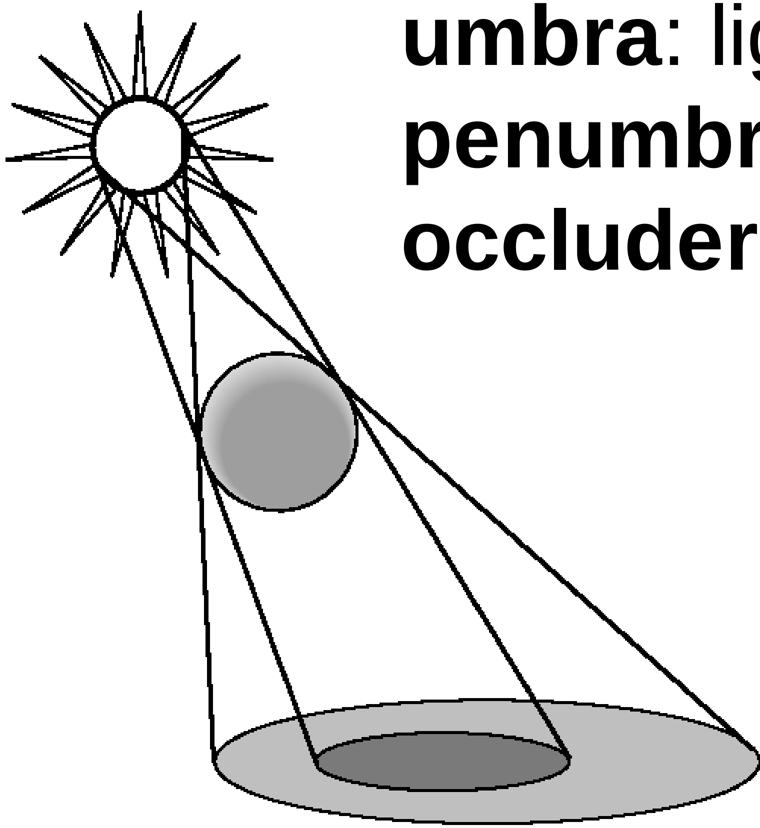
# Advanced Shading I: Shadow Rasterization Techniques

# Shadow Terminology



**umbra**: light totally blocked
**penumbra**: light partially blocked
**occluder**: object blocking light

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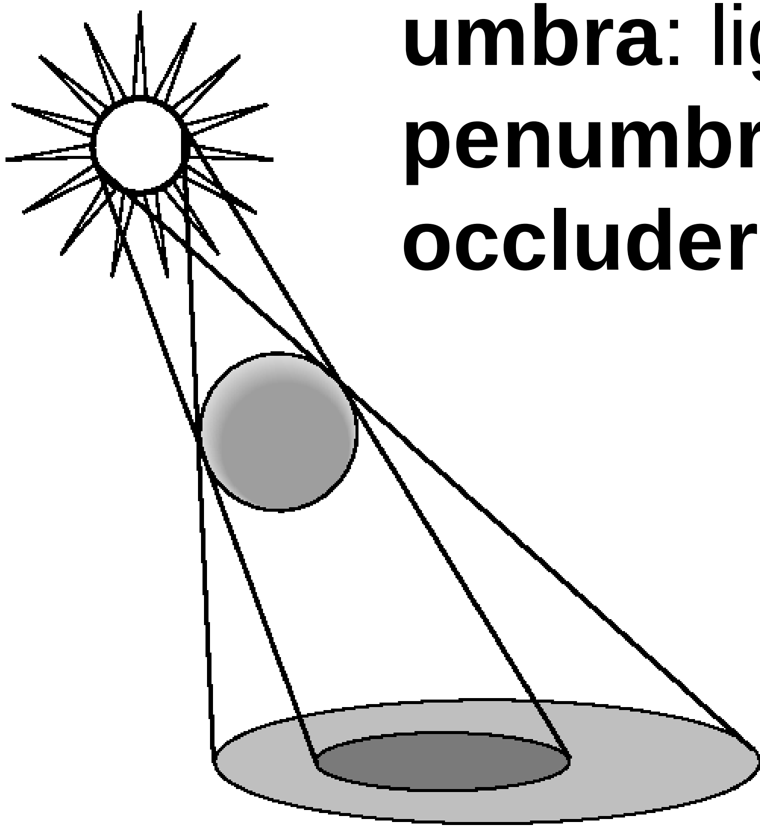
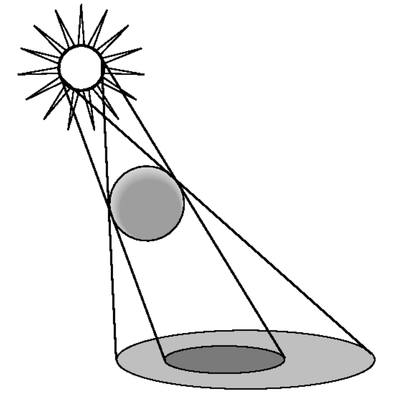


**umbra**: light totally blocked
**penumbra**: light partially blocked
**occluder**: object blocking light

point lights have
no penumbra

# Shadow Rendering



**Hard shadows**: umbra only

- easy with ray tracing (shadow rays)

**Soft shadows:** penumbra and umbra

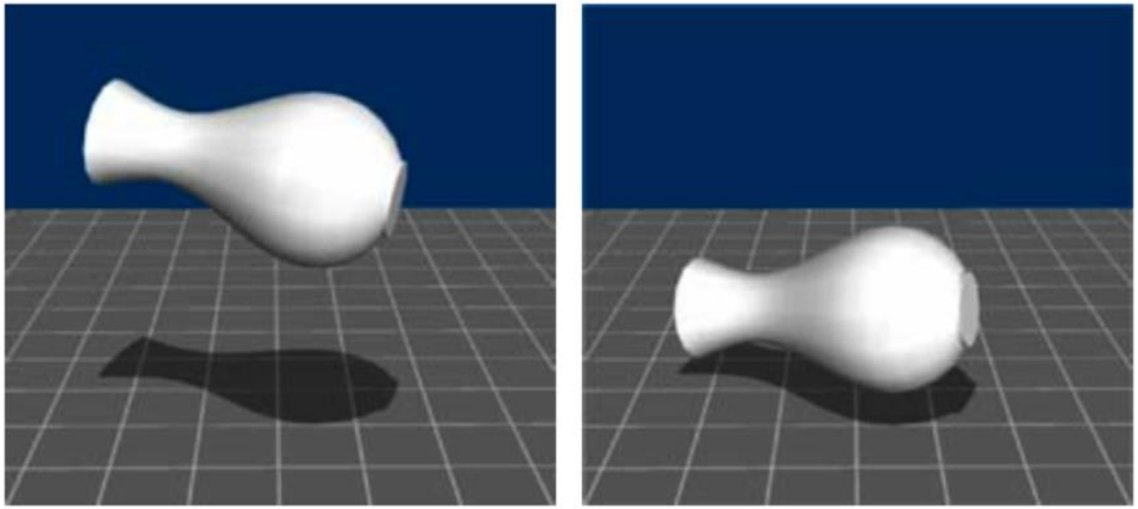
- very difficult without global illumination

