Shadows

Light and shadows

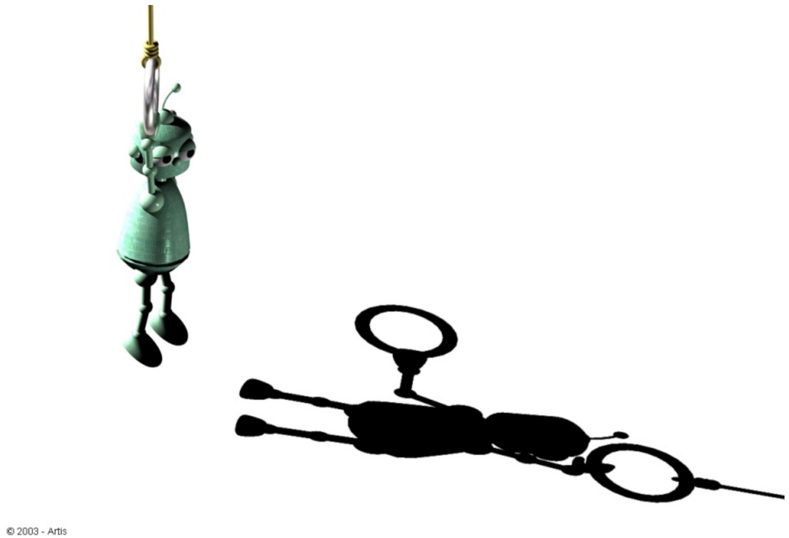
- Shadows increase realism:

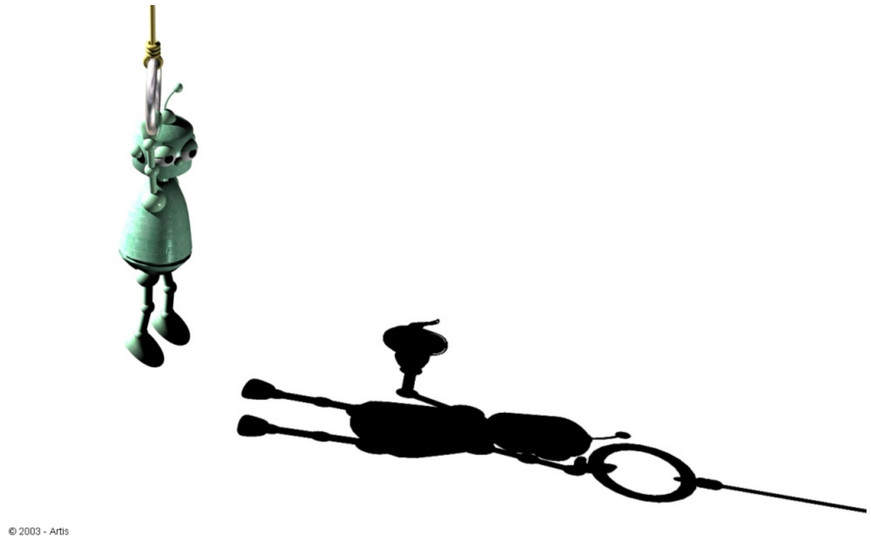
Zaxxon (1982)

Cry Engine

Light and shadows

- Shadows increase realism
- Shadows help you perceive:
  - hidden objects





Light and shadows

- Shadows increase realism
- Shadows help you perceive:
  - hidden objects
  - the relative position of objects

Light and shadows

- Shadows increase realism
- Shadows help you perceive:
  - hidden objects
  - the relative position of objects
  - the object shape

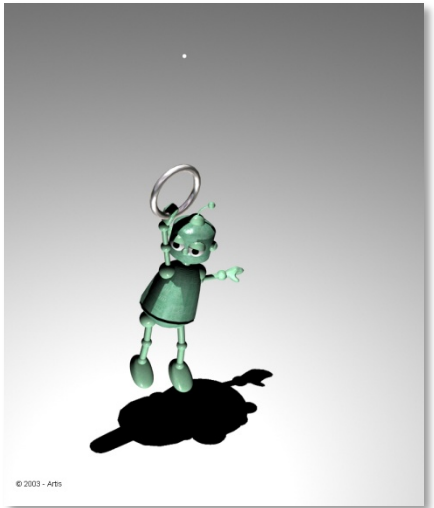
Light and shadows

- Constraints for real-time shadows
  - Light sources — Dynamic
  - *Shadow Casters* — Dynamic
  - *Shadow Receivers* — Dynamic

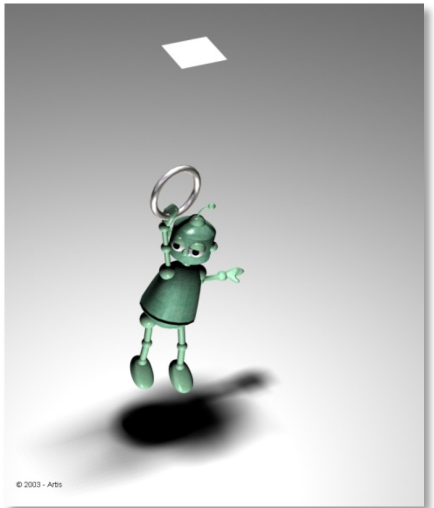
Doom 3 (2004)

Light and shadows

- 2 kind of shadows:
  - **Hard shadows**
    - Point light source

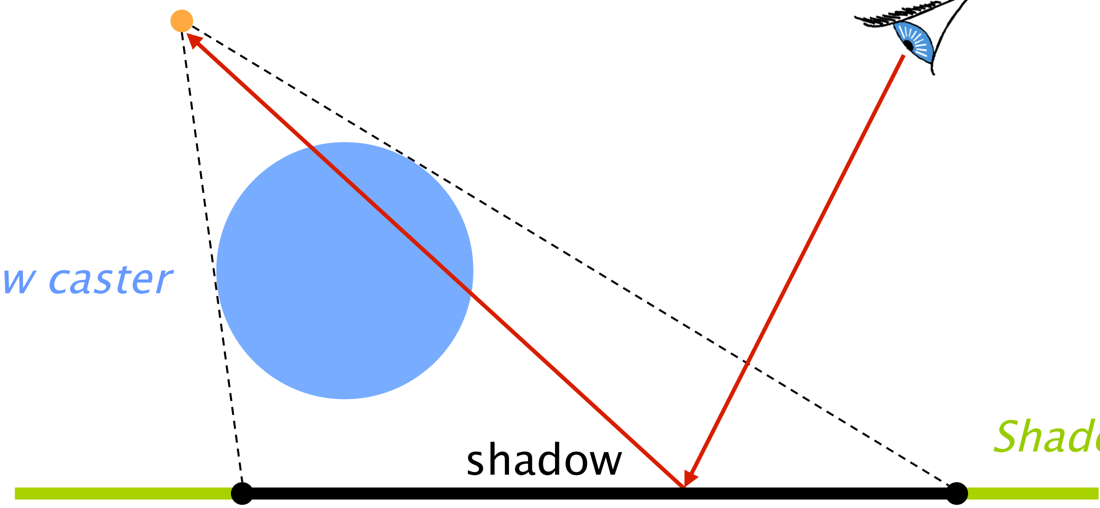


  - **Soft shadows**
    - Extended light source

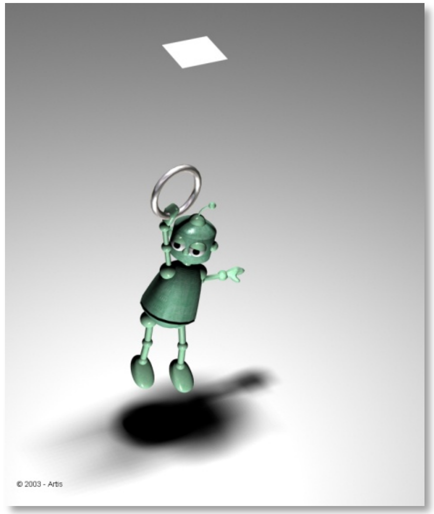


Hard shadow

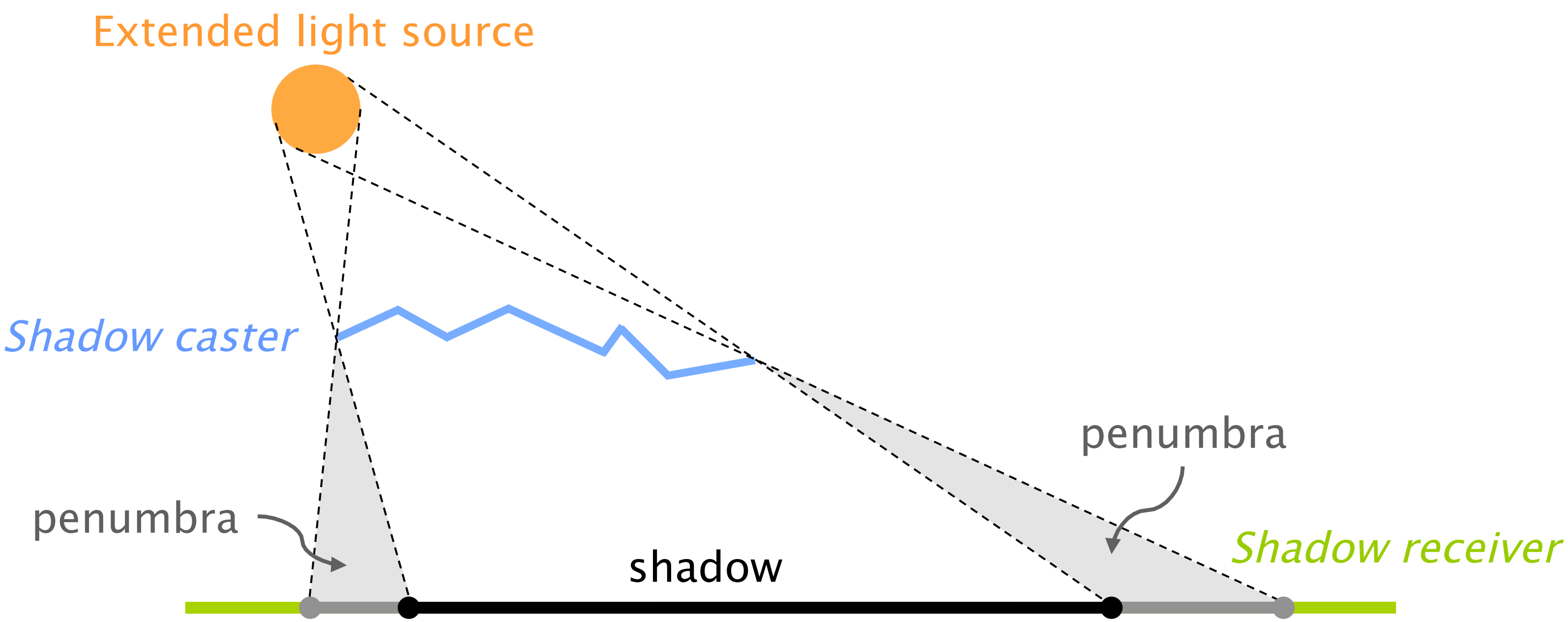
- Point light source
- A point is *in shadow* if it is not visible from the light source

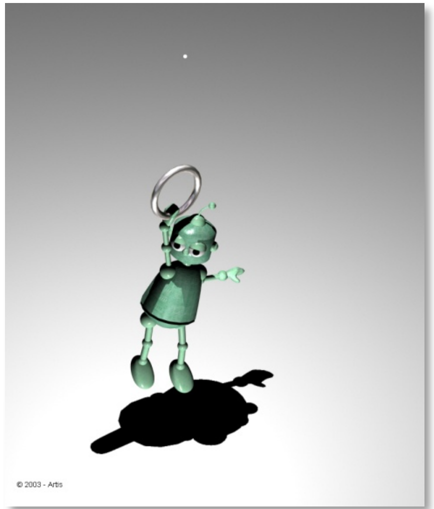


Soft shadow



- 3 areas:
  - Shadow: light source completely hidden
  - Penumbra: light source partially hidden
  - Lit: light source completely visible

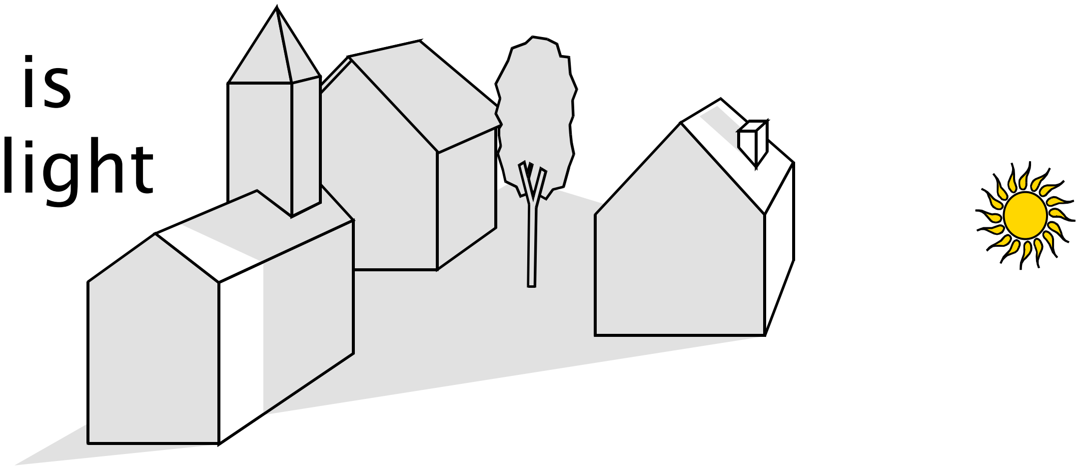




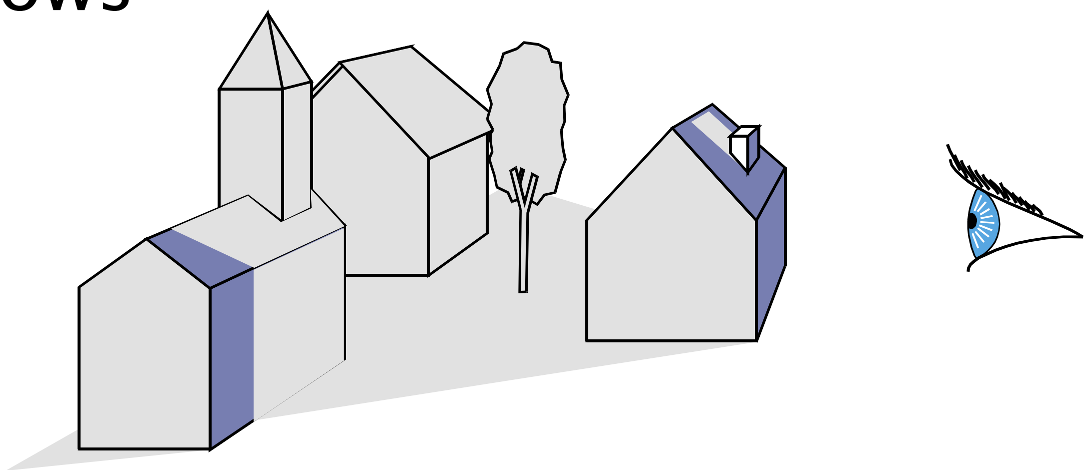
Computing hard shadows

Shadows/visibility

- A point is lit if it is visible from the light source

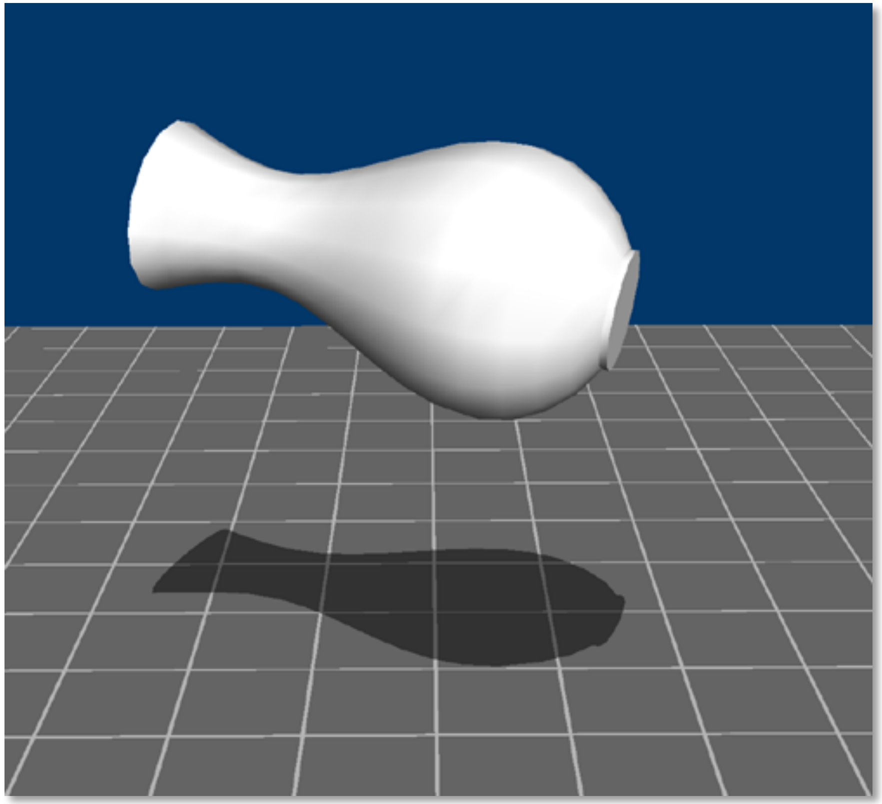


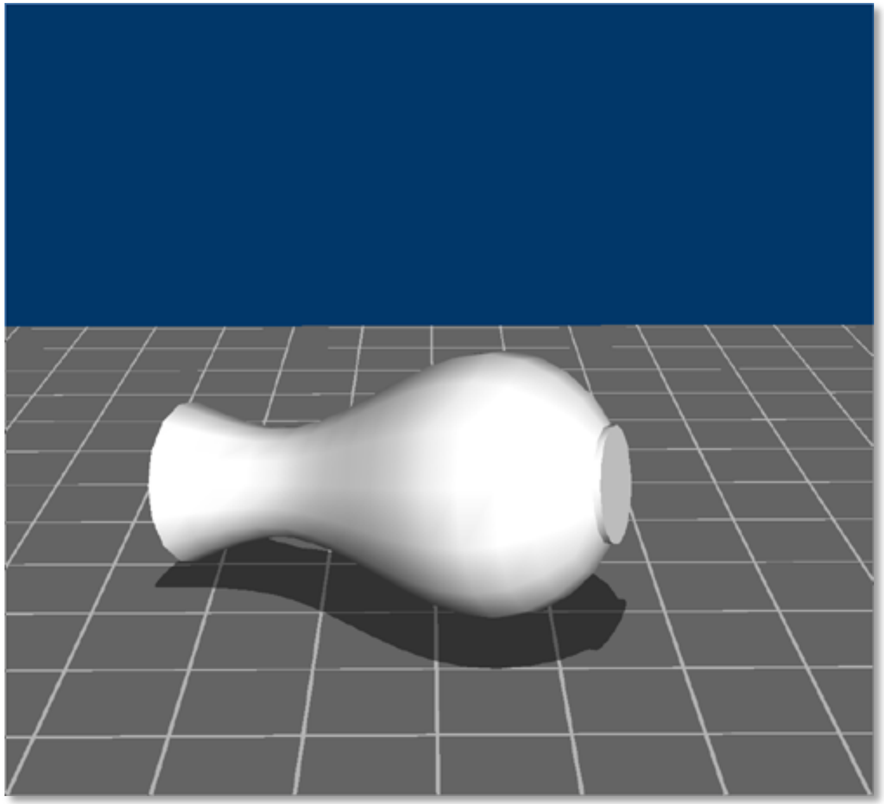
- Computing shadows= visible surface determination



