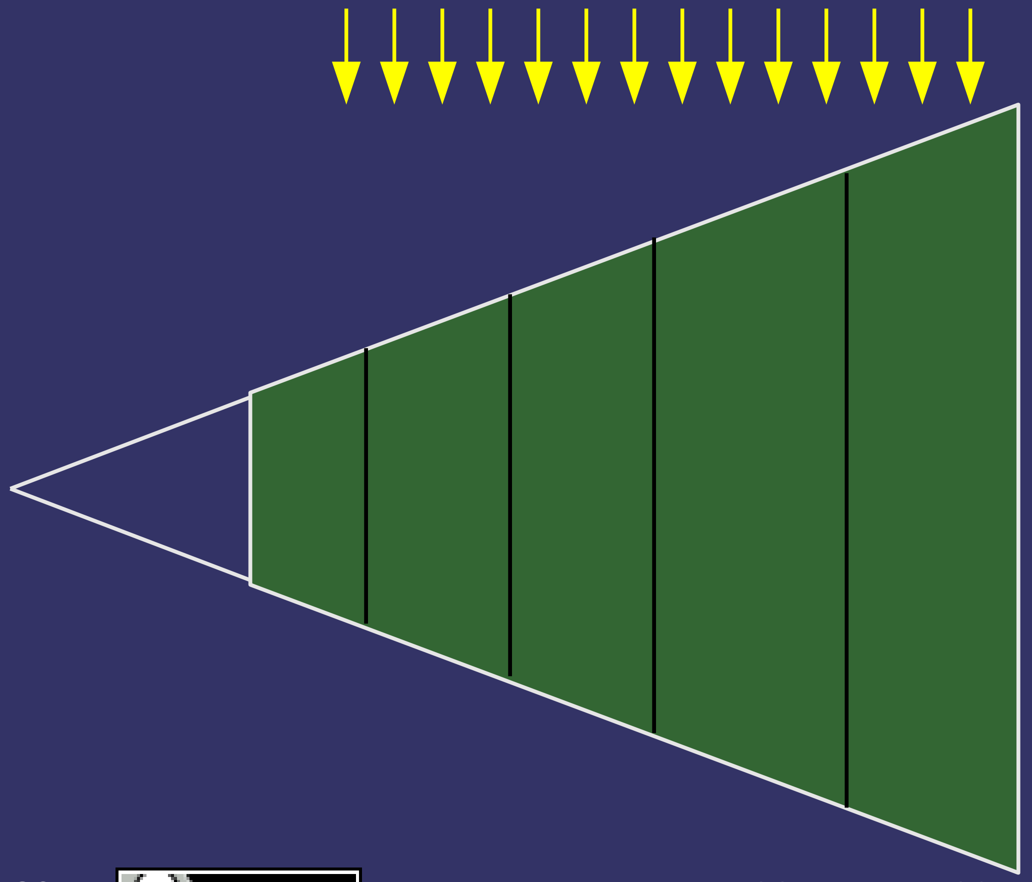
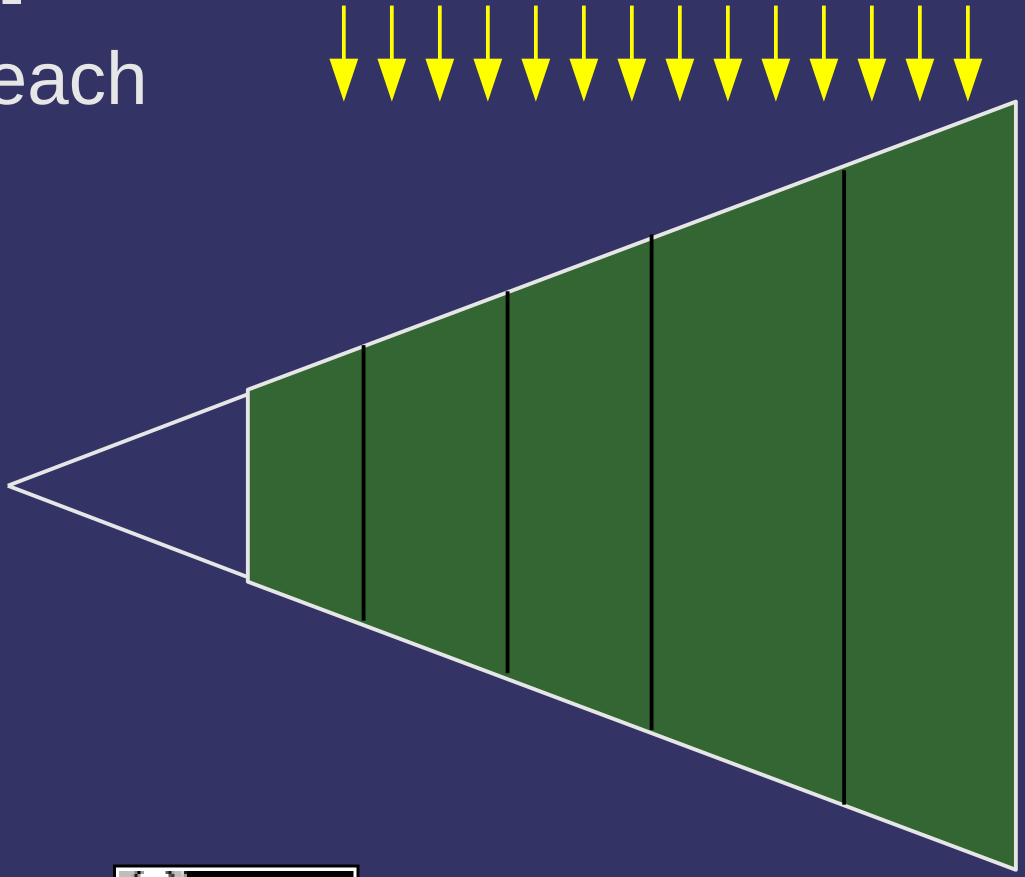
Parallel-Split Shadow Maps