Today: rasterizing hard shadows

# Projection Shadows

Easiest case:

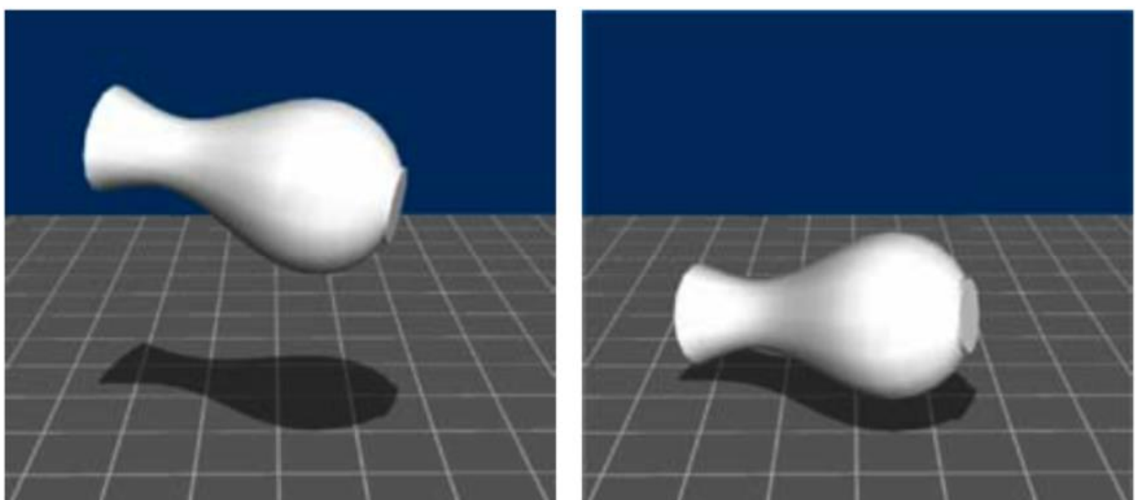
- one object
- one light
- shadow cast on flat ground



# Projection Shadows

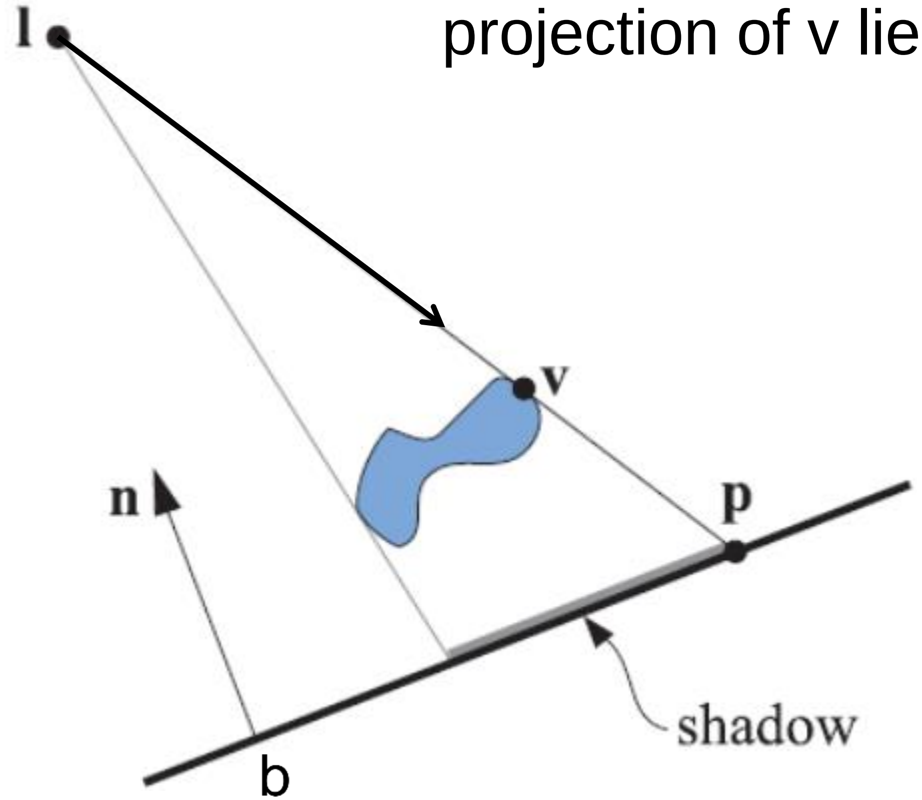
Main idea: render scene twice

- once as usual
- once with object shaded black and **flattened** onto plane



# Projection Shadows

projection of v lies along ray $l + (v - l)t$



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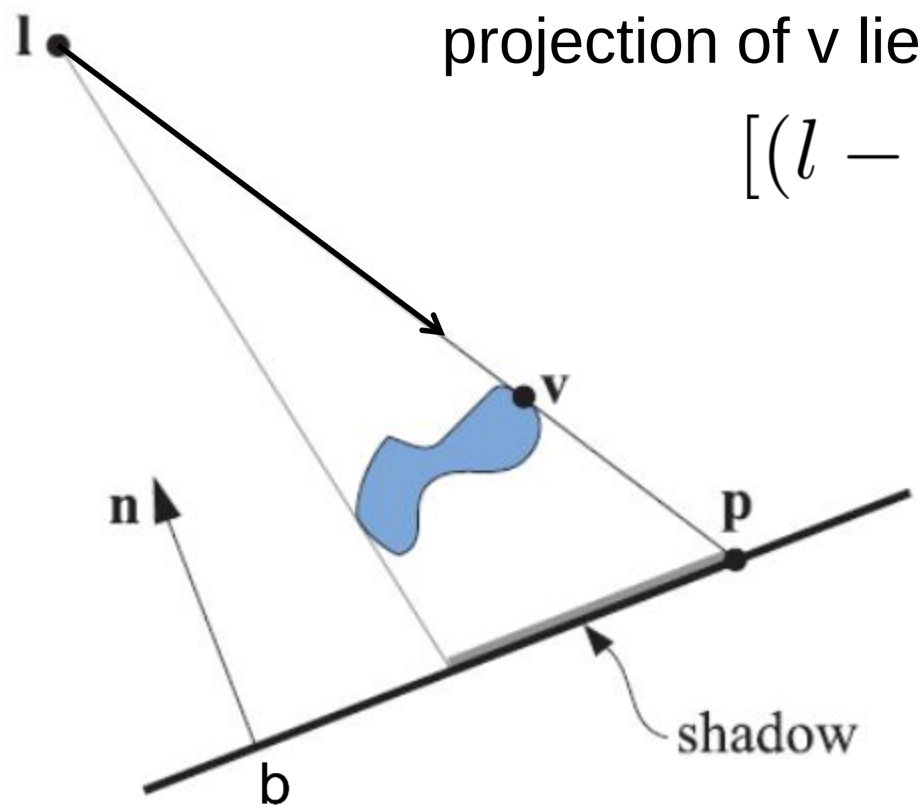