Flat shadows

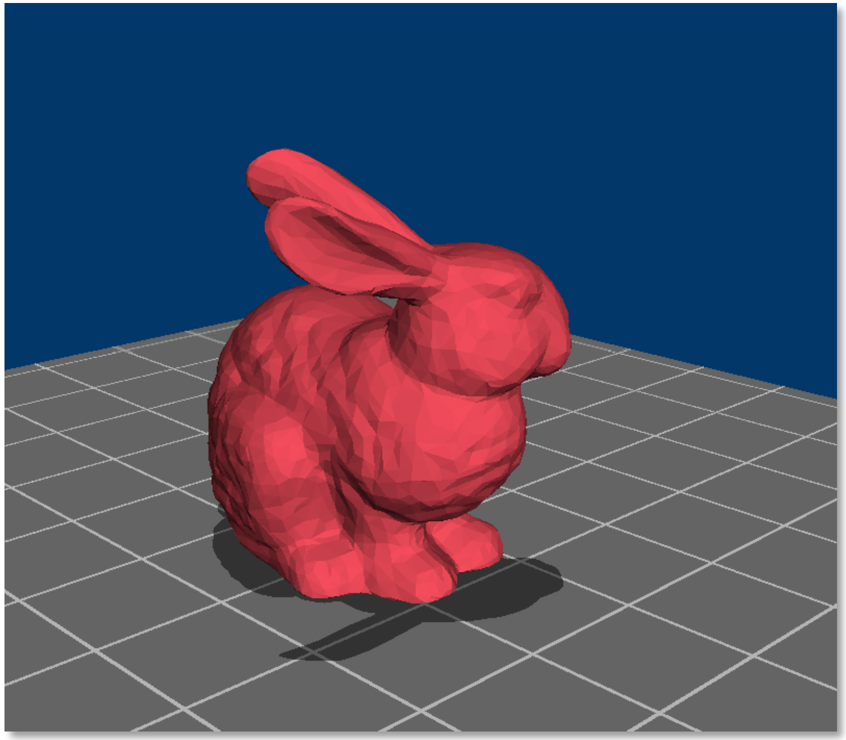
- Draw the graphics primitives again, projected on the ground

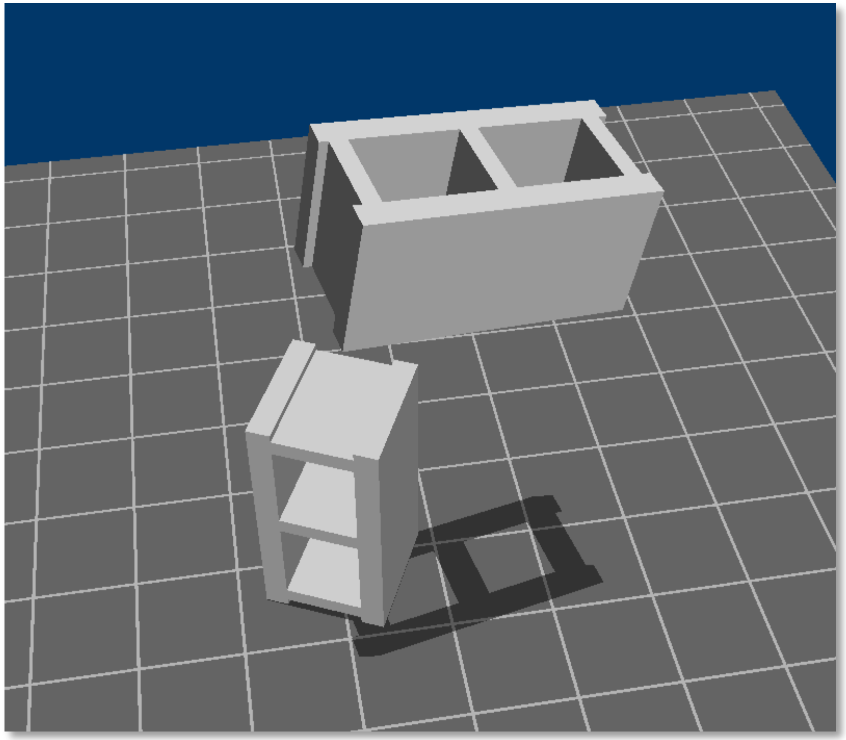




Flat shadows+/-

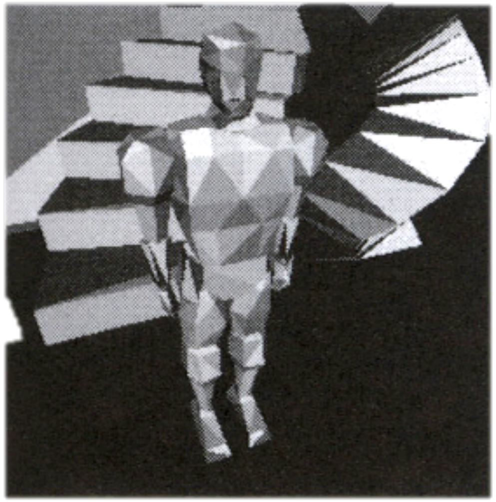
- + Fast, easy to code
- - No self shadows, no shadows on curved surfaces, no shadows on other objects





Using textures

- Separate between occluder and receiver
- Draw a picture of the occluder, seen from the light source
- Use it as a texture on the receiver



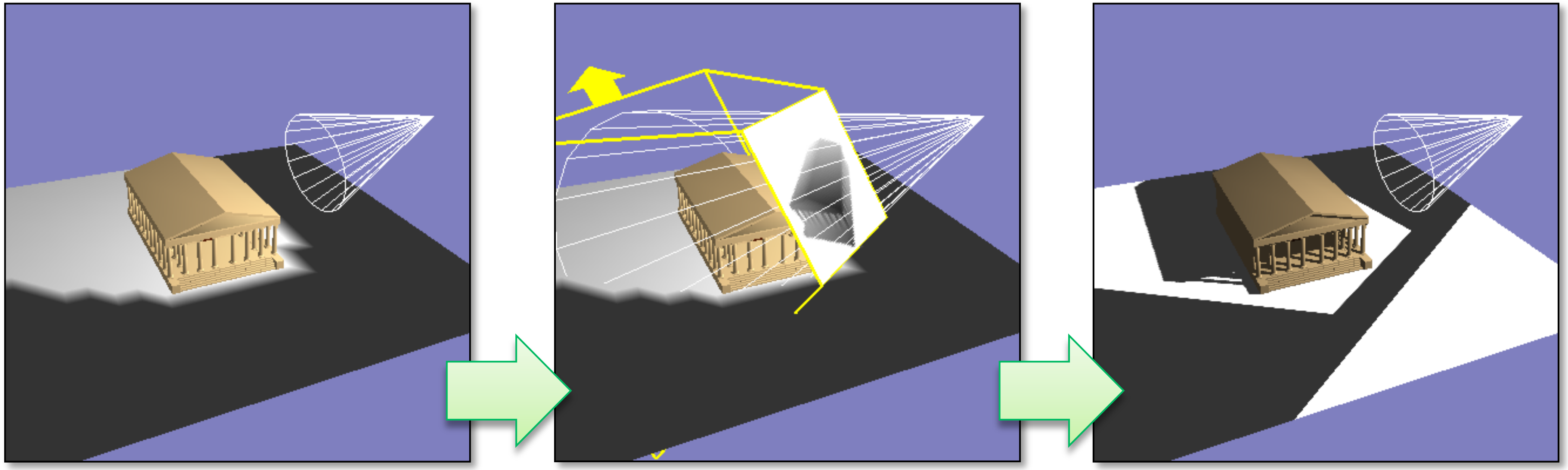
From the light source　　From the viewpoint

Möller & Haines "Real Time Rendering"

Modern shadow algorithms

- **Shadow Maps**
  - Image space approach
- **Shadow Volumes**
  - Object space approach

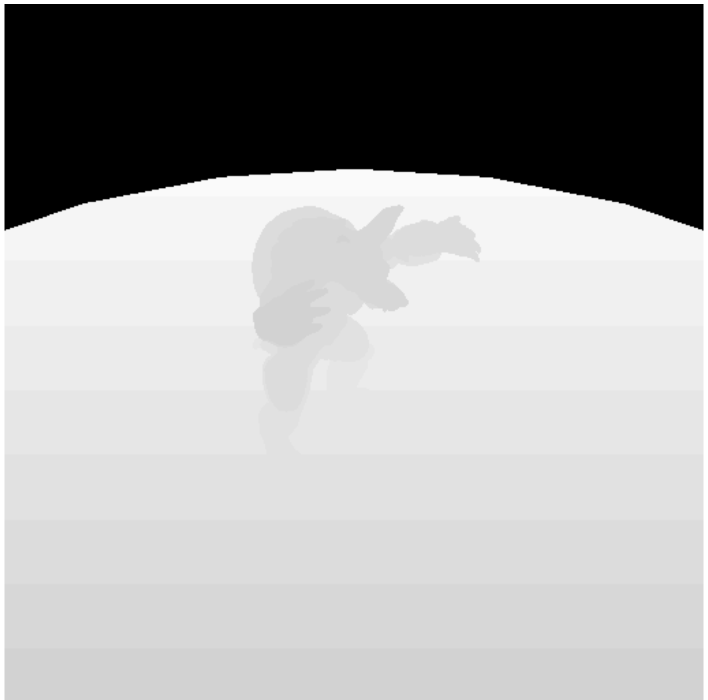
Shadow maps



1. *Offscreen* rendering **from the light source**
   - Keep z-buffer in a texture
2. Rendering **from the view point**
   - Transform current pixel into light space coord.
   - Compare current depth with depth in texture
   - Change lighting depending on visibility test

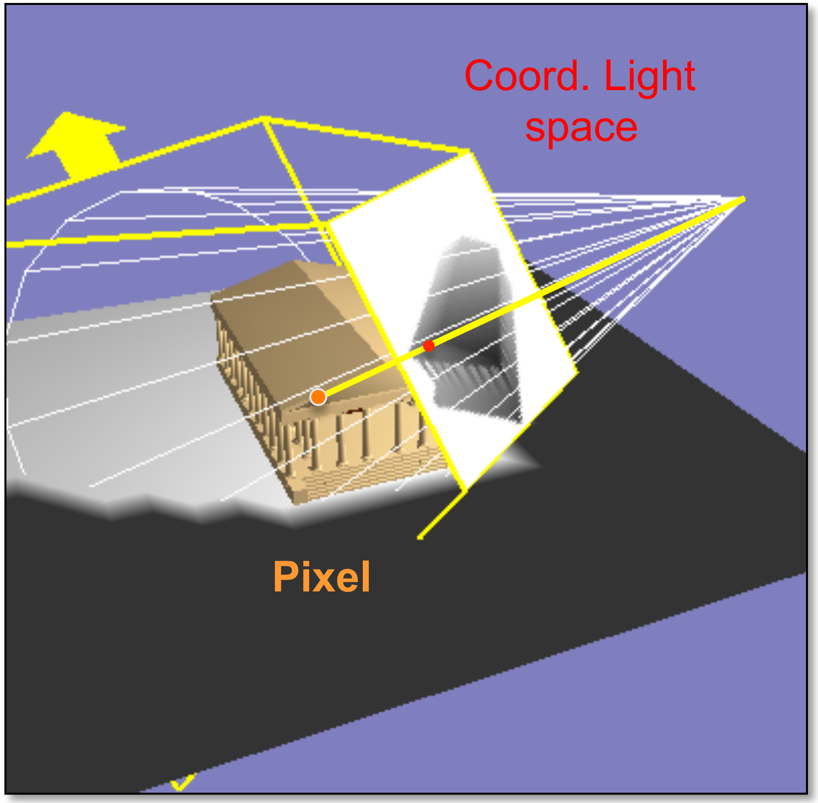
Shadow maps : step 1

- offscreen rendering from the light source:
  - Transformation + projection matrix
  - Light space coordinates
  - Store depth into an FBO
- FBO -> texture



Shadow maps : step 2

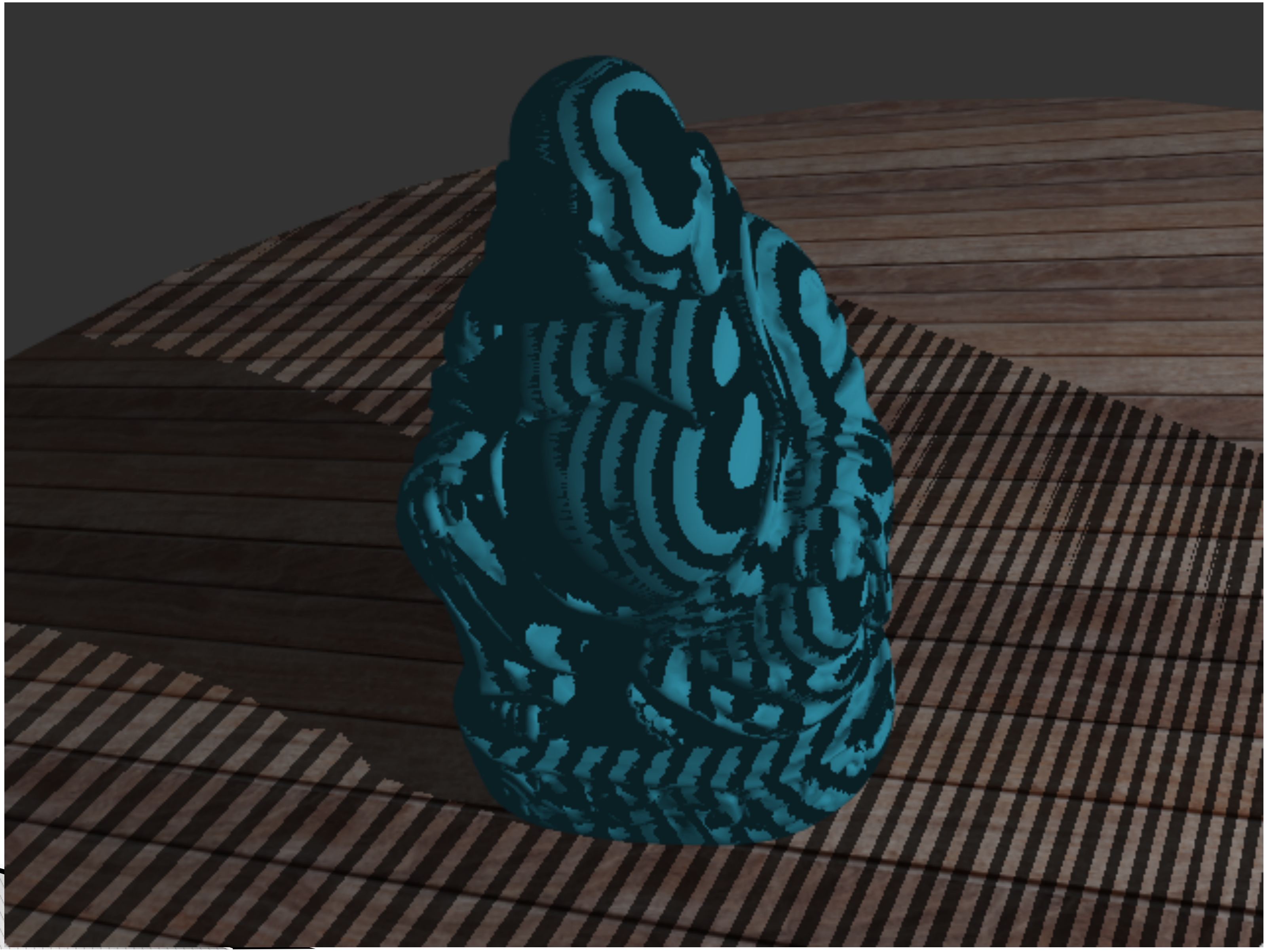
- Standard rendering
- Vertex shader:
  - Compute projection in screen space
  - And in light space
- Fragment shader :
  - Interpolate coordinates
  - Coord. texture shadow map
  - z = distance light source
  - z from shadow map
  - Comparison
  - ⚠Coord. texture $=[0,1]^2$



Shadow maps: comparison

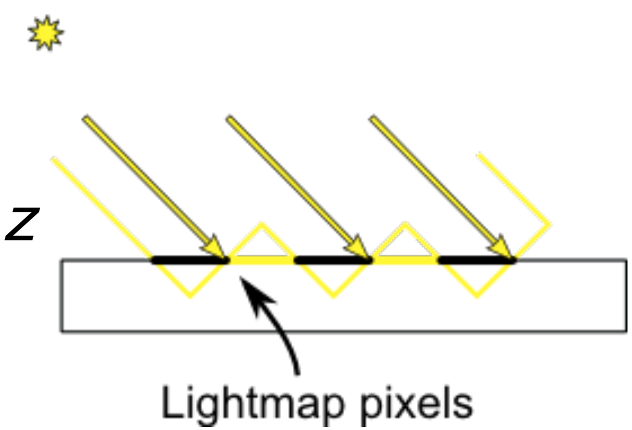
- z_shadowMap < z_computed
  - In shadow
  - Ambient lighting only
- z_shadowMap == z_computed
  - Lit
  - Ambient + Diffuse + Specular
- z_shadowMap > z_computed
  - Should not happen, in theory