- PSSMs solve most of these problems
  - Split view frustum into m parts with planes parallel to the near / far plane



Parallel-Split Shadow Maps

- PSSMs solve most of these problems
  - Split view frustum into m parts with planes parallel to the near / far plane
  - Calculate light's view-projection matrix for each split region



Parallel-Split Shadow Maps

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  - Split view frustum into m parts with planes parallel to the near / far plane
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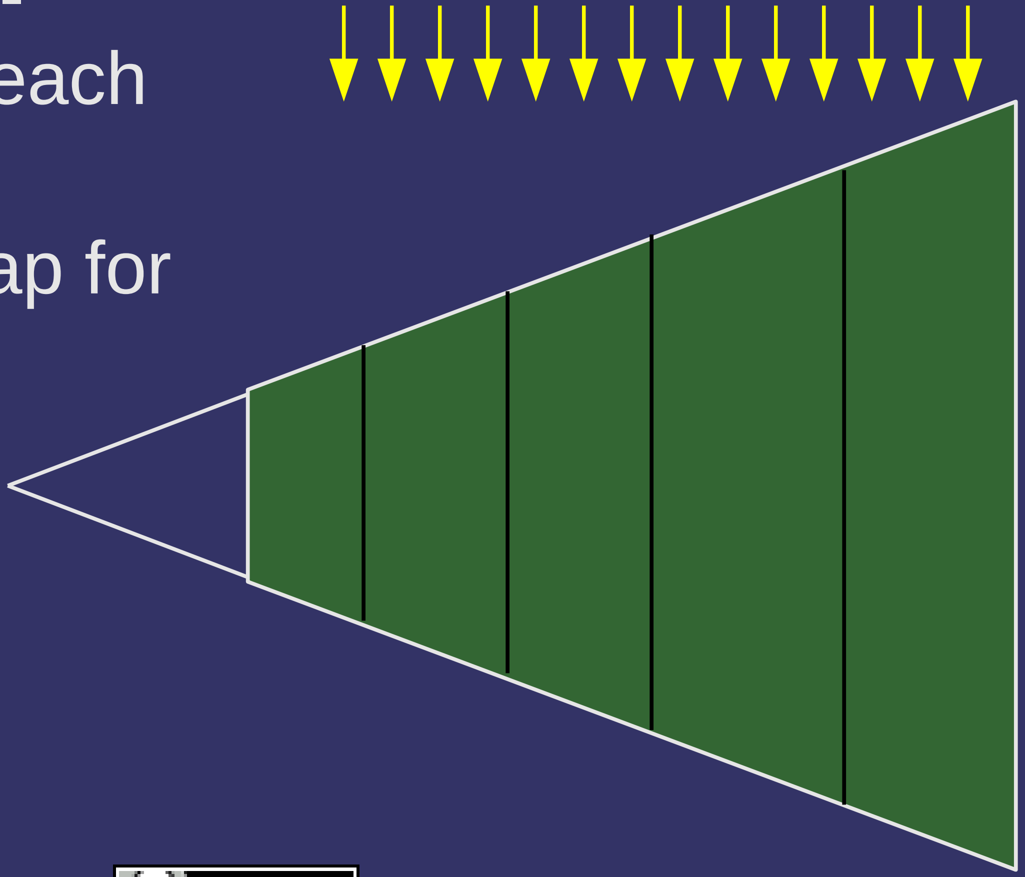
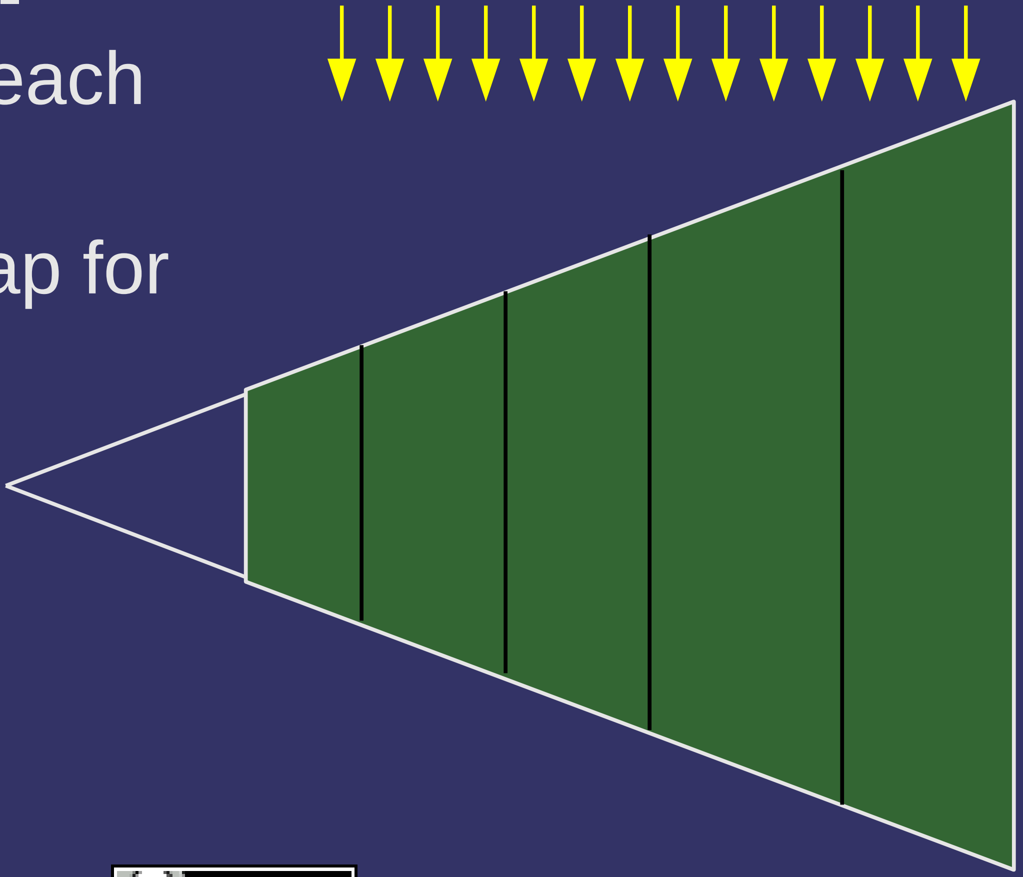
  - Generate shadow map for each split region



Parallel-Split Shadow Maps

- PSSMs solve most of these problems
  - Split view frustum into m parts with planes parallel to the near / far plane
  - Calculate light's view-projection matrix for each split region
  - Generate shadow map for each split region
  - Apply shadow maps to scene



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Parallel-Split Shadow Maps

- Aliasing occurs when $d > d_i$

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

  - Rename r_i as z, and call dz the change in z relative to one unit in ds

$$d = \frac{dz}{z\,ds} \frac{N \cdot V}{N \cdot L}$$

  - Ignoring perspective aliasing, this means that we want dz / zds to be constant over the entire view
    - Call this constant ρ