projection of v lies along ray $l + (v - l)t$

$$[(l - b) + (v - l)t] \cdot \hat{n} = 0$$

$$t = \frac{(b-l)\cdot\hat{n}}{(v-l)\cdot\hat{n}}$$

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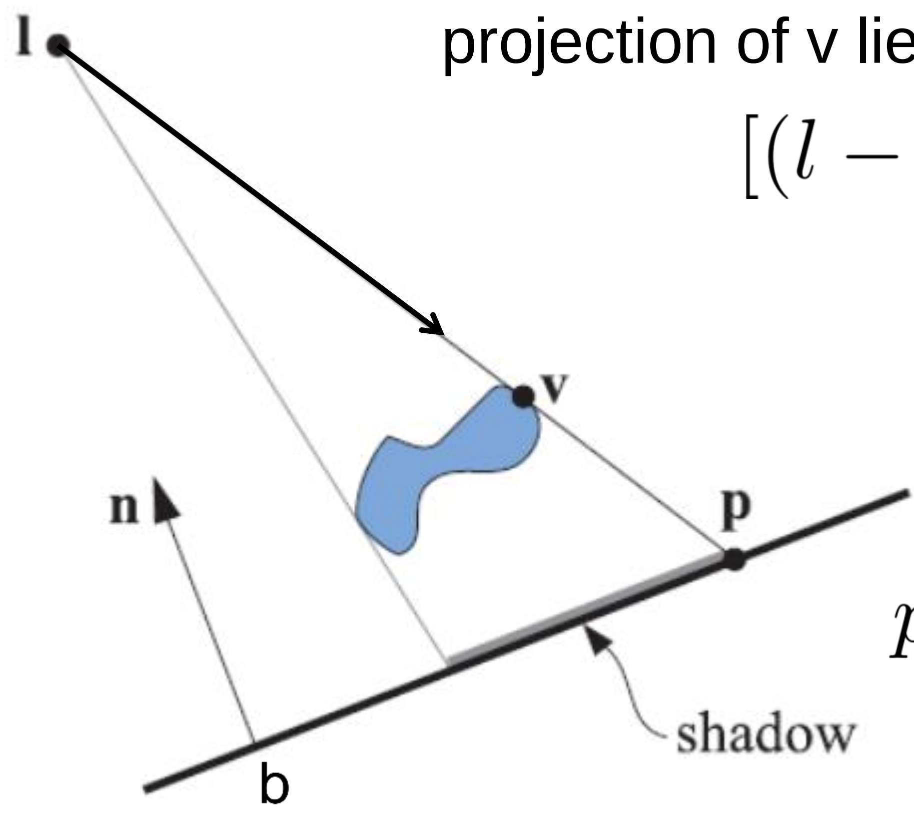


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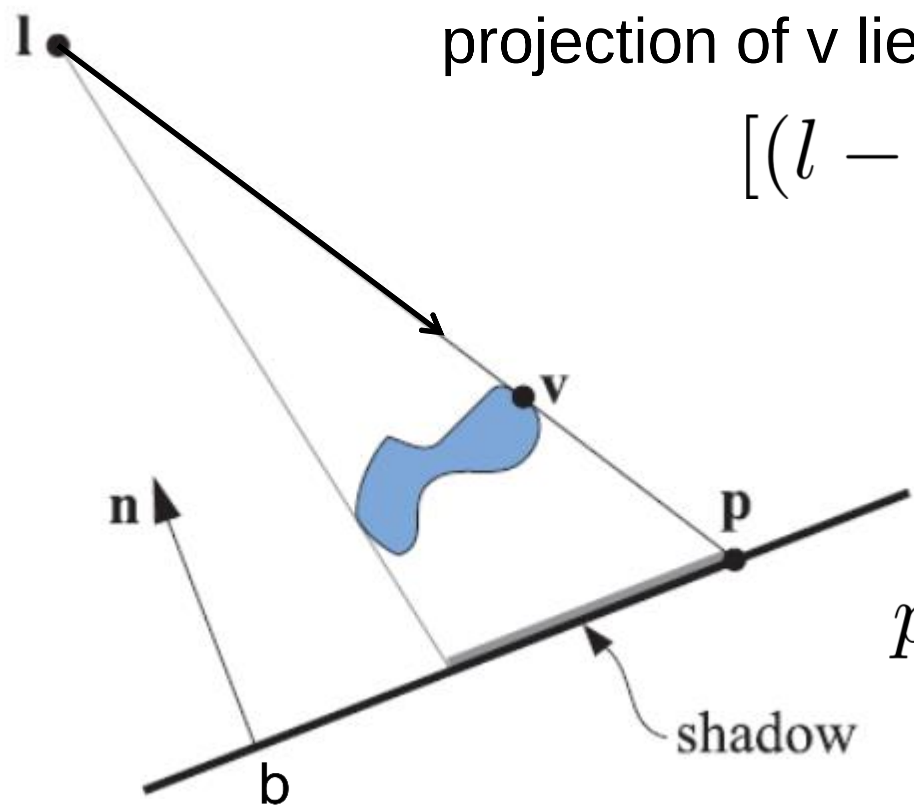


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how to write as affine transformation?

# Projection Operation

Needed:

$$M \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} = \frac{(x, y, z)}{(x, y, z) \cdot \hat{n}}$$

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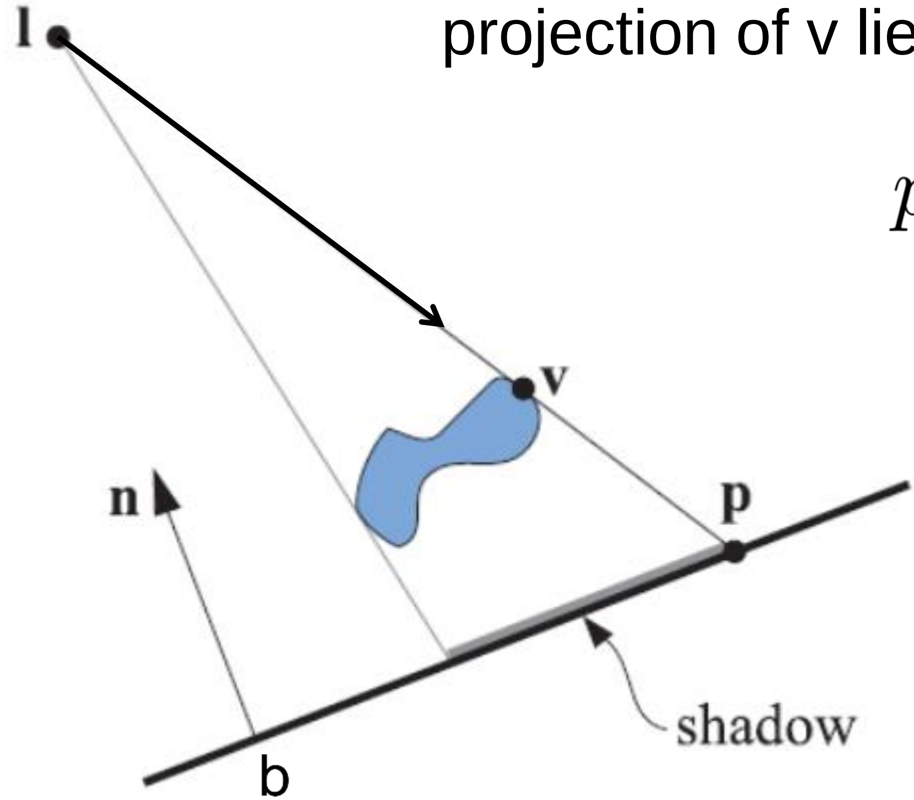
$$M = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ & \hat{n}^T & & 0 \end{bmatrix}$$