Shadow maps: 1^{st} picture



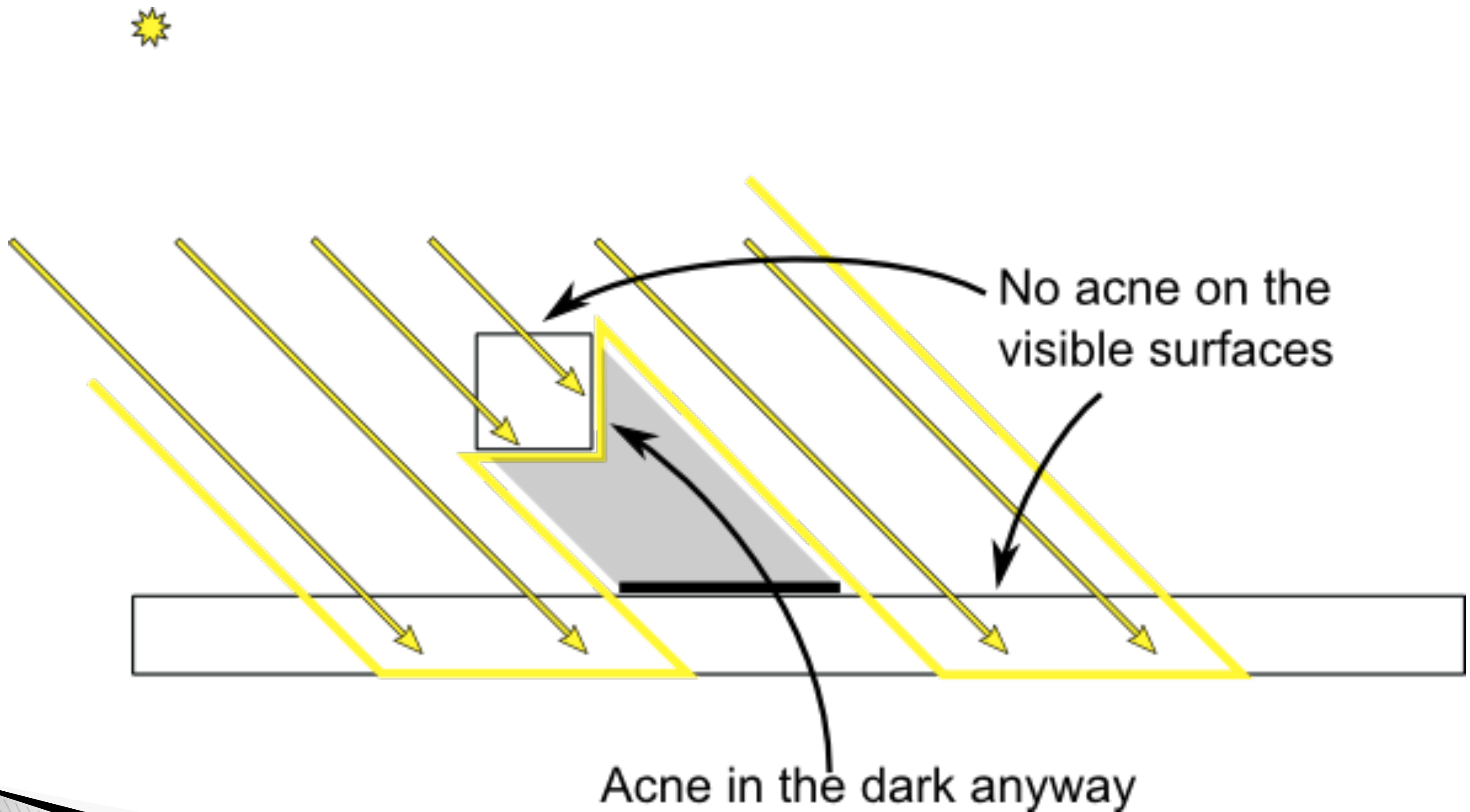
Shadow maps: 1st picture

- "it's not a bug, it's a feature"
- What's happening?
  - Comparison *z* stored/interpolated *z*
  - *z* value constant for each pixel
  - Self-shadowing
- Solutions:
  - Comparison with *z*+epsilon (bias)
  - Draw only back-sided surfaces

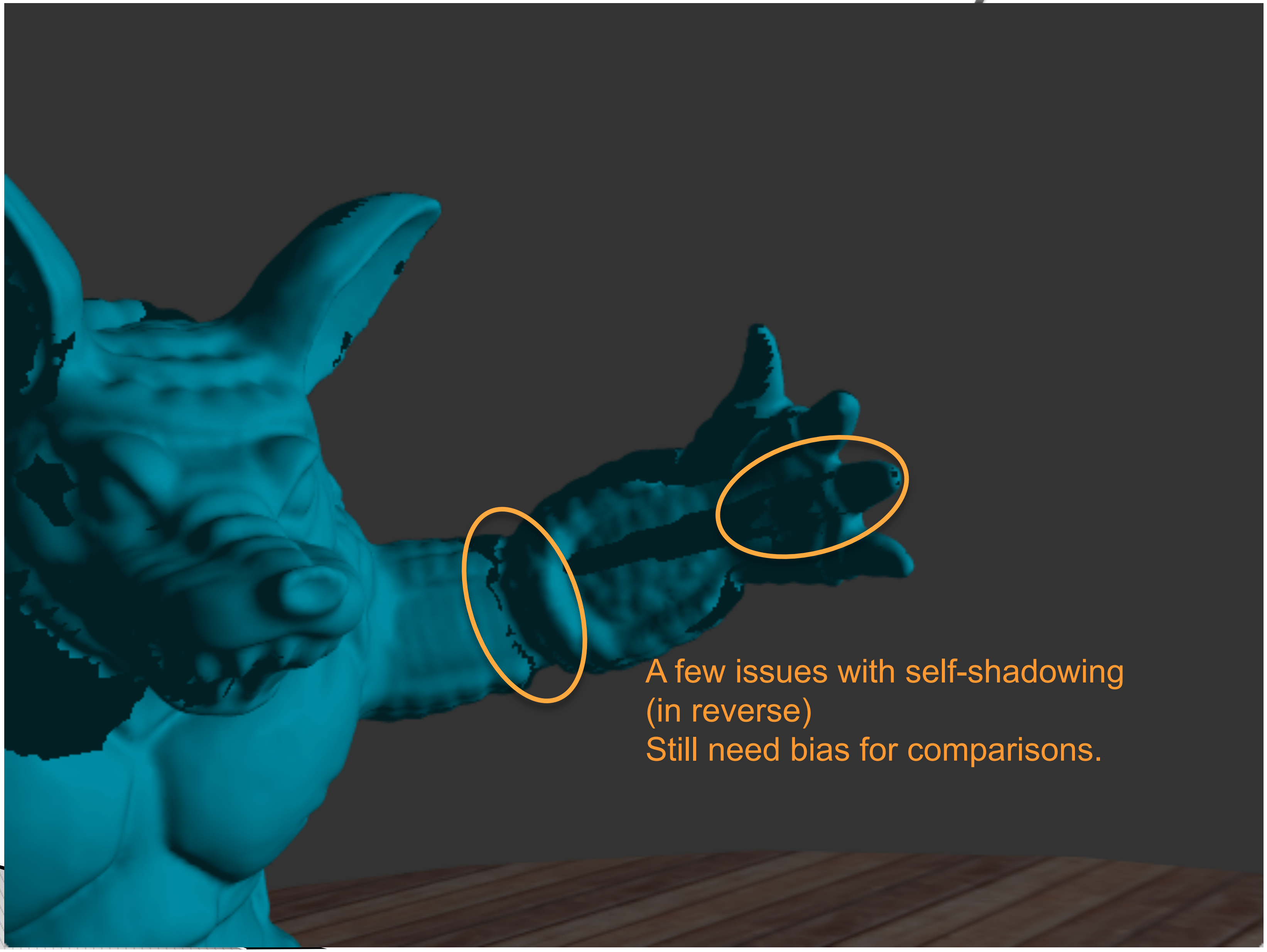


Back-sided surfaces only

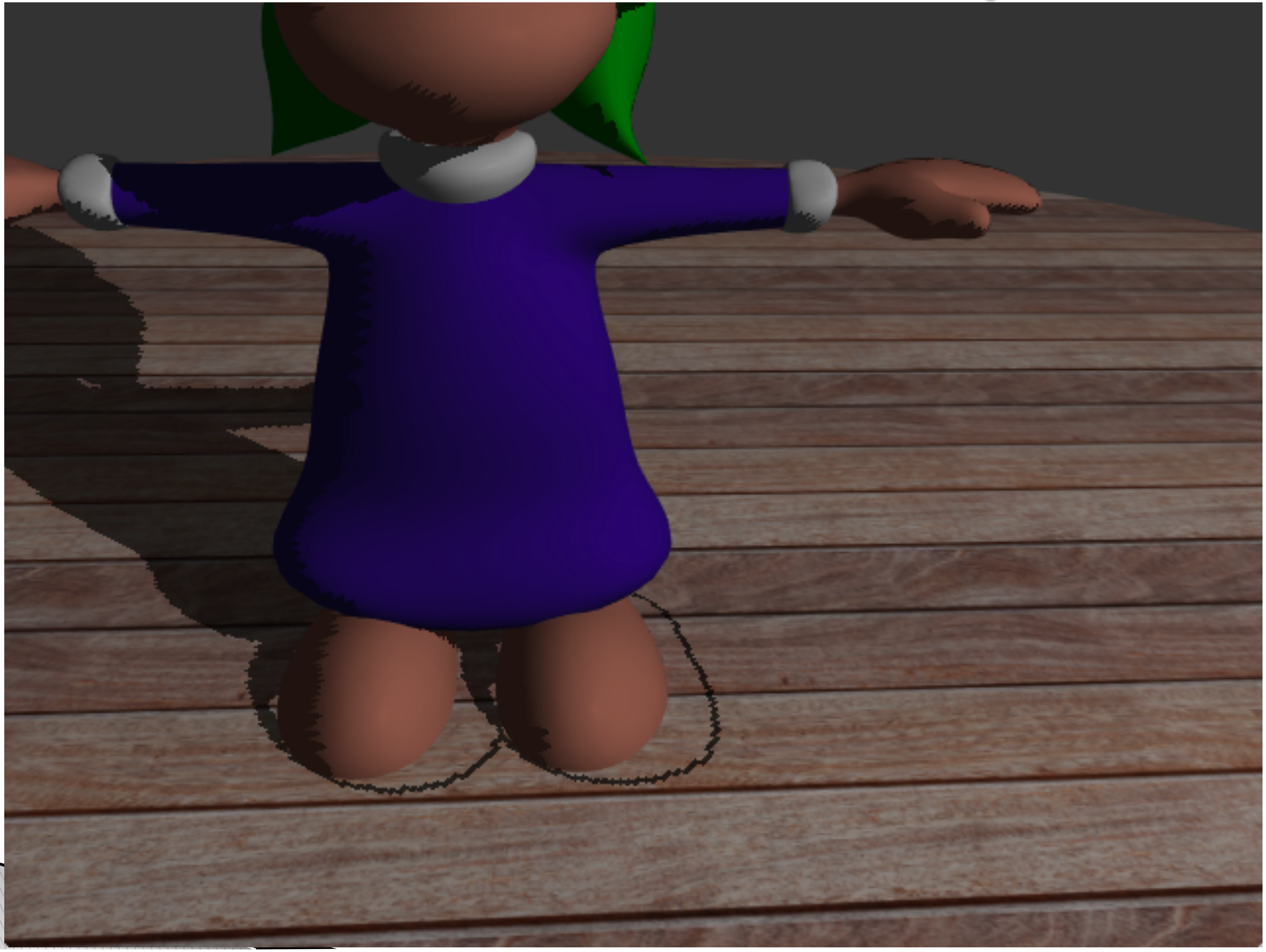
- Easy: glCullFace(GL_FRONT);