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Parallel-Split Shadow Maps

- Optimal shadow map distribution is:

$$\frac{ds}{z\,dz}=\rho\Rightarrow s(z)=\int_0^s ds=\frac{1}{\rho}\int_n^z\frac{1}{z}dz=\frac{1}{\rho}\ln\left(\frac{z}{n}\right)$$

  - Since $s(f)$ = 1, $\rho = \ln(f / n)$

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Parallel-Split Shadow Maps

- Current hardware can't do this non-linear z transform
  - Discretely perform the mapping in steps at the split planes

$$s_i = \mathrm{s}(C_i^{\log}) = \frac{1}{\ln(f/n)} \ln\left(\frac{C_i^{\log}}{n}\right)$$

  - Each split gets 1 / m of total texture resolution, substituting i / m for s_i

$$C_i^{\log} = n\left(\frac{f}{n}\right)^{i/m}$$

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Parallel-Split Shadow Maps

- Alternately, the view frustum could be divided into equally sized pieces

$$C_i^{uni} = \frac{(f - n) \times i}{m} + n$$

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Parallel-Split Shadow Maps

- Neither split strategy works very well
  - Logarithmic splitting groups split-planes too close to the near plane
  - Uniform splitting doesn't group split-planes close enough to the near plane

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Parallel-Split Shadow Maps

- Neither split strategy works very well
  - Logarithmic splitting groups split-planes too close to the near plane
  - Uniform splitting doesn't group split-planes close enough to the near plane
- Instead, use a hybrid of the two

$$C_i = \lambda C_i^{\log} + (1 - \lambda) C_i^{uni}$$

  - λ is tunable parameter
  - The paper calls this the *practical split scheme*

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Parallel-Split Shadow Maps

- Light transformation matrices are determined much like before
  - Calculate view-projection matrix for light relative to whole view frustum
  - Transform each split region to light's post-projection space
  - Calculate AABB for transformed split region
  - Use AABB to calculate “crop” transformation to scale and center split region to full view

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Parallel-Split Shadow Maps

- To apply shadows, the shader must determine which region contains the current fragment
  - Determine the split-plane, C_s, nearest the camera but farther away than the current fragment
  - C_s determines which shadow map to apply
  - The light transforms, C_i distances, and shadow maps (samplers) must be provided to the shader as arrays of uniforms
    - m is a compile-time constant

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Parallel-Split Shadow Maps

- Only directional lights have been dealt with so far

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Parallel-Split Shadow Maps

- Only directional lights have been dealt with so far
  - Light transformations for each split region are calculated from the light's post-projection space

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Parallel-Split Shadow Maps

- Only directional lights have been dealt with so far
  - Light transformations for each split region are calculated from the light's post-projection space
  - For point lights, transform by the light's view-projection matrix *first*
    - This effectively converts the point-light to a directional light!

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References

Zhang, F., Sun, H., Nyman, O. “Parallel-Split Shadow Maps on Programmable GPUs,” in *GPU Gems 3,* ed. Hubert Nguyen, pp. 202 – 237. Boston, MA: Addison-Wesley, 2008. http://appsrv.cse.cuhk.edu.hk/~fzhang/pssm_project/

Wimmer, M., Scherzer, D., and Purgathofer, W. “Light Space Perspective Shadow Maps,” in *Proceedings of Eurographics Symposium on Rendering*, pp. 143 - 151. Norrköping, Sweden: Eurographics Association, 2004. http://www.cg.tuwien.ac.at/research/vr/lispsm/

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Next week...

- More shadow maps
  - Optimal light viewing frustum calculations
  - Resolution matched shadow maps
  - Omni-directional lights
  - Texture atlases for shadow maps
  - Read:

Brabec, Stefan and Annen, Thomas and Seidel, Hans-Peter, "Shadow Mapping for Hemispherical and Omnidirectional Light Sources." In *Advances in Modeling, Animation and Rendering* (Proceedings Computer Graphics International 2002) , pages 397-408. Springer, 2002. http://www.mpi-inf.mpg.de/~brabec/

Aaron E. Lefohn and Shubhabrata Sengupta and John D. Owens, "Resolution Matched Shadow Maps." ACM Transactions on Graphics , vol. 26 , no. 4 , pages 20:1--20:17. ACM, 2007. http://www.idav.ucdavis.edu/publications/print_pub?pub_id=919

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