# Projection Shadows

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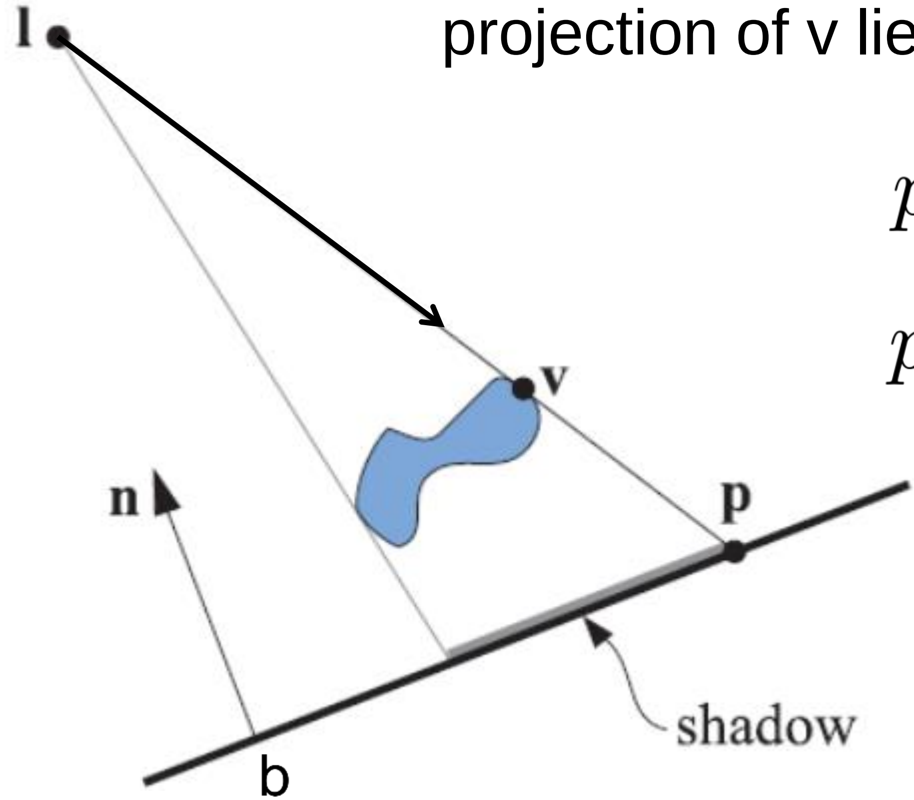



projection of v lies along ray $l + (v - l)t$

$$p = l + (v - l)\frac{(b-l)\cdot\hat{n}}{(v-l)\cdot\hat{n}}$$

$$p = T_l S_{(b-l)\cdot\hat{n}} M T_{-l} v$$

# Projection Shadows

Pros:

- easy to code

Cons:

# Projection Shadows

Pros:

- easy to code, fast

Cons:

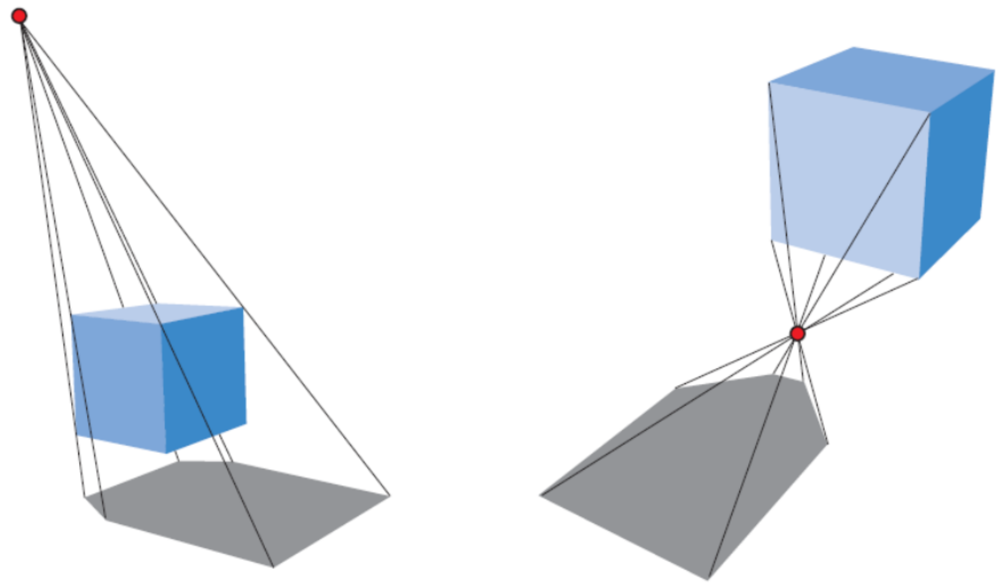
- only draws shadows on flat surfaces
- no soft shadows
- no self-shadows

# Projection Shadows

Multiple lights?

- fake with alpha blending

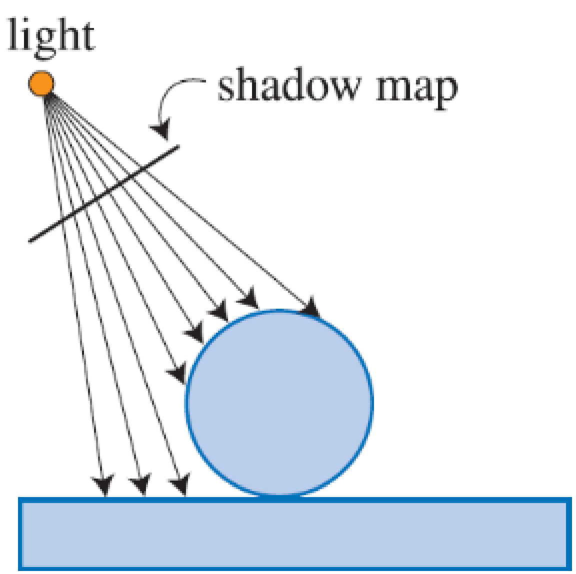
Final gotcha:

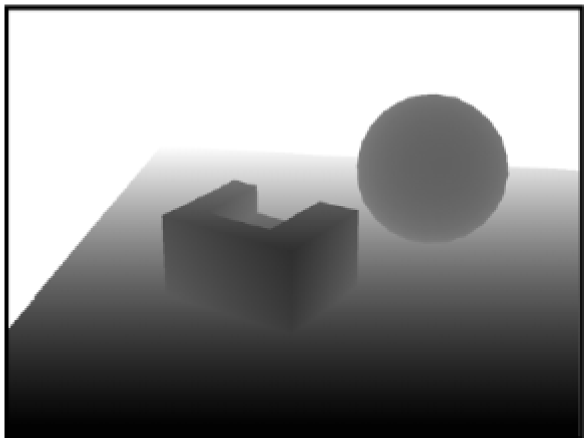


# Shadow Maps

Render scene **from the light**

- record depth only

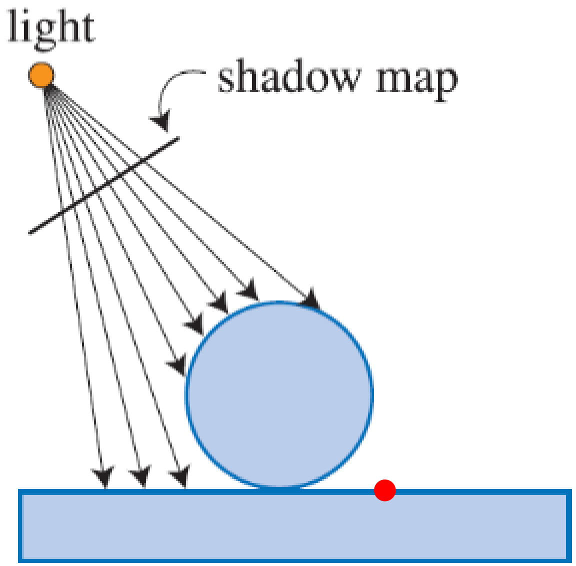


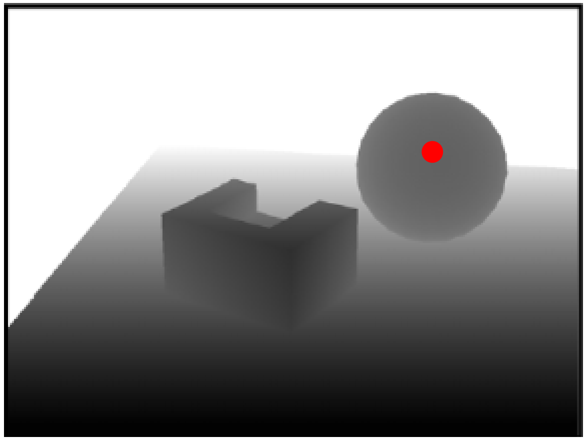



why useful?

# Shadow Maps

To shade a pixel, calculate: 1) pixel to light distance; 2) shadow map value



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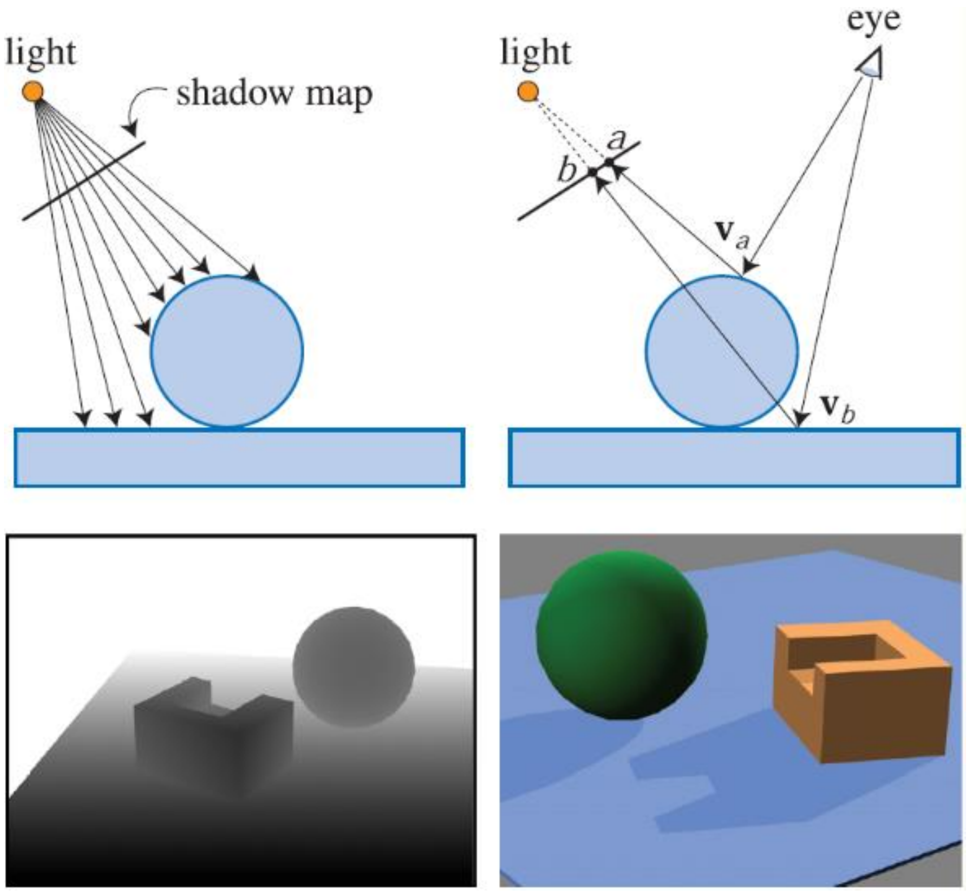
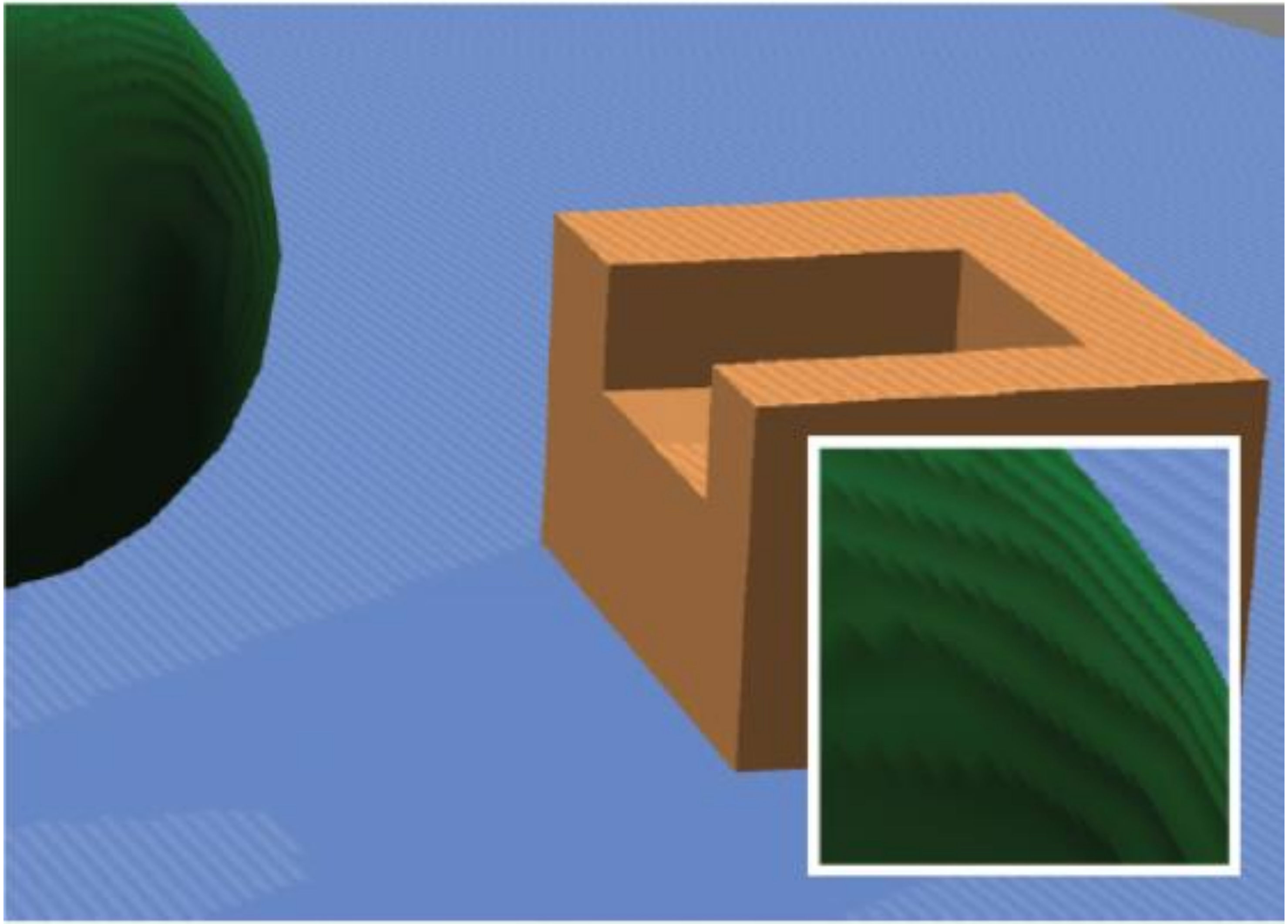