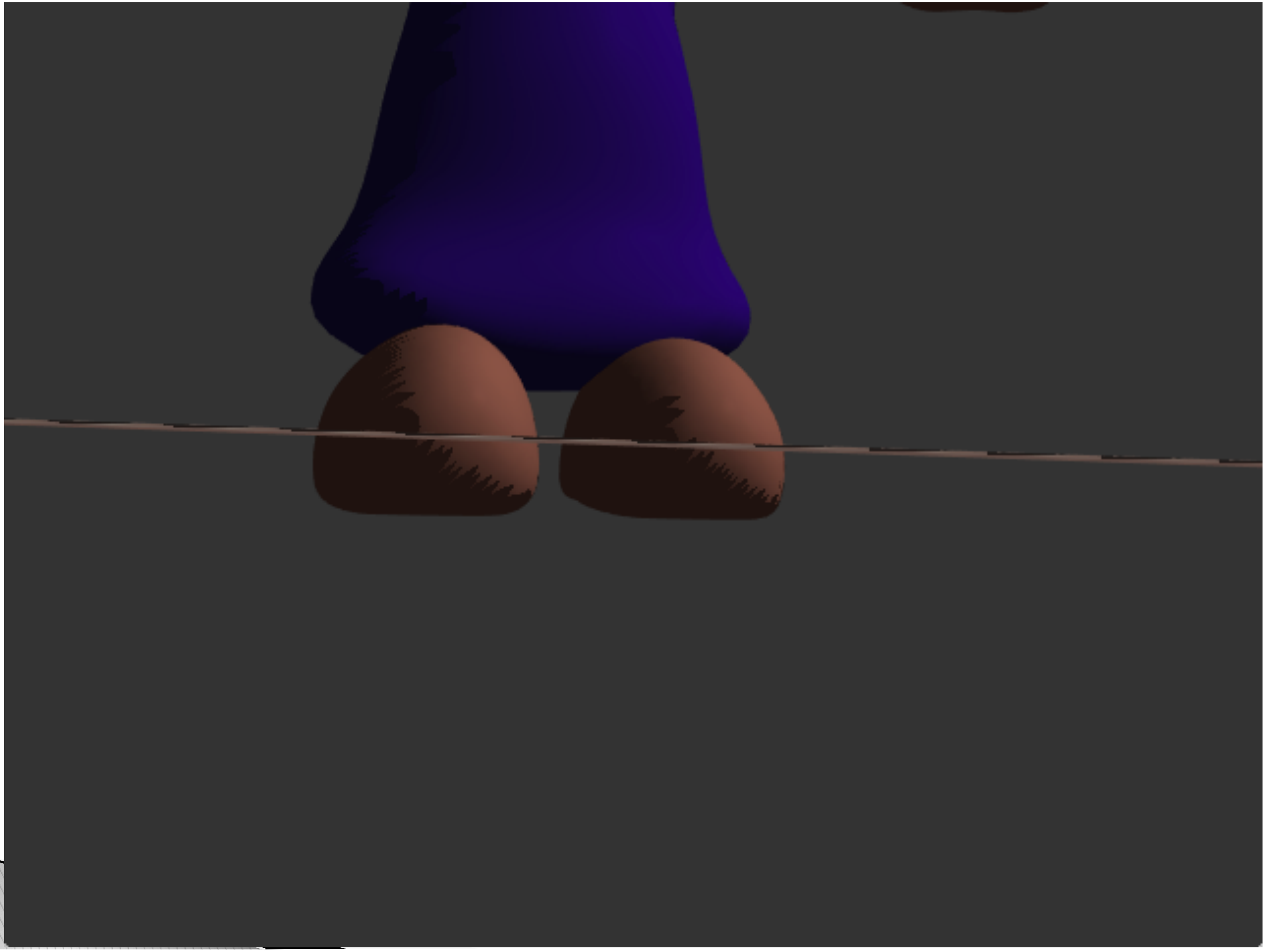
Back-sided surfaces only



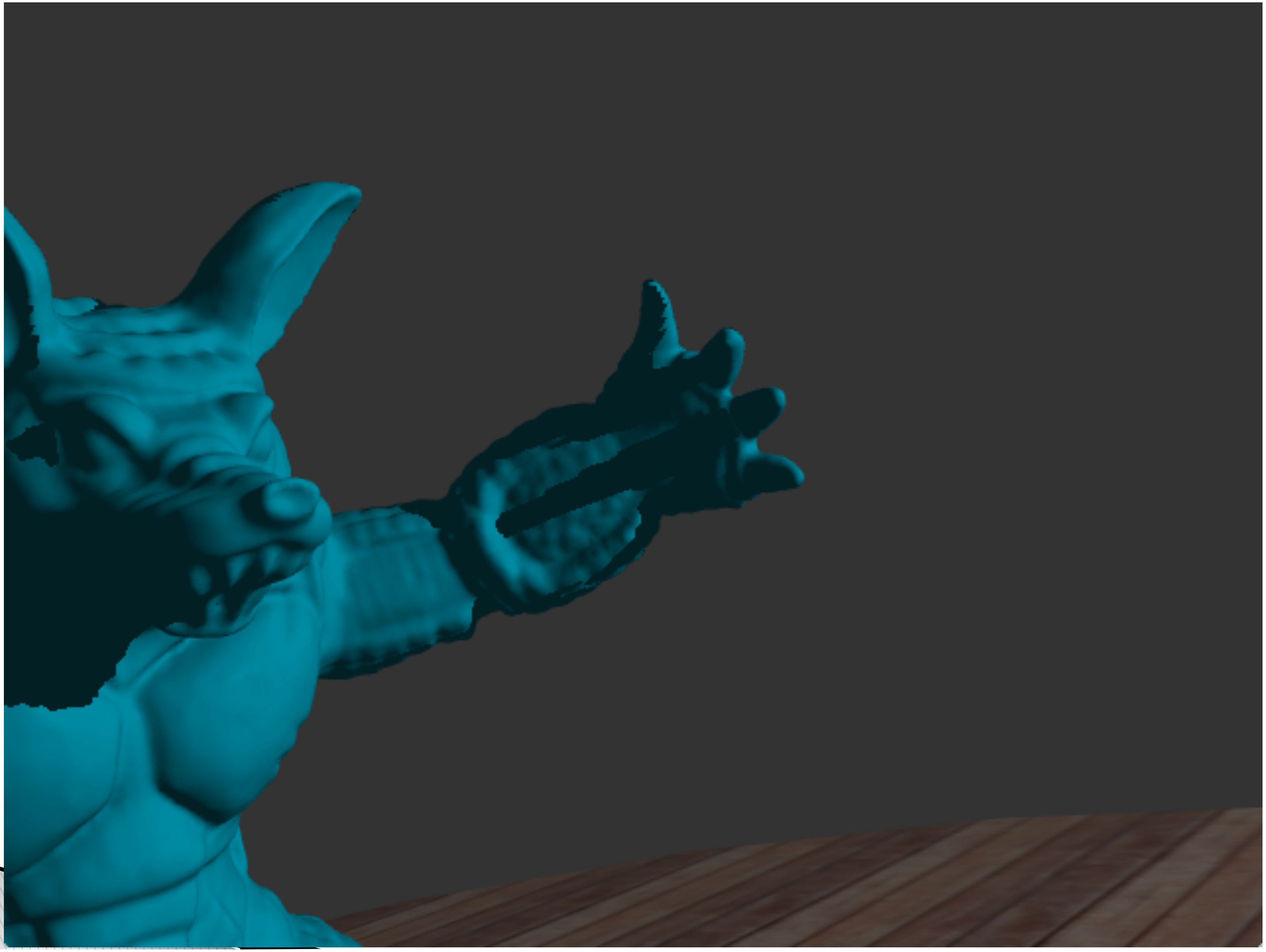
Back-sided surfaces only



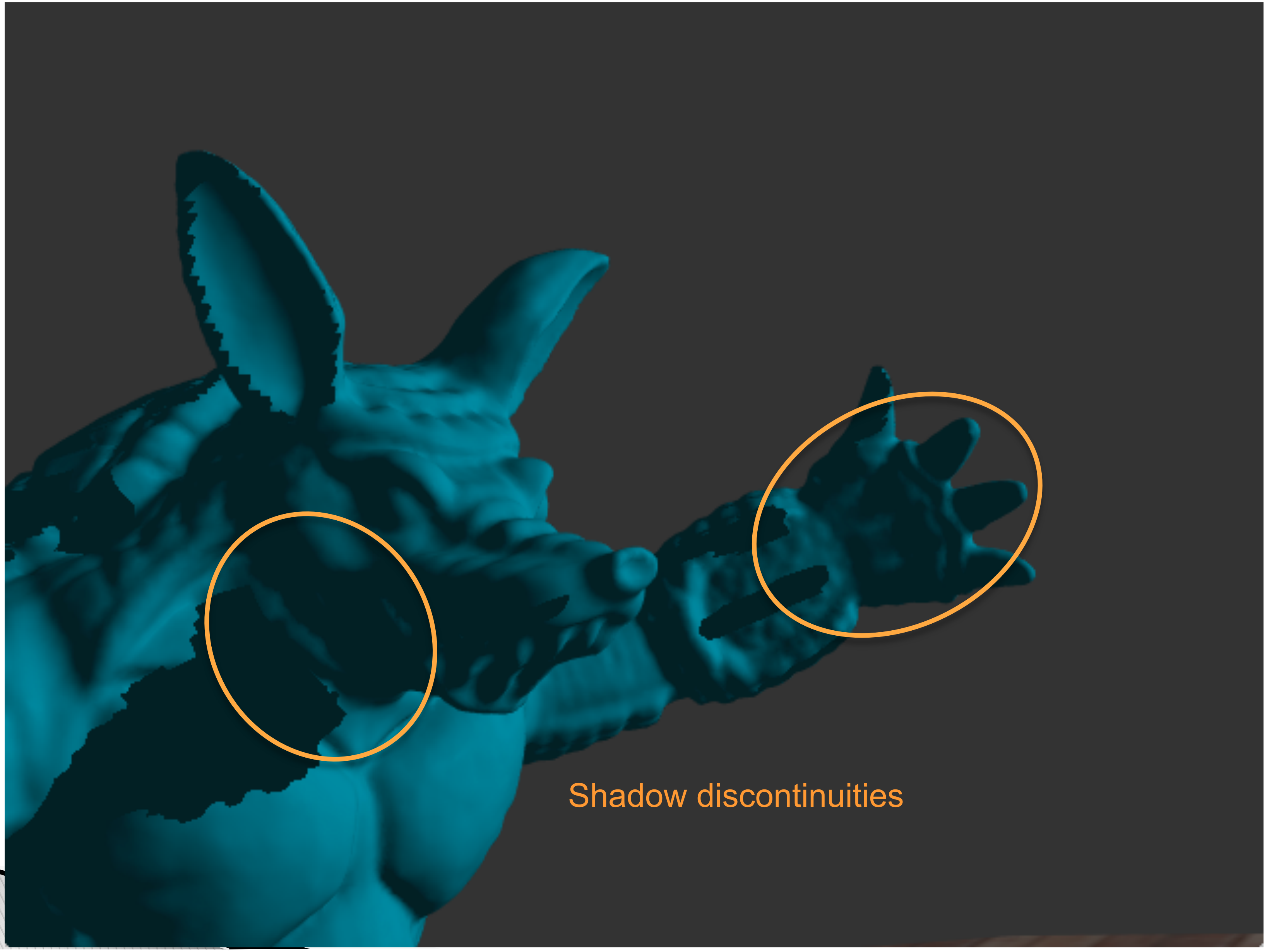
Behind the Scenes



Small constant bias (5e-3)



Medium constant bias (1.5e-2)



Other bias methods

- Slope-dependent: tan(angle N,L)*$a + b$
  - $b > 0$, $a = ?$
- Relative: $z1*(1 - \text{epsilon}) < z2$

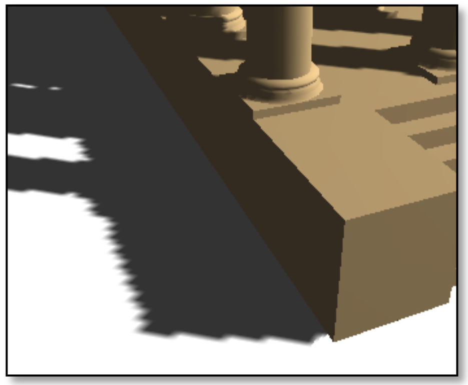
Projection / light source

- It's a *projection*:
  - Must divide by *w*
- What does it mean if $w < 0$?
  - What should we do?
- What should we do if we're outside shadow map?
  - How can we check?

Shadow maps: pro & cons

- **Pros**
  - Easy to implement
  - Works, regardless of the geometry of the scene
  - Cost does not depend on scene complexity

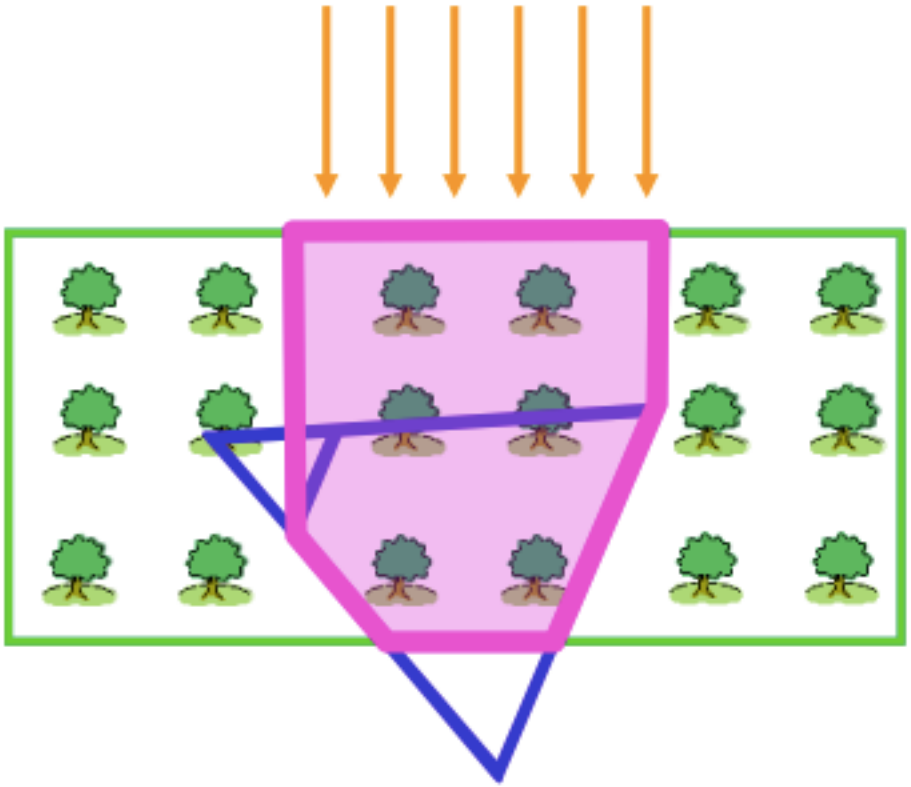
- **Cons**
  - Several (>= 2) scene rendering
  - Omni-directional light sources?
  - Sampling/aliasing
    - Increasing shadow map resolution is not enough (light source facing viewer)



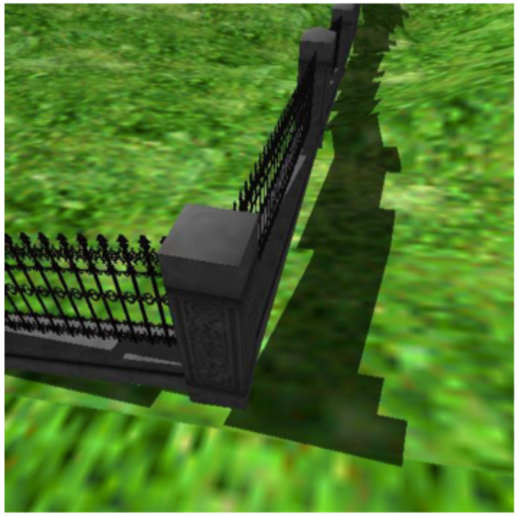
Aliasing issues: solutions

- Increase shadow map resolution
- Focus shadow map on visible parts of the scene
- Adapt sampling (warping)
  - Depending on light-source distance
- Multi-resolution Shadow maps
  - Cascading shadow map

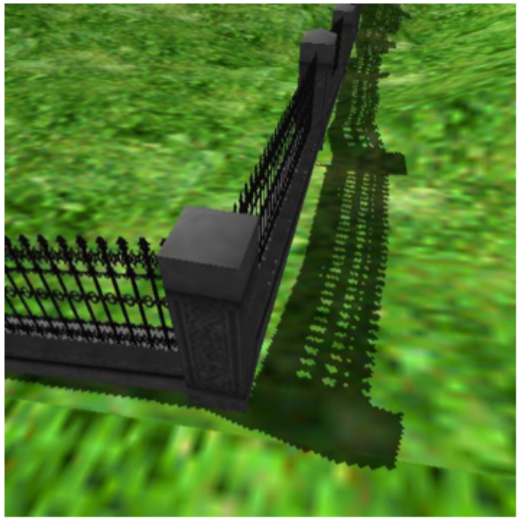
Focus the shadow map



Increases the practical resolution

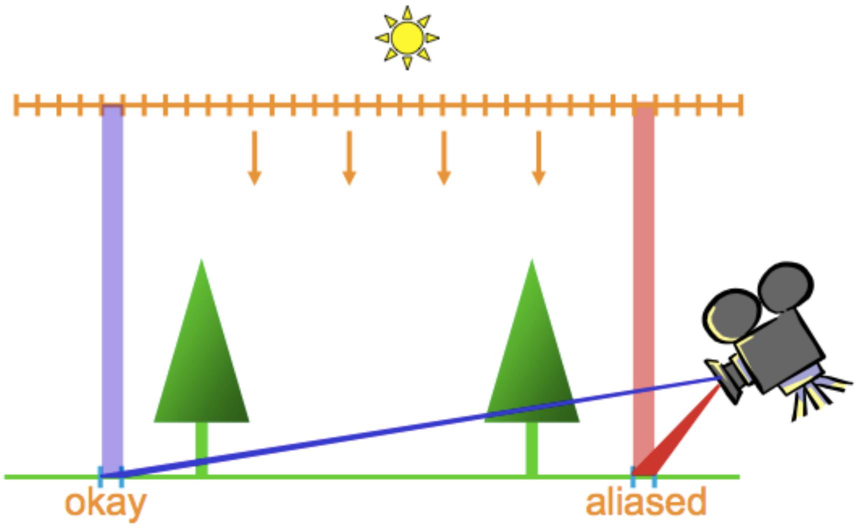


Unfocused

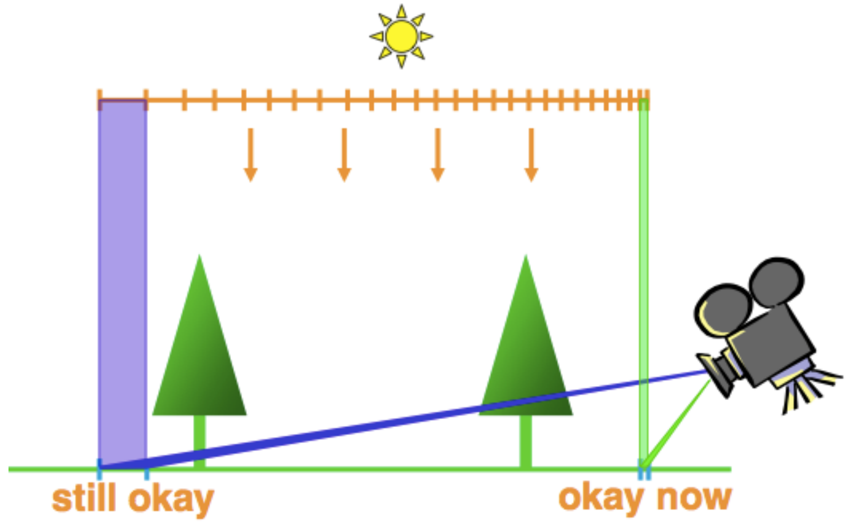


Focused

Warping for shadow maps



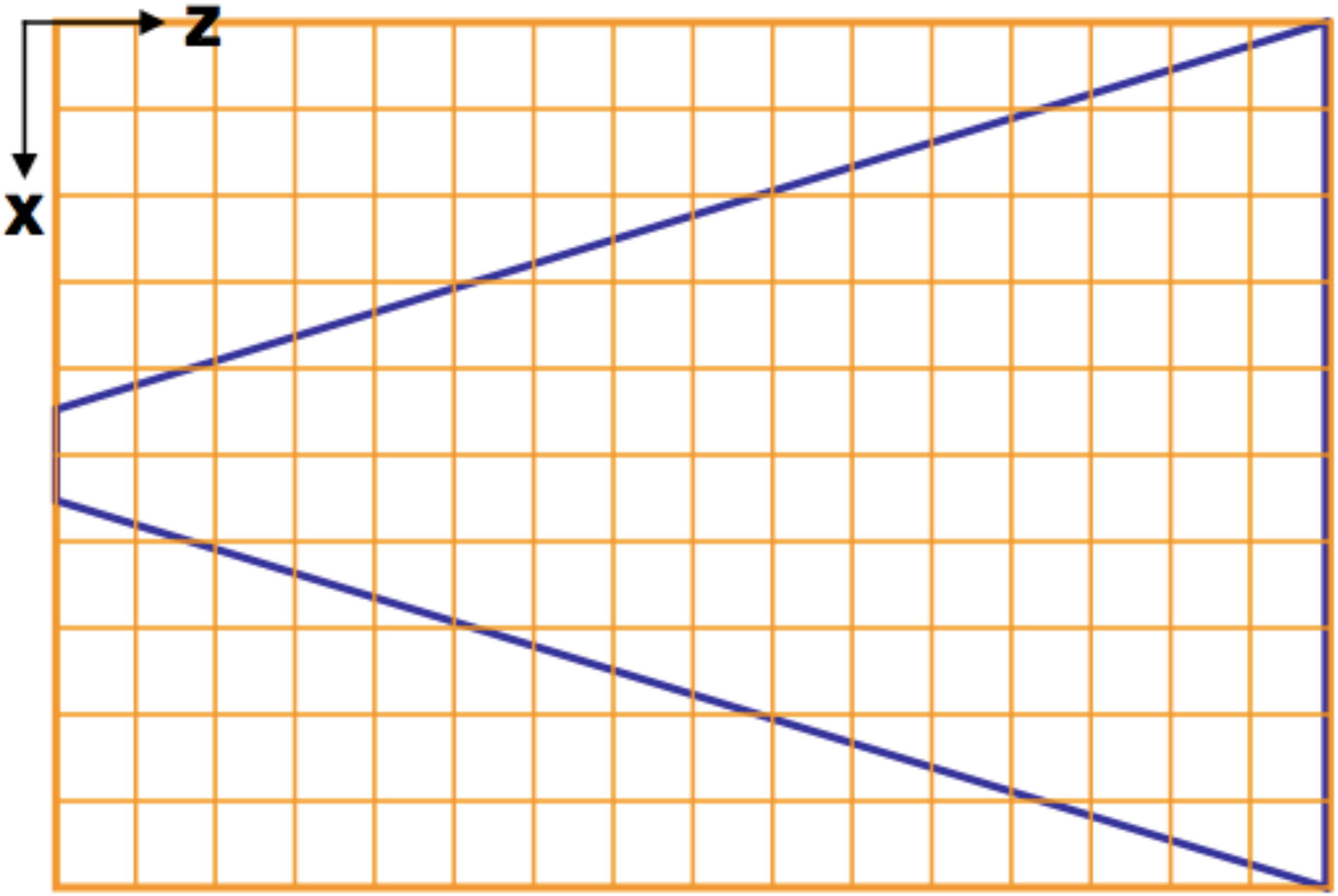
Uniform sampling in z



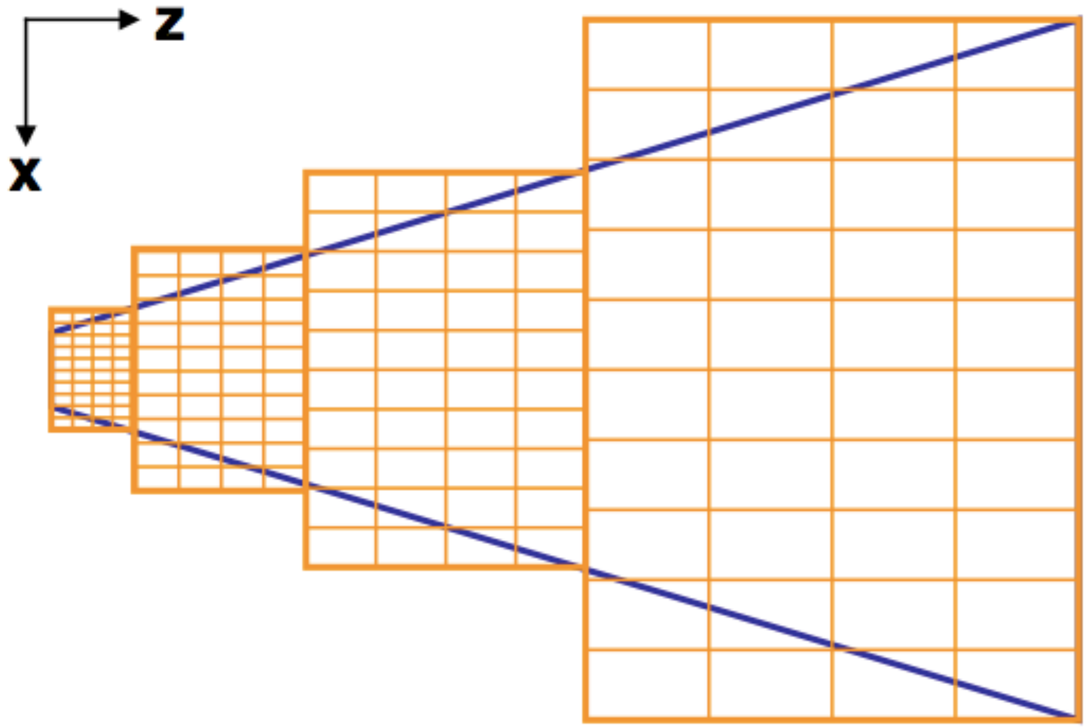
Variable sampling in z

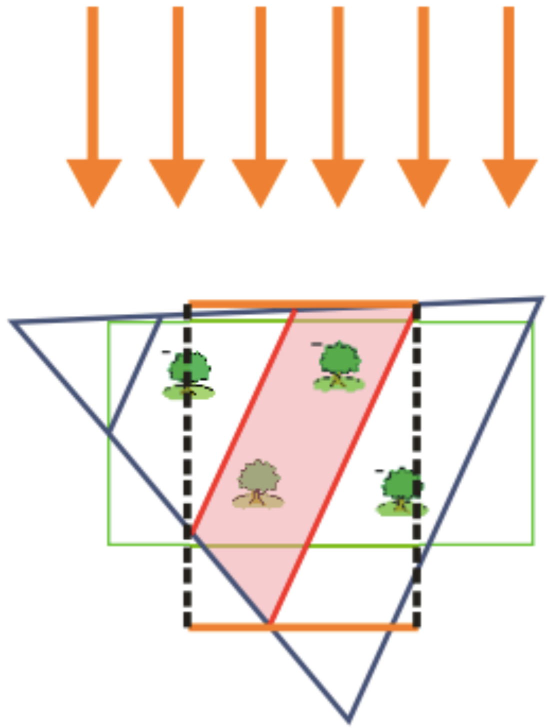
- How?
- Linear projection
  - Not centered on the light source
  - Optimized based on view frustum + LS position
- TSM, LiSPSM...

Cascading shadow maps

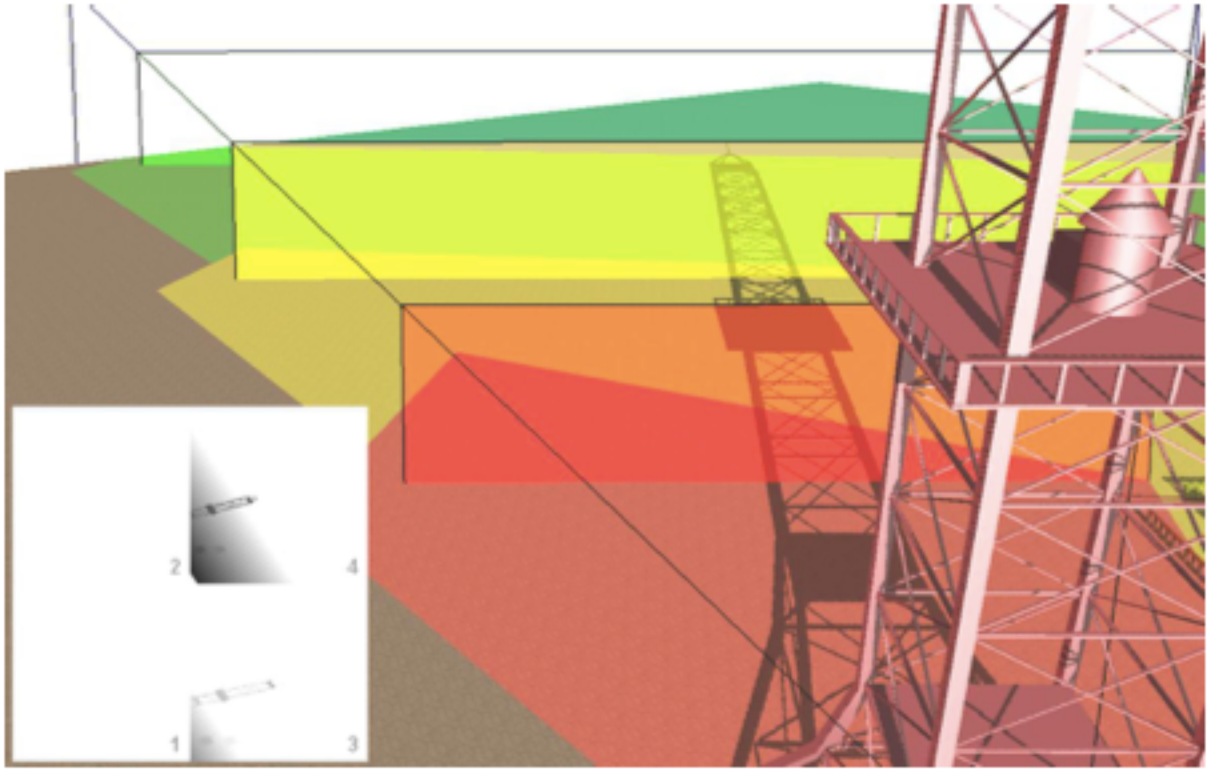


Cascading shadow maps

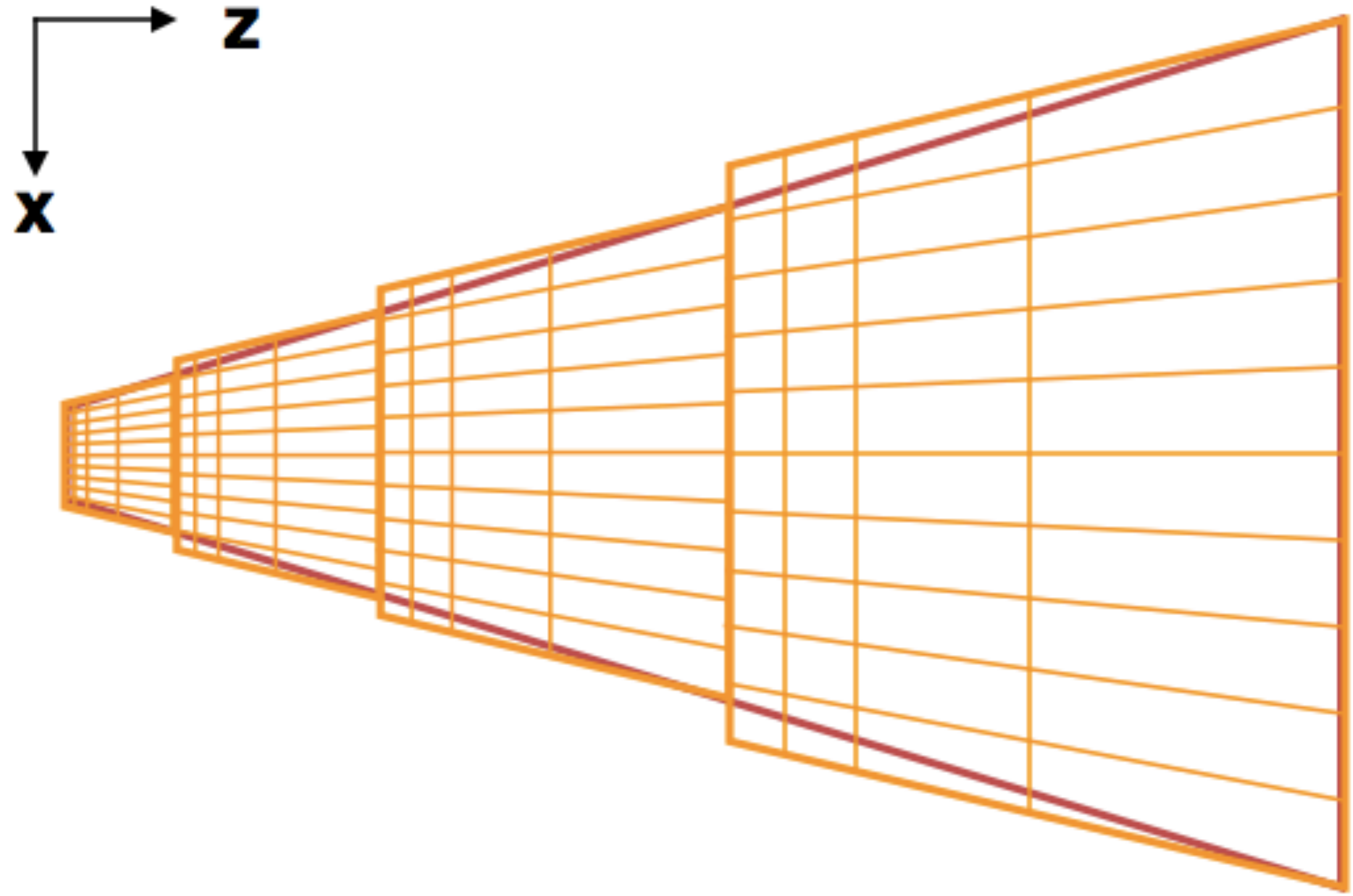


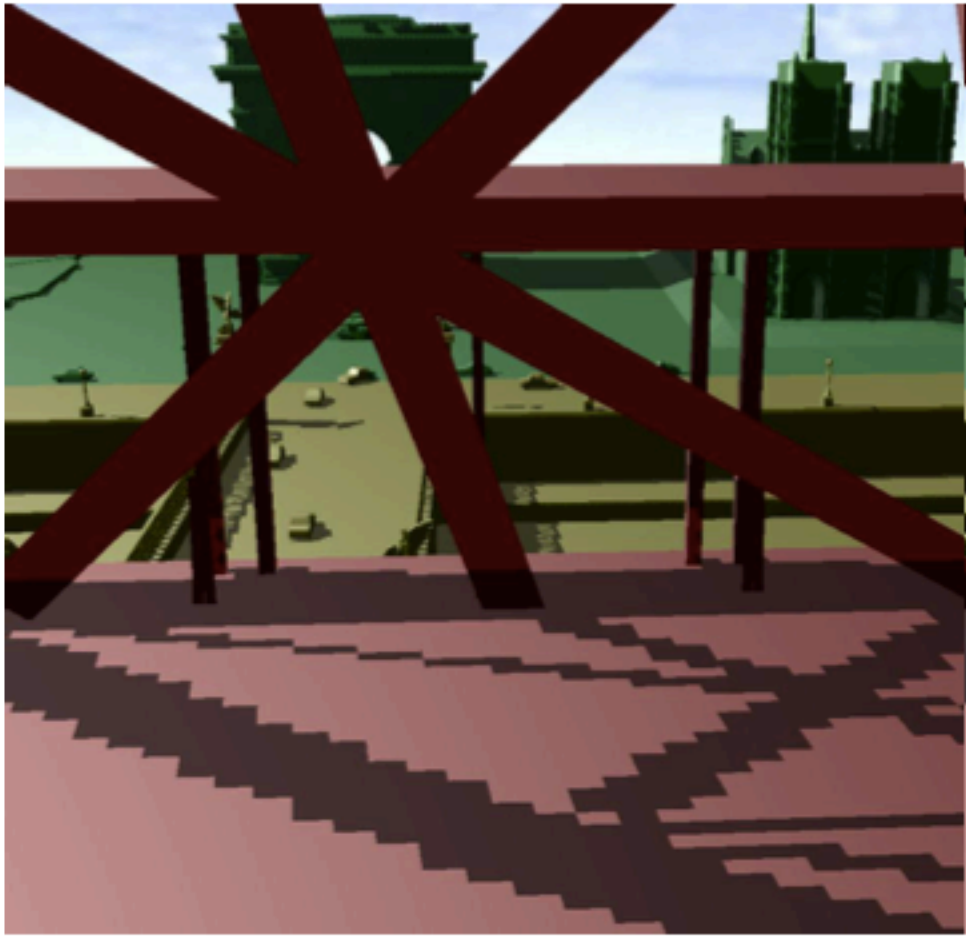


Cascading shadow maps

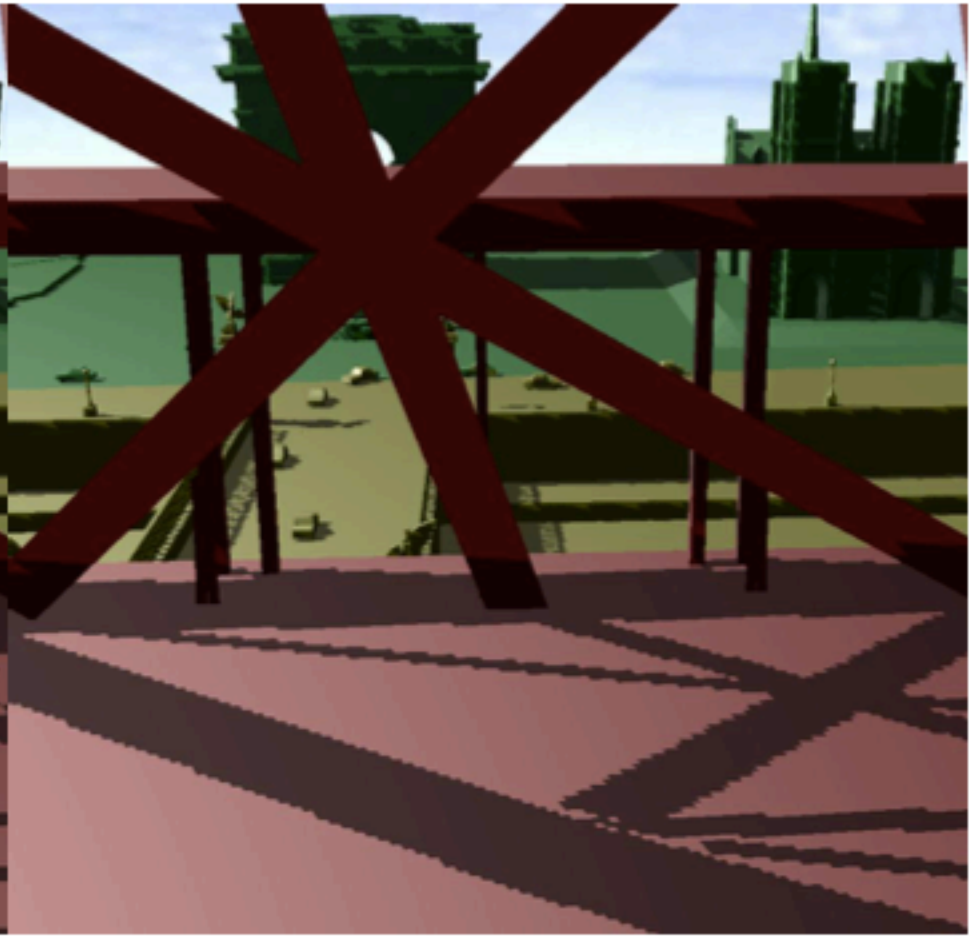


Cascading + warping





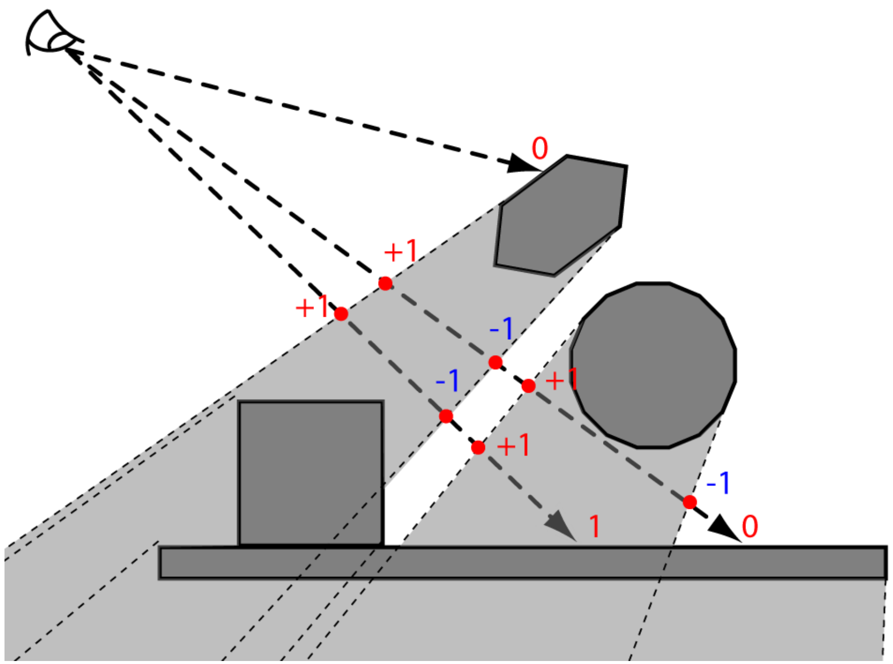
Partitioning



Partitioning + warping

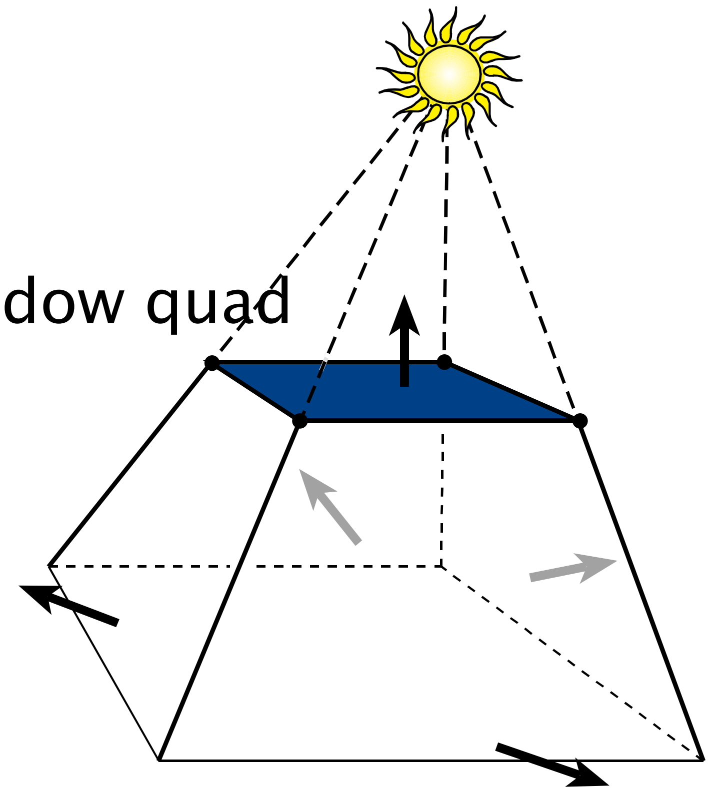
Shadow Volumes algorithm

1. For each *shadow casters*, build a **shadow volume**
2. For each fragment, **count** how many times we enter/leave a shadow volume
   > 0 : in shadow
   = 0 : lit



Shadow Volumes algorithm

- Building a shadow volume
  - Silhouette of each object from the light source
  - Infinite quads touching
    - the light source
    - Each silhouette edge
- Counting entering/leaving
  - Use the *stencil buffer*
  - Use the orientation of each shadow quad for the sign



Extract the silhouette?