compare pixel-to-light
distance to shadow map

if equal, no shadow
if greater, in shadow

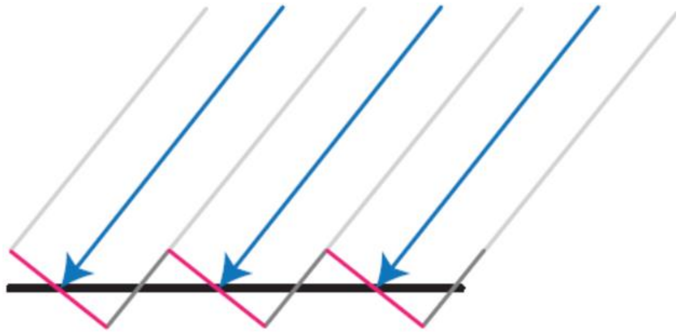
# What's The Bug? Part I



# What's The Bug? Part I

Floating point == is very dangerous

- numerical floating-point error
- depth buffer has finite precision



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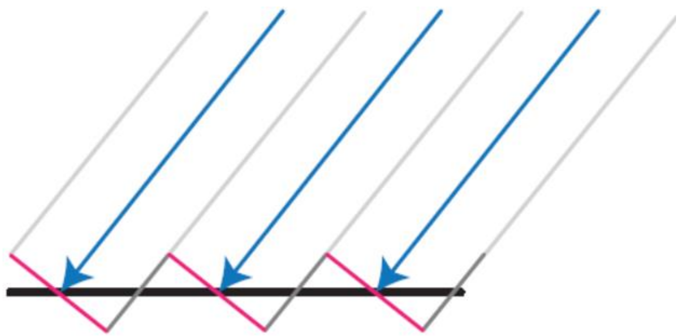
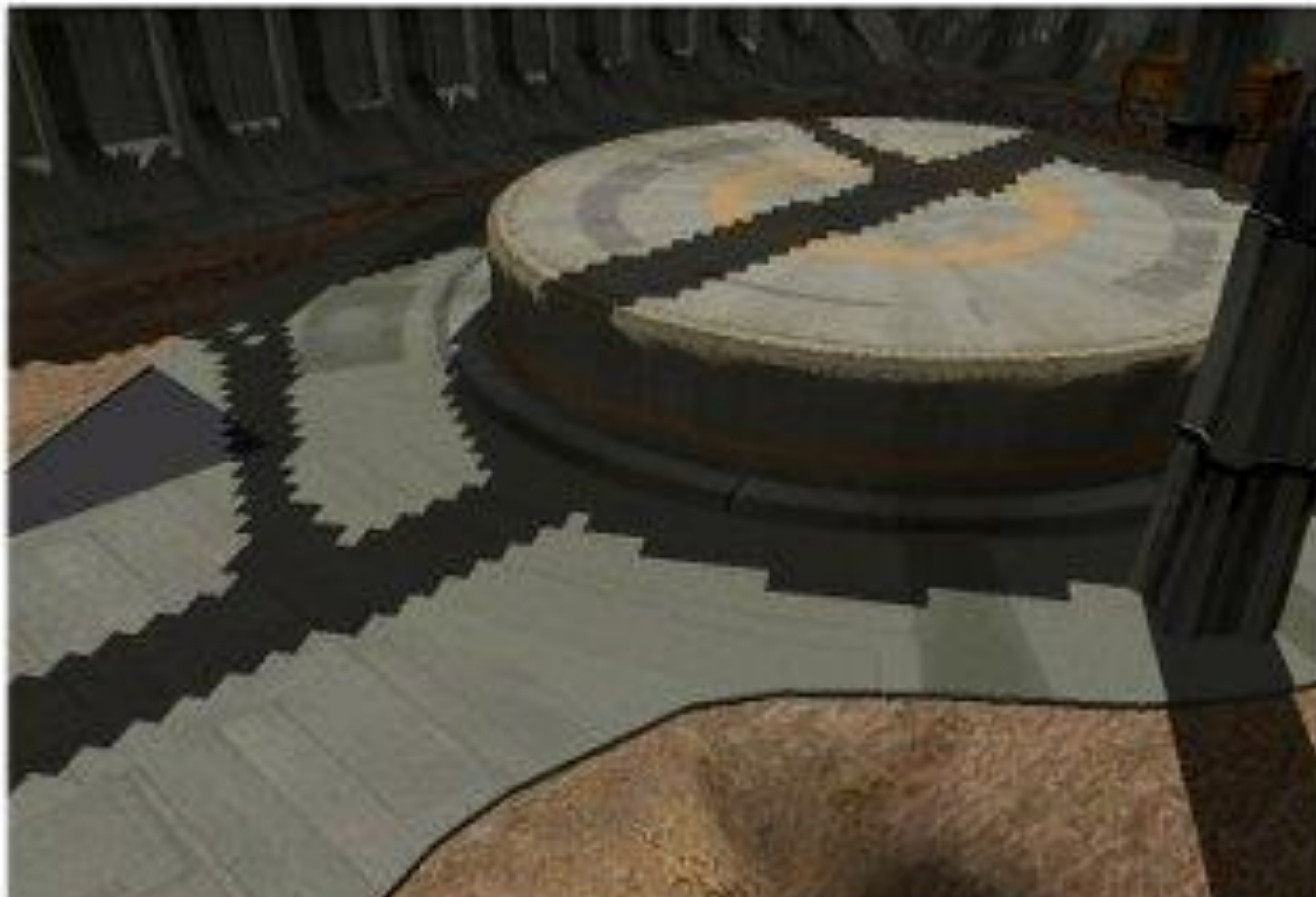