- Silhouette of each object from the light source

How? 1mn

Building semi-infinite quads?

How? 1mn

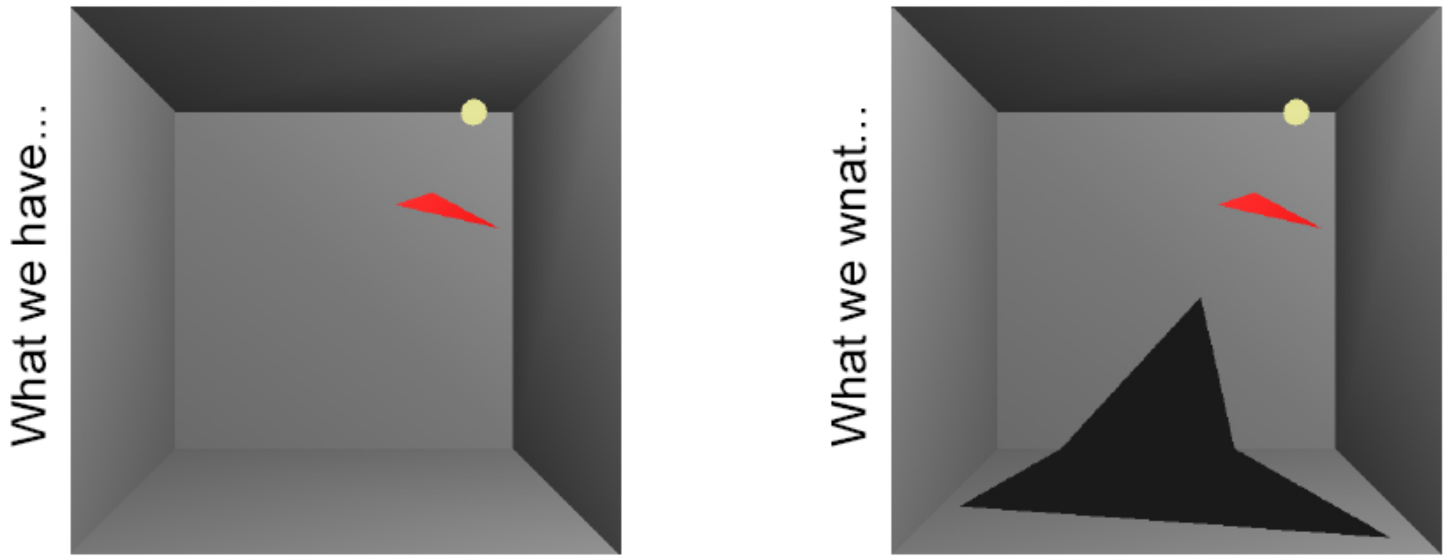
How do we count?

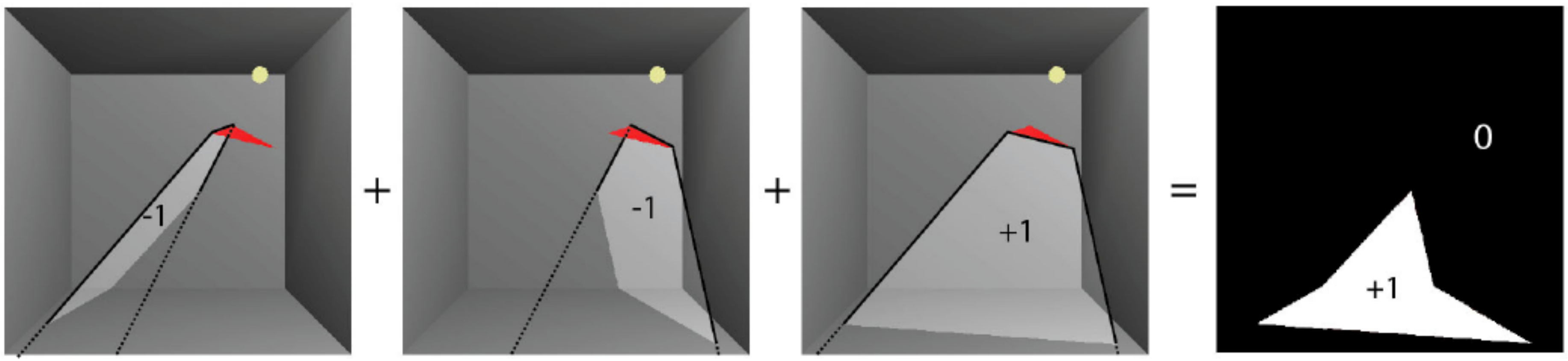
- Use the Stencil buffer
  - Shadow volume side visible, front-facing: +1
  - Shadow volume side visible, back-facing: -1

- 2 rendering pass:
  - First front-facing, then back-facing
  - glCullFace(...)
- 1 rendering pass:

```
glStencilOpSeparate(GL_FRONT, GL_KEEP, GL_INCR_WRAP, GL_KEEP);
glStencilOpSeparate(GL_BACK, GL_KEEP, GL_DECR_WRAP, GL_KEEP);
```

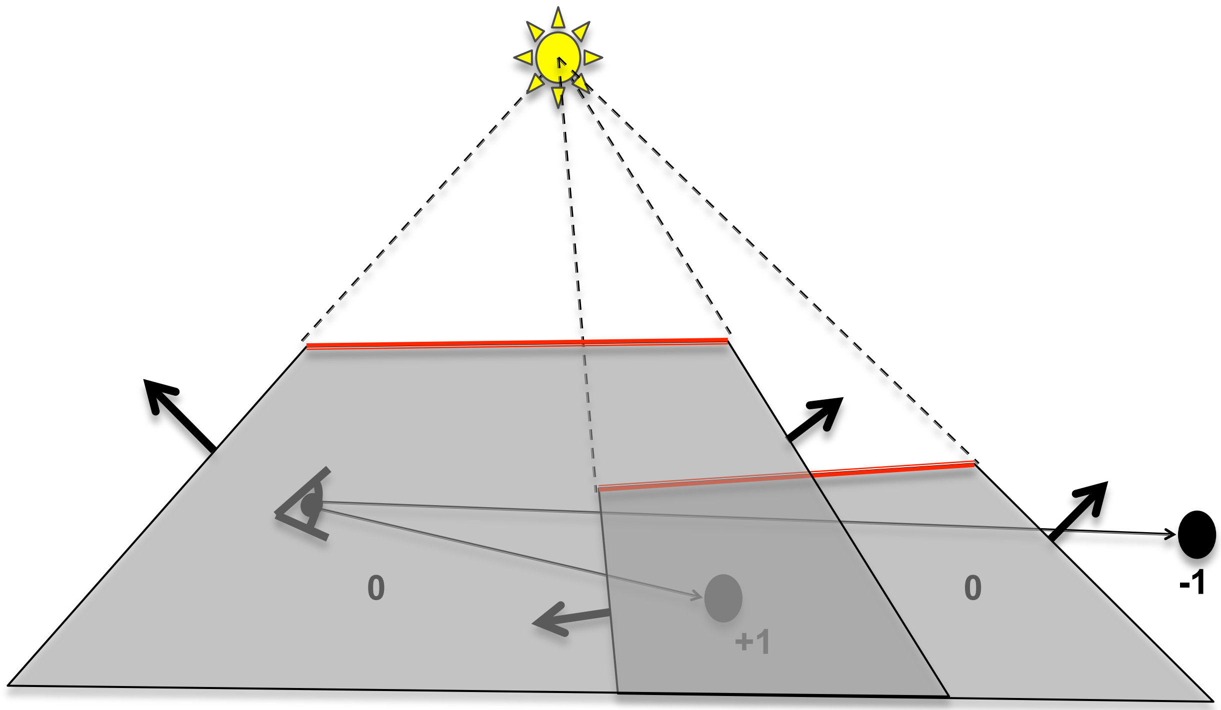
Z-pass by example: how the stencil buffer is used





Z-pass: issue

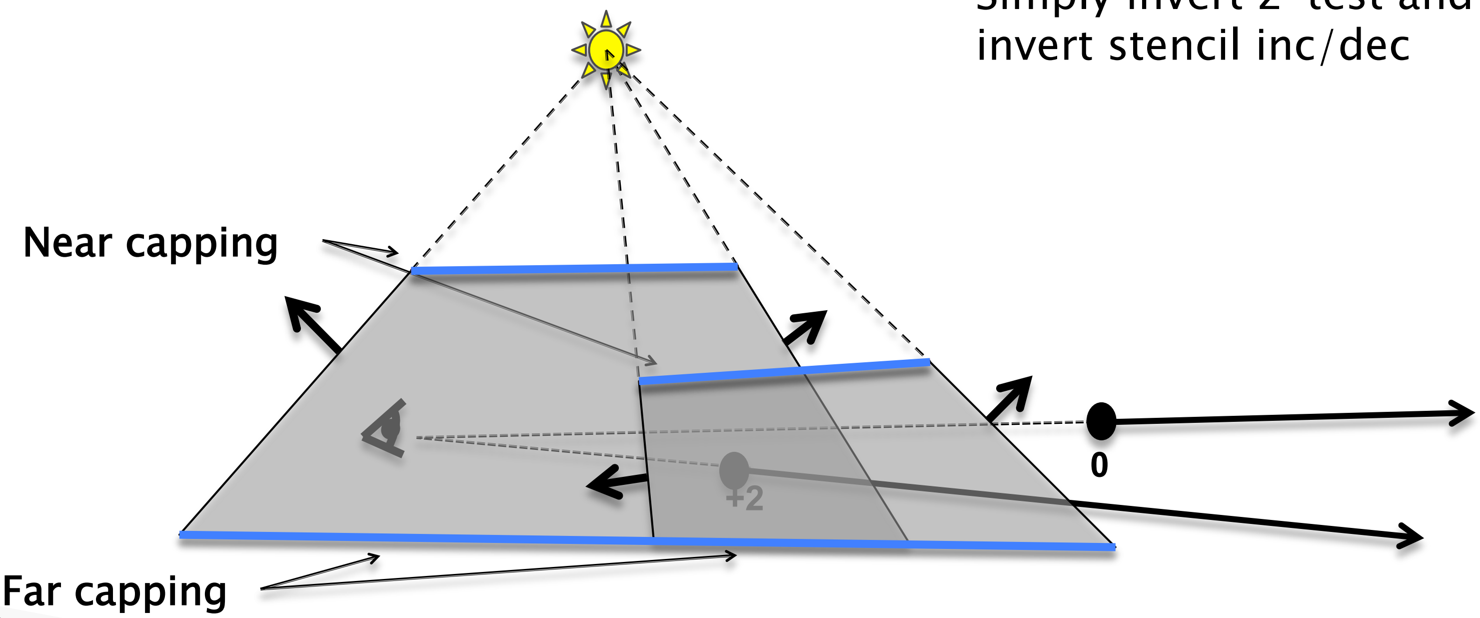
- What if the eye is in shadow?



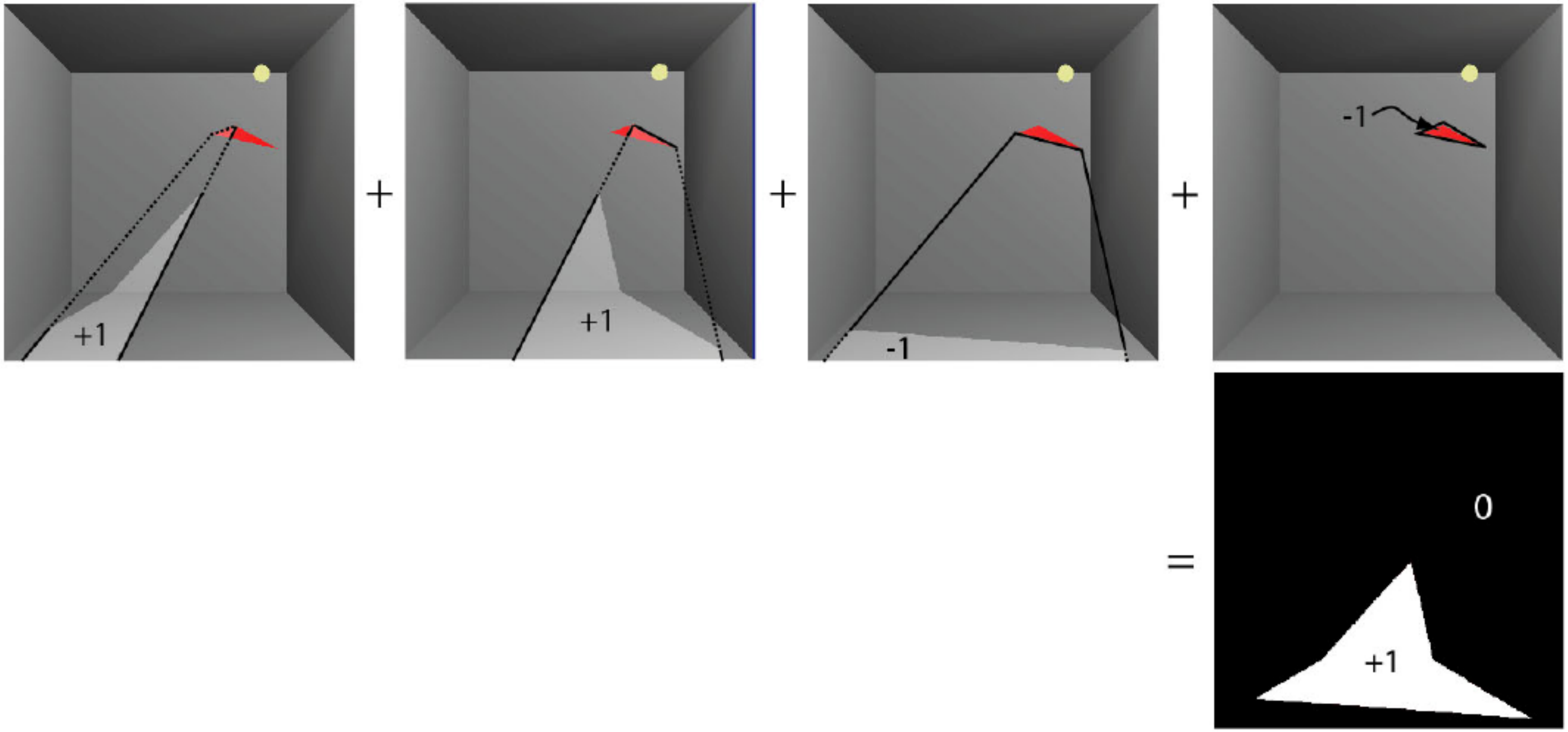
Z-fail

- Have a lit point as reference
- A point at infinity must be lit
- Need to cap the shadow volume

Simply invert z-test and
invert stencil inc/dec



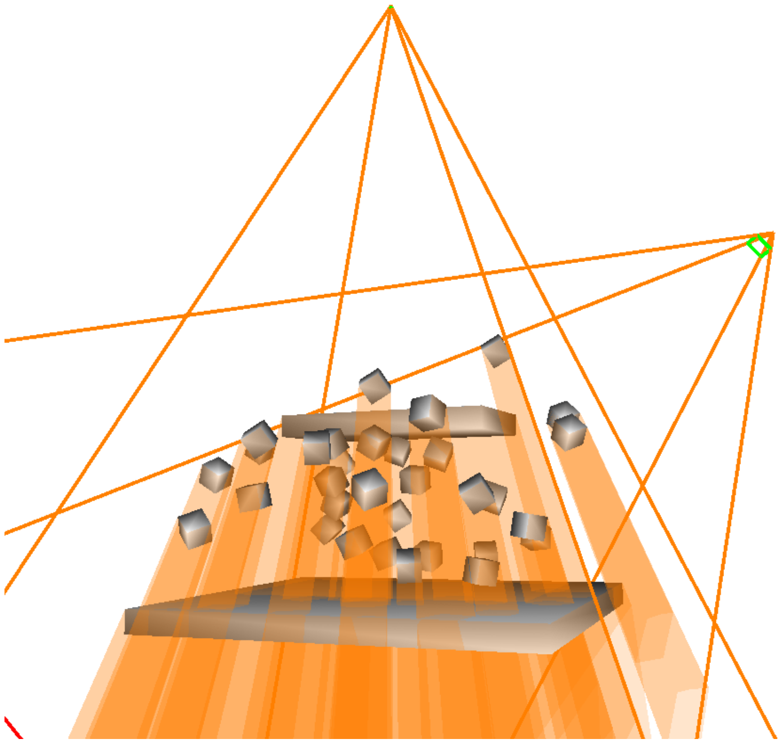
Z-fail by example



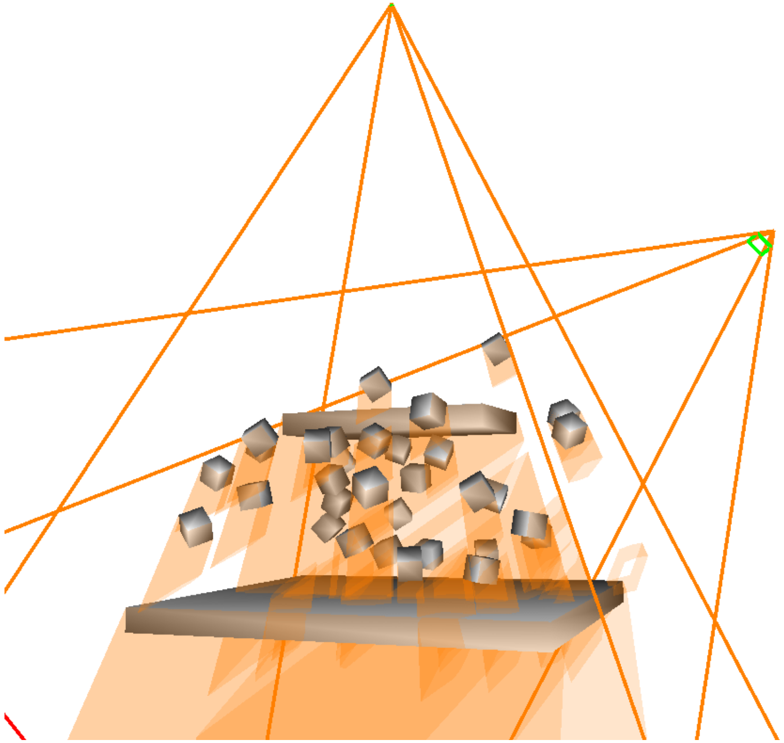
Shadow volumes: pro&cons

- **Pros:**
  - Sharp shadows
  - Arbitray positions for light source/caméra
  - Robust (if well programmed)
- **Cons:**
  - silhouette computation (CPU/GPU)
  - requirements on scene geometry (manifold, closed surfaces)
  - Rendering the scene twice, + the shadow volumes

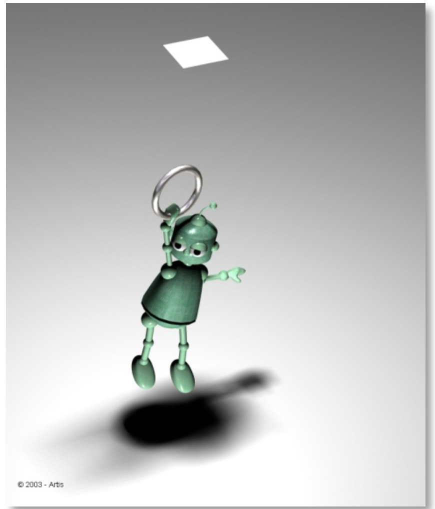
Overdraw



Shadow volumes



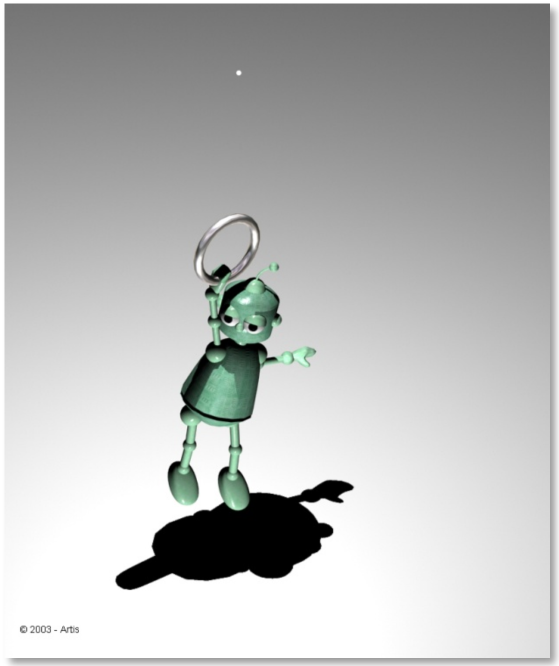
CC Shadow volumes

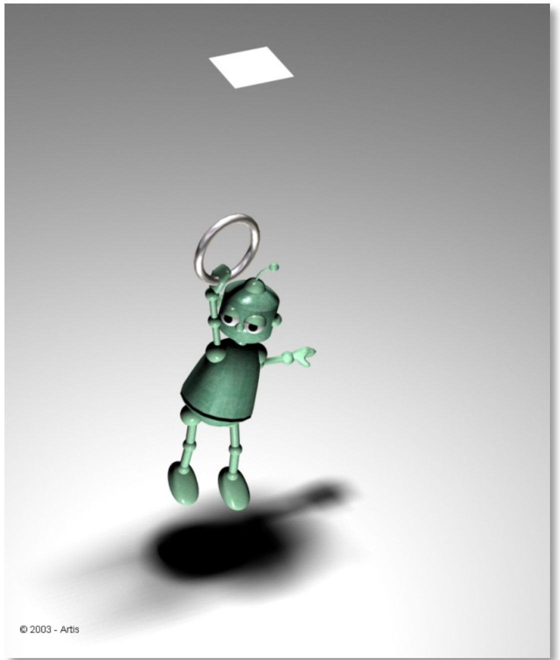


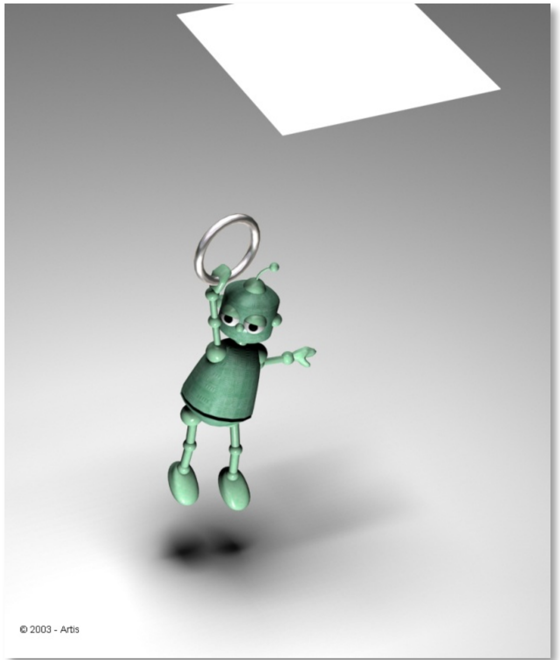
Soft shadow computations

Soft shadows

- More complex
  - **Point-to-area** visibility, with continuous value
    - Instead of binary point-point visibility
    - silhouette?

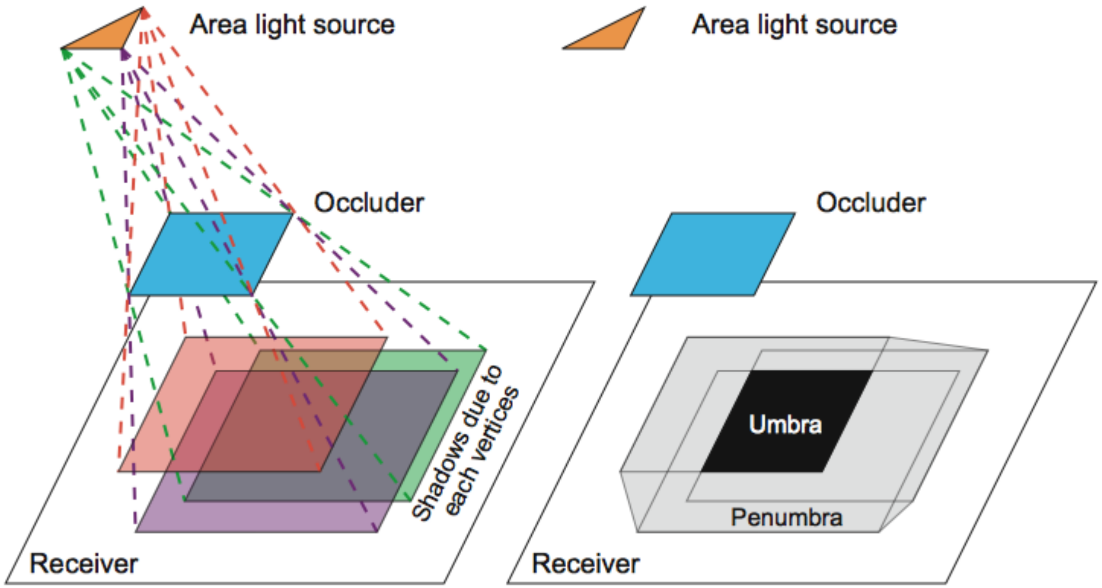


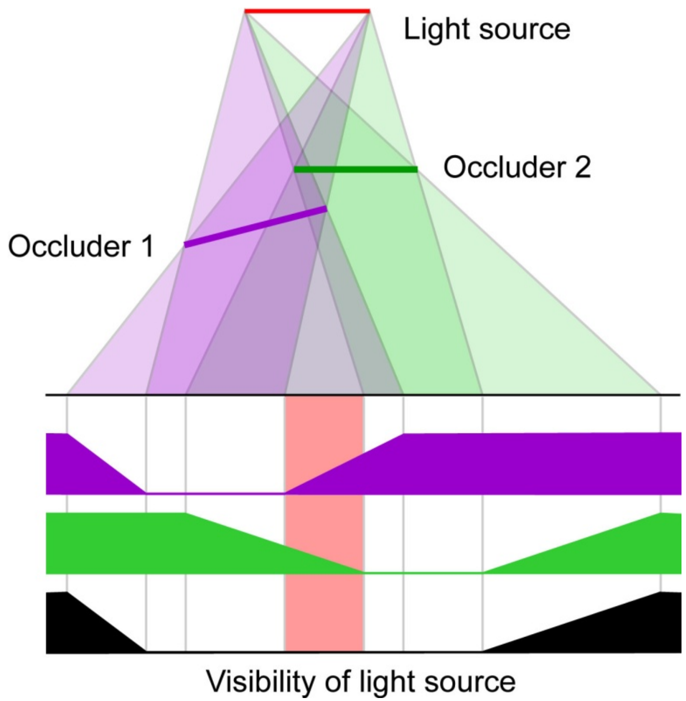




Soft shadows

- More complex
  - **Point-to-area** visibility, with continuous value
    - Instead of binary point-point visibility
    - silhouette?
  - Shadow of the sum ≠ sum of shadows
    - A hides 50% and B hides 50%, A+B doesn't hide 100%





Soft shadows

- More complex
  - **Point-to-area** visibility, with continuous value
    - Instead of binary point-point visibility
    - silhouette?
  - Shadow of the sum $\neq$ sum of shadows
    - A hides 50% and B hides 50%, A+B doesn't hide 100%
- Many algorithms
  - With varying accuracy
    - Approximating the *shadow casters*
    - Precomputations (*Precomputed Radiance Transfert*)
  - With varying speed

Soft shadows through sampling

- Accumulating shadows:
  - Compute several hard shadows
  - Add them, average the results
  - *accumulation buffer*
  - Needs many samples
    - Computation time proportional to # échantillons

4 échantillons

1024 échantillons

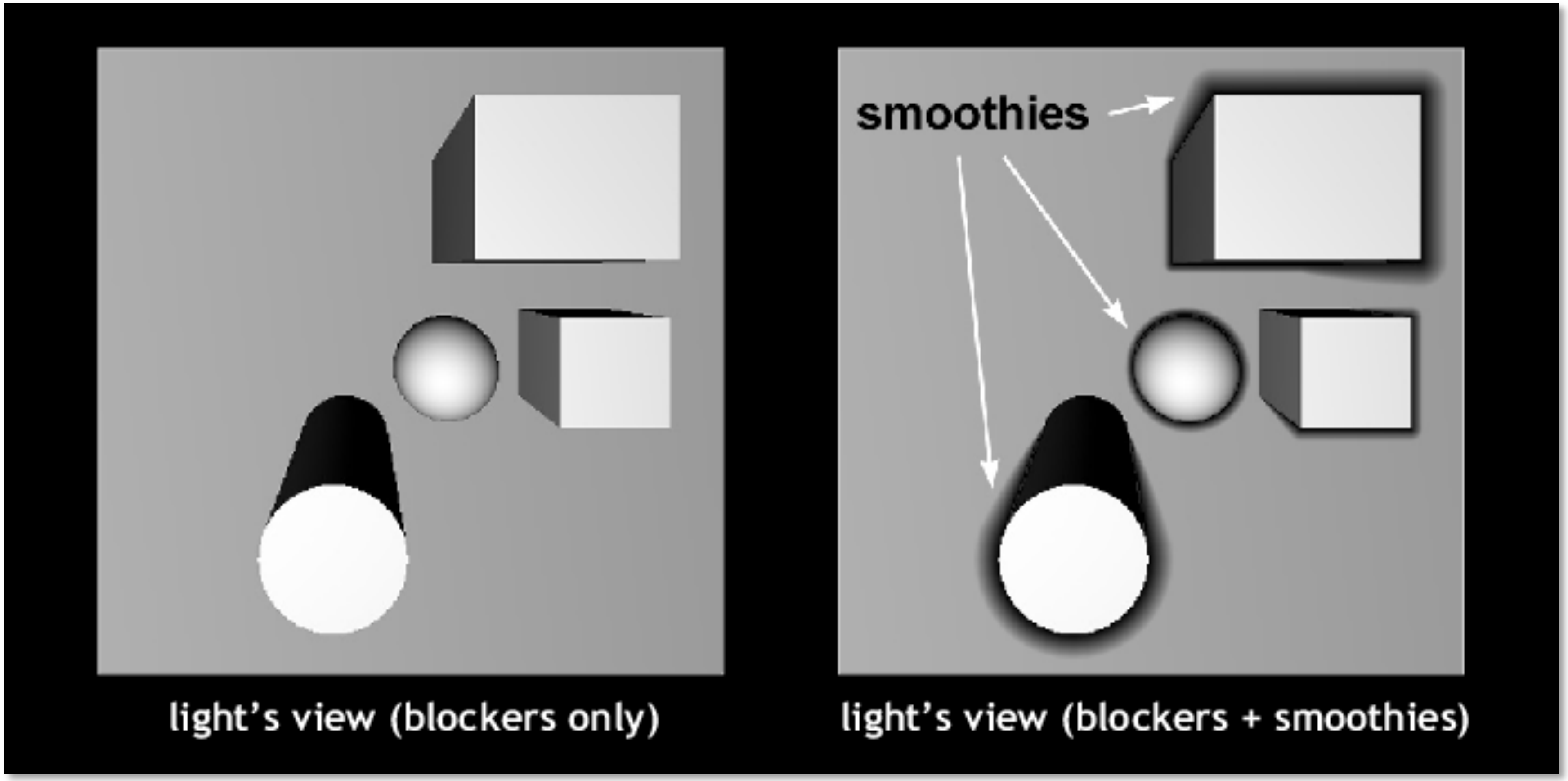
Soft-shadow volume

- For each silhouette edge:
  - Compute volume around penumbra (wedge)
  - For each pixel in this wedge
    - Compute attenuation coefficient
- Beautiful, realistic, expensive

Penumbra wedges [Sig03] *U. Assarson, T. Möller*

Object/image methods

Rendering Fake Soft Shadows with Smoothies [SoR03]
E. Chan, F. Durand



Shadow mapping extension

- *Percentage Close Filtering* (PCF)
  - Filter shadow map around sampling point
  - Possible GPU speed-ups (2x2 kernel)
  - Pre-filtered, stored in mip-map

1 sample

9x9 kernel

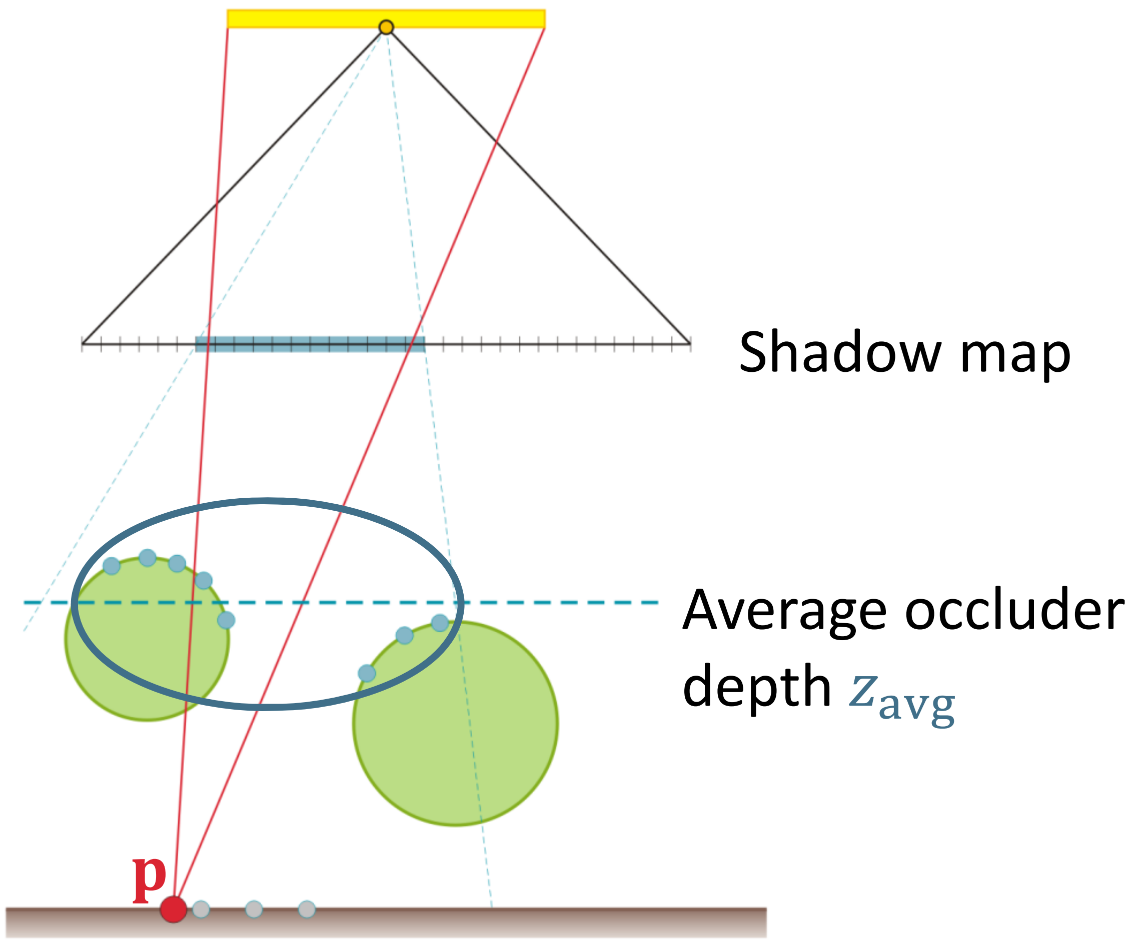
17x17 kernel

Shadow mapping extension

- *Percentage Closer Soft Shadows* (PCSS) [Fernando 05]
  - Compute kernel size first, by sampling shadow map
  - Filter using PCF (or extensions)