Fix by including tolerance ("bias") in check

# What's The Bug? Part II



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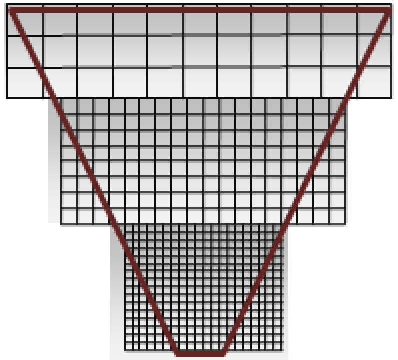
Cascaded shadow maps: use higher-resolution shadow map near eye



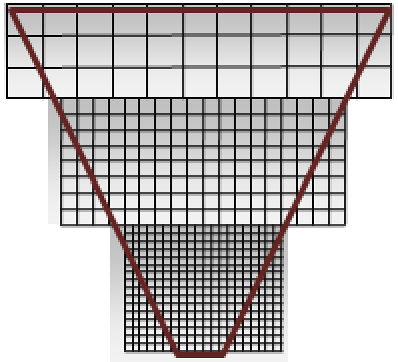
# What's The Bug? Part II

Shadow map is too coarse

- shadows are **aliased**

Cascaded shadow maps: use higher-resolution shadow map near eye

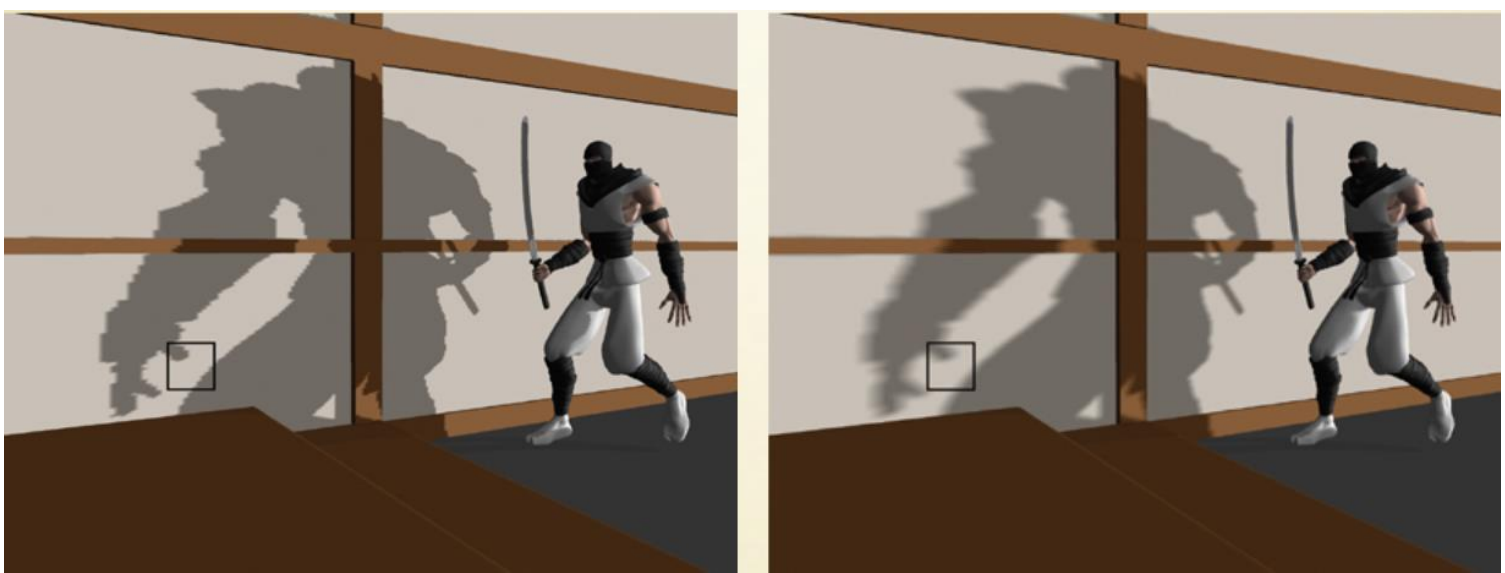
- highest-quality fix
- complicated
  - (have to partition shadow map)



# Percentage Closer Filtering

Sample several nearby pixels on shadow map instead of only one pixel

Set shadow intensity proportional to number of "shadow" votes



# Shadow Maps

Very common real-time technique

- used in Unreal Engine, etc

Pros:

- works with curved objects
- works with self-shadows

Cons:

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Pros:

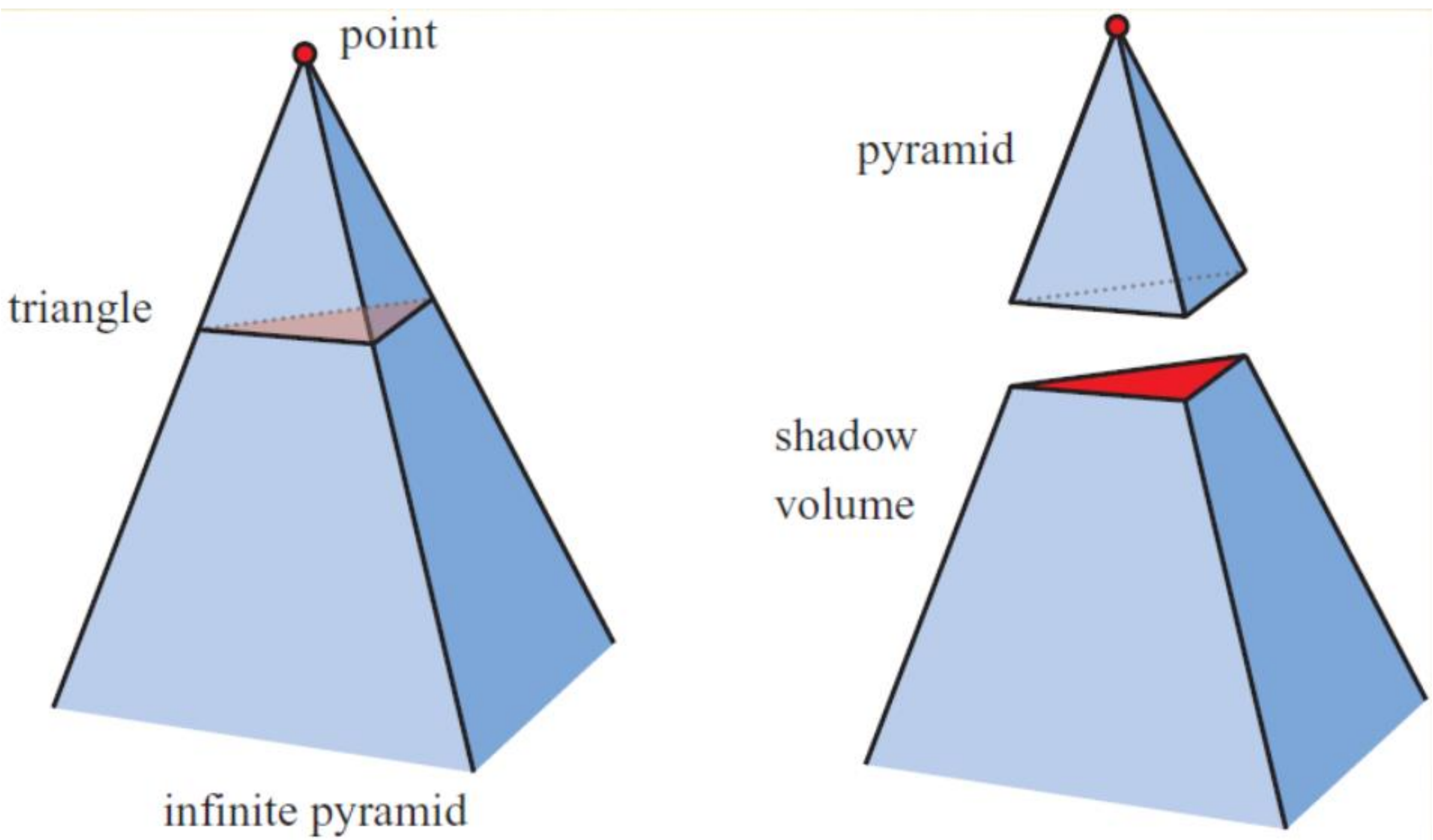
- works with curved objects
- works with self-shadows