PCSS

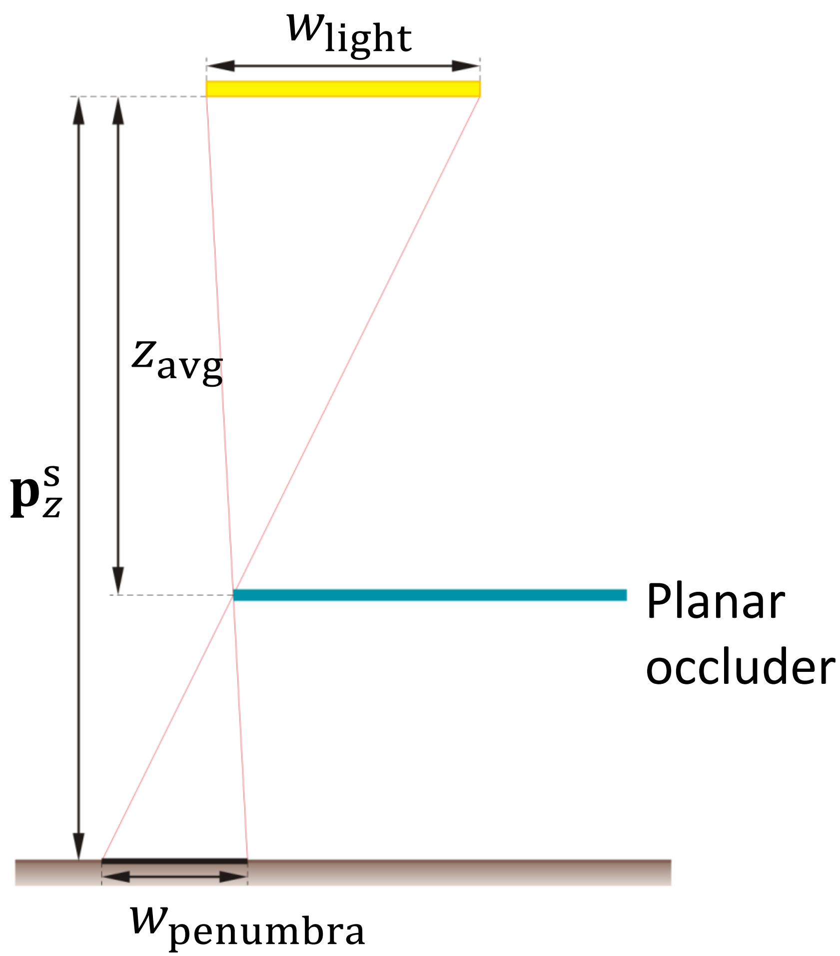
- 1. Blocker search



PCSS

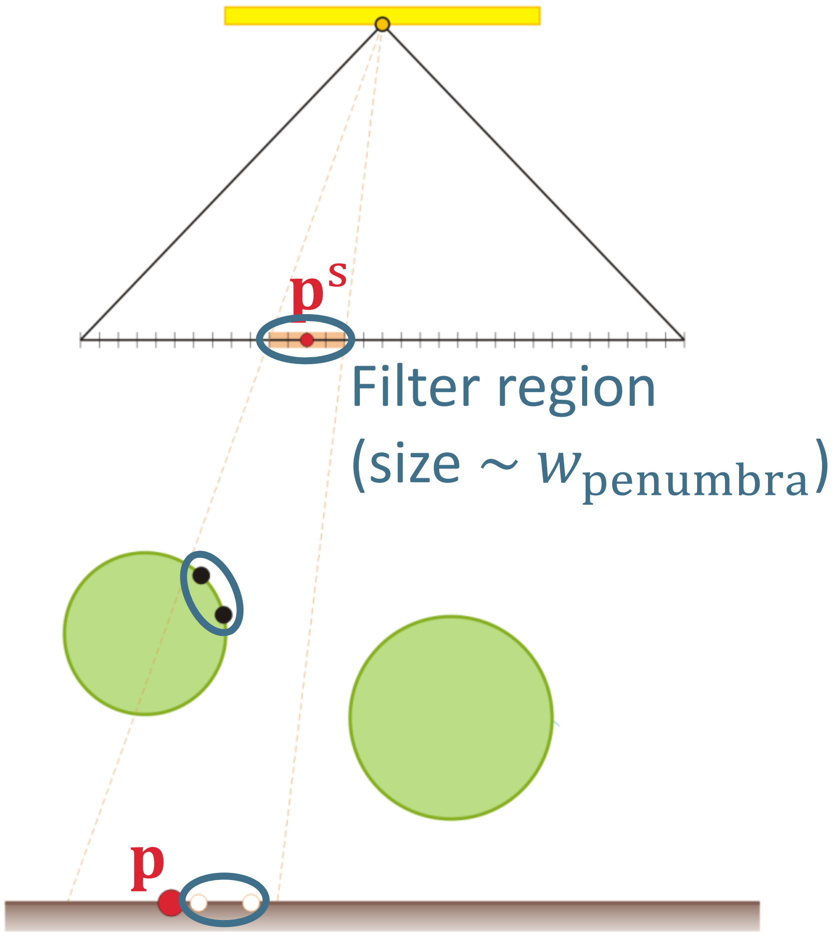
- 2. penumbra size

$$w_{\text{penumbra}} = \frac{\mathbf{p}_z^s - z_{\text{avg}}}{z_{\text{avg}}} w_{\text{light}}$$



PCSS

- 3. filtering



(here, occlusion = 50 %)

PCSS : issues (1)

- 1. blocker search
- 2. penumbra size
- 3. filtering

2 steps requiring several access to shadow map

PCSS : issues (2)

- Easy, quite fast
- Visually pleasing results
  - For a small light source

- No physical realism
- Visible artefacts
  - For large penumbra width
  - If occluders hidden from center of light source
  - For non-flat occluders

Shadow mapping extensions

- *Percentage Closer Soft Shadows* (PCSS) [Fernando 05]

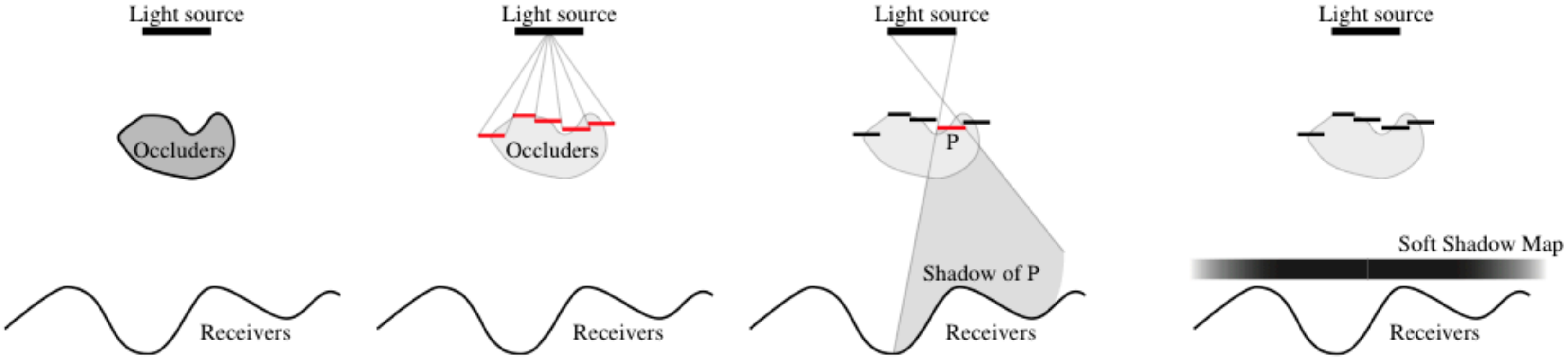
PCSS

PCF

Hellgate: London (2007)

Soft shadow maps

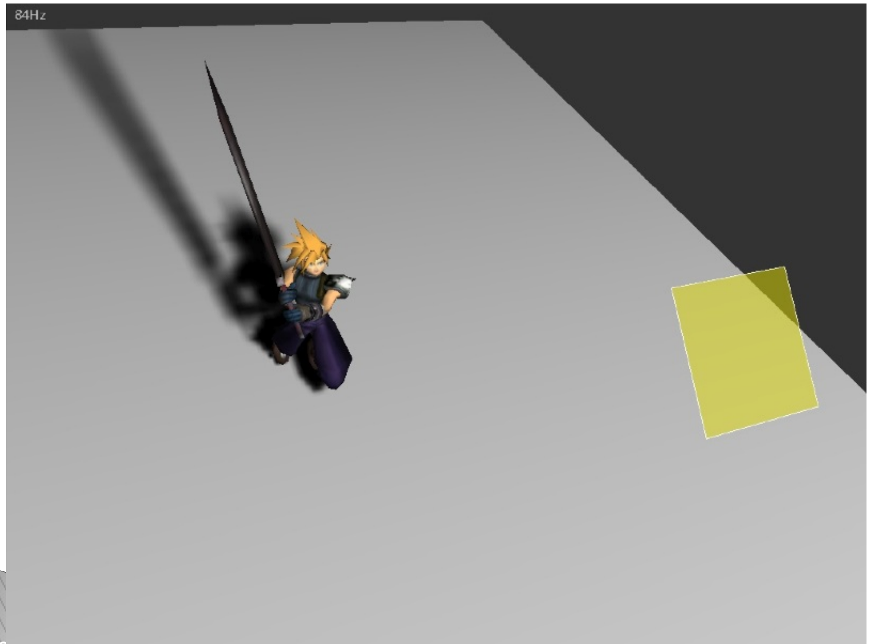
Soft Shadow Maps [AHLHHS06] *Atty et al.*
Real-time Soft Shadow Mapping by Backprojection [GBP06] *Guennebaud et al..*

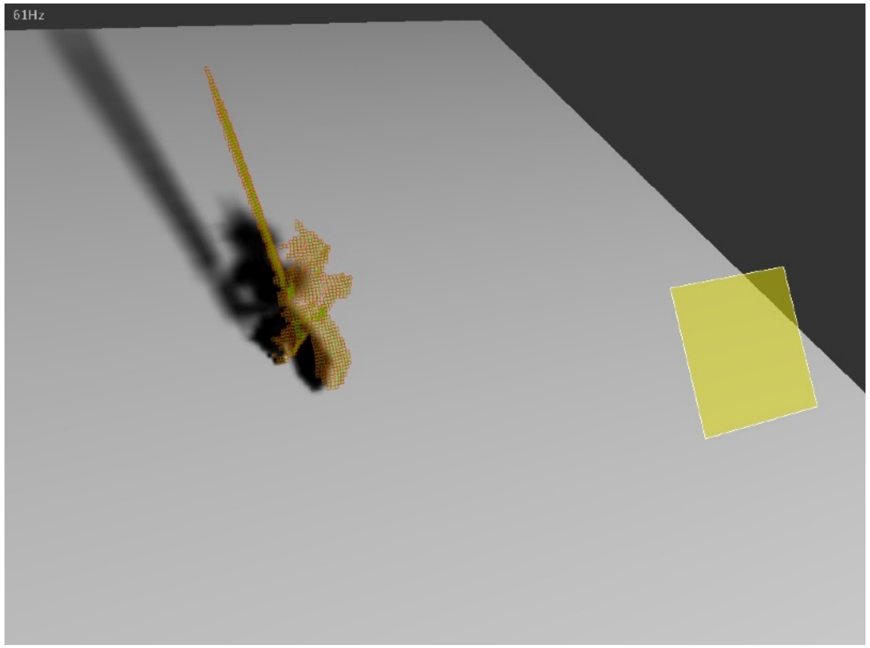


(a) Scene view (b) Discretizing occluders (c) Soft shadows from one micro-patch (d) Summing the soft shadows

Back-projection

- Shadow map = object discretization
- Compute shadow of discretized object
- Realistic, real-time, animated scene
- [Atty06] et [Guennebaud06]





Back-projection

Ambient occlusion

Motivation

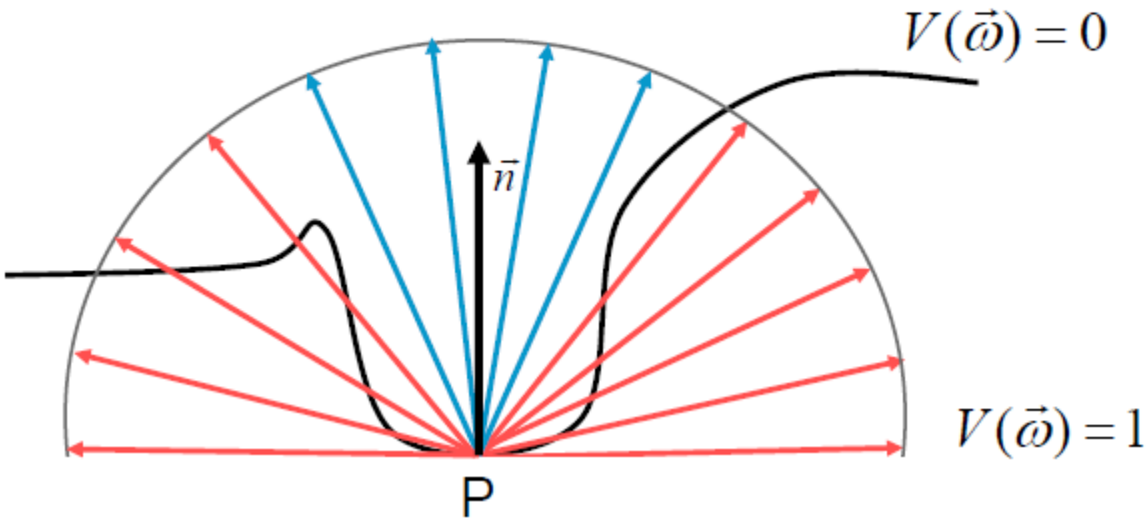
- Approximating the occlusion under distant lighting
  - Ambient term taking visibility into account
- Perceptually related to depth, curvature and spatial proximity

Definition

- Integral of visibility over hemisphere Ω:

$$A_P(\vec{n}) = \frac{1}{\pi}\int_{\Omega} V_P(\vec{\omega})(\vec{n}.\vec{\omega})d\omega$$

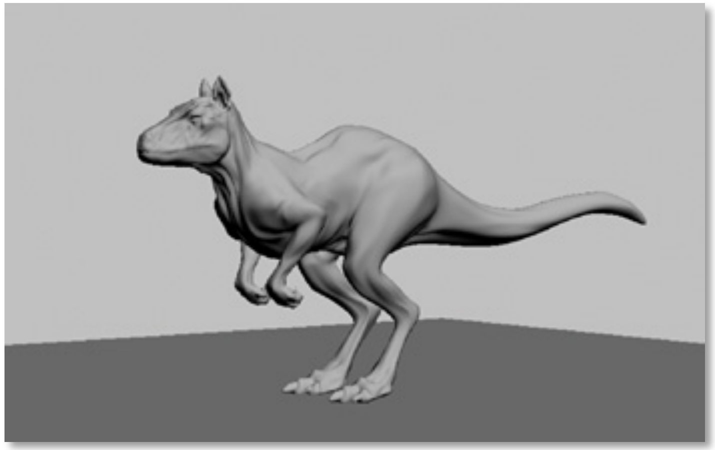
  - Cosine term ⇨ diffuse lighting
  - Usually, attenuation depending on the distance to P



Computing the integral

GPU Gems, chap 17

- Sampling
  - Precomputation (*ray-casting*)
  - Store in a texture



Diffuse

+ Rendering at no extra cost
- Slow precomputation
- Static scene

Diffuse + AO

Computing the integral

- *Screen-Space Ambiant Occlusion* (SSAO)
  - Use the *depth buffer* as an approximation of the scene
  - For each pixel, sample the hemisphere on the GPU
  - Filtering for noise reduction

\+ Independent form scene complexity

\+ No pre-computation

\+ Dynamic scene

\- Longer rendering

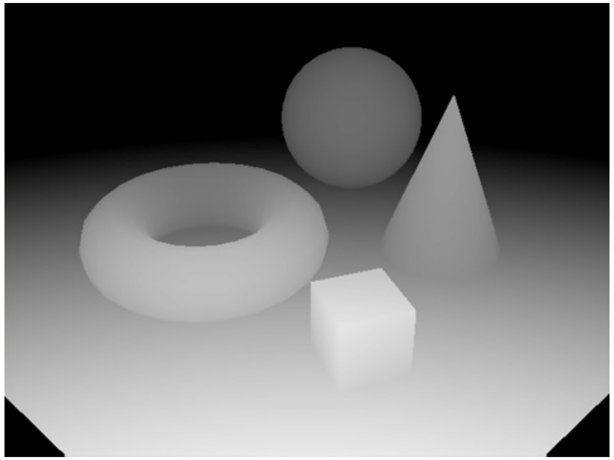
Cry Engine 2

Deferred shading

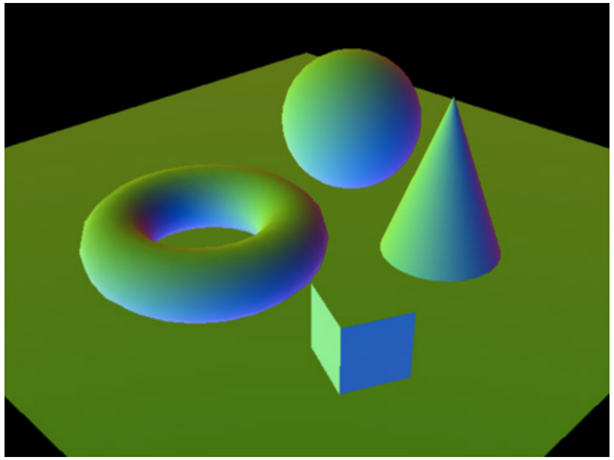
- Fragment shaders get expensive:
  - Complex materials, textures, indirect lighting...
- Pb. for complex scenes/multi-layers:
  - Shading for all surfaces
  - Even if they're invisible
  - Z-buffer test *after* the fragment shader
- Need: visibility before shading materials
  - Theoretically impossible
  - Solution: *deferred shading*

Deferred shading

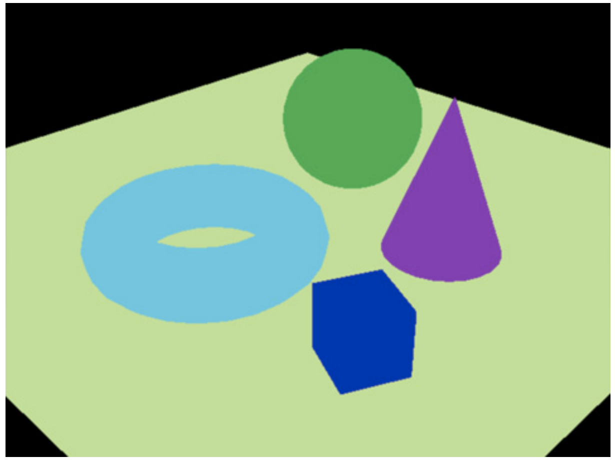
- 1st pass: rendering into 3–4 aux. buffers



Position (x,y,z)

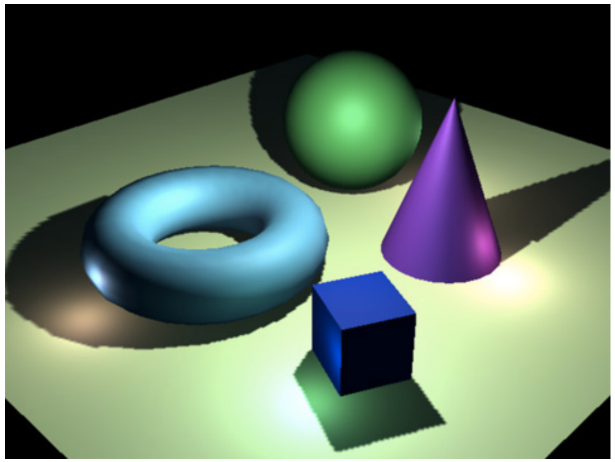


Normals



Colors, materials, textures

- 2nd pass: compute shading using these buffers



Deferred shading + SSAO

- SSAO :
  - Needs a geometry buffer
  - Is expensive: must reduce number of calls
- Deferred shading :
  - Has a geometry buffer
  - Did visibility as pre-computation
- Good match of algorithms

Beyond SSAO

Approximating Dynamic Global Illumination in Image Space
Ritschel et al. 2009