Cons:

- very prone to aliasing artifacts
- still no soft shadows

# Shadow Volumes

Consider single light, single triangle



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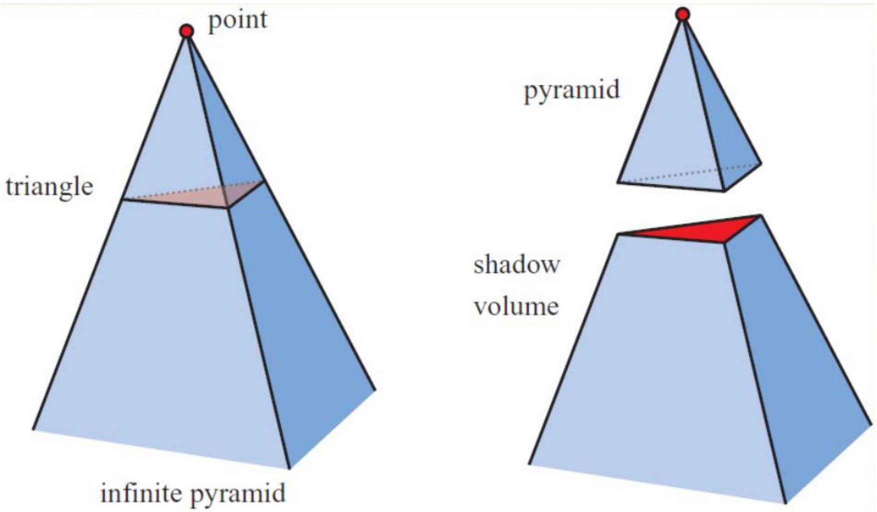
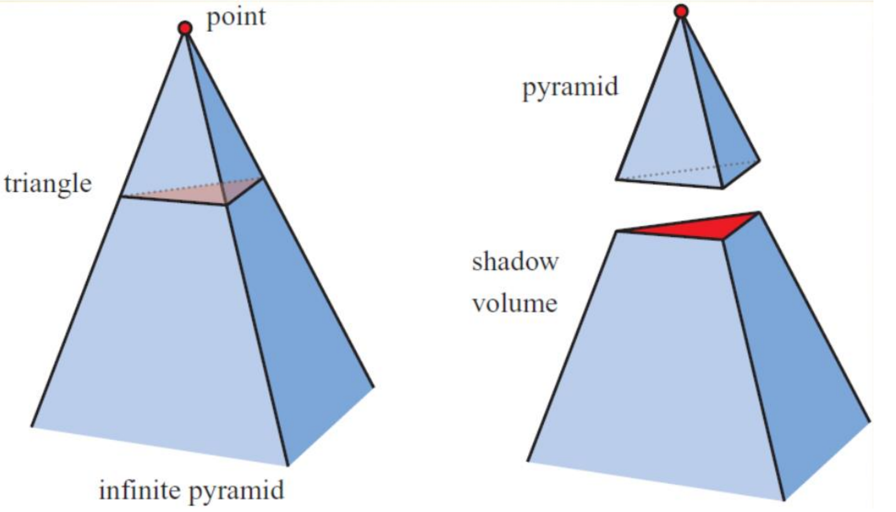



Main idea:

- build **3D object** representing the shadow volume

If pixel is inside volume, it is in shadow

# Shadow Volumes




Main idea:

- build **3D object** representing the shadow volume

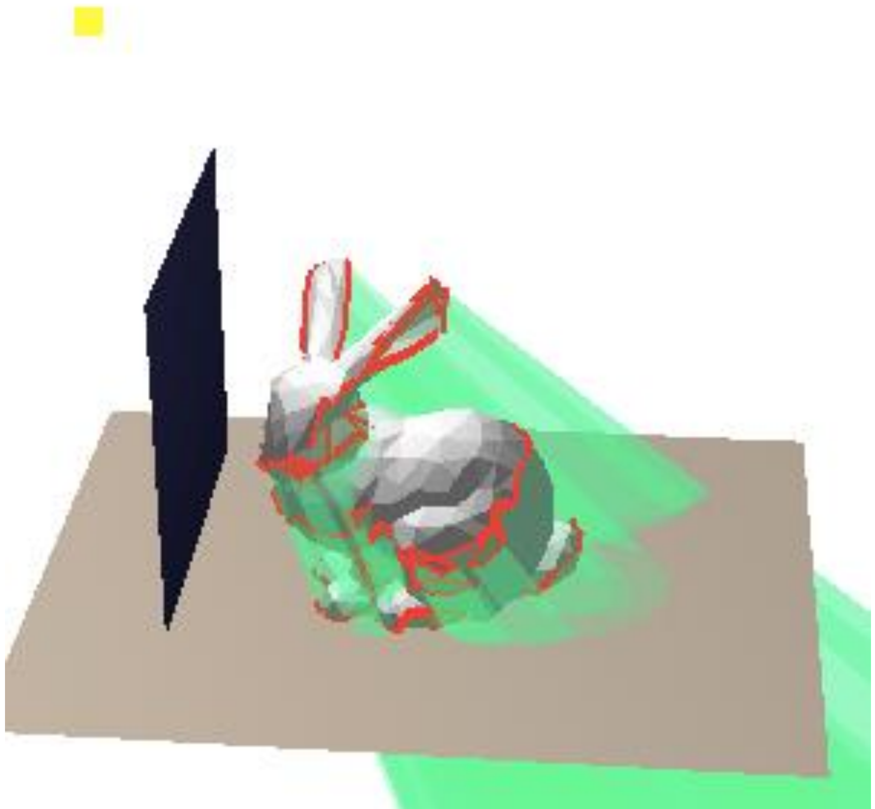
If pixel is inside volume, it is in shadow

- shoot ray from pixel to eye, count number of intersections
- odd = in shadow

# Shadow Volumes

For more complicated object, look only at **silhouette edges**

- edges connecting front-facing to back-facing triangles



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Increasingly popular in real-time graphics

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Pros:

- high-quality shadows (no aliasing)
- self-shadows automatically included

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Increasingly popular in real-time graphics

Pros:

- high-quality shadows (no aliasing)
- self-shadows automatically included

Cons:

- **slow** and complicated
- shadows chunky if meshes too coarse
- **still** no soft shadows