Image Processing and Computer Graphics

Shadow Algorithms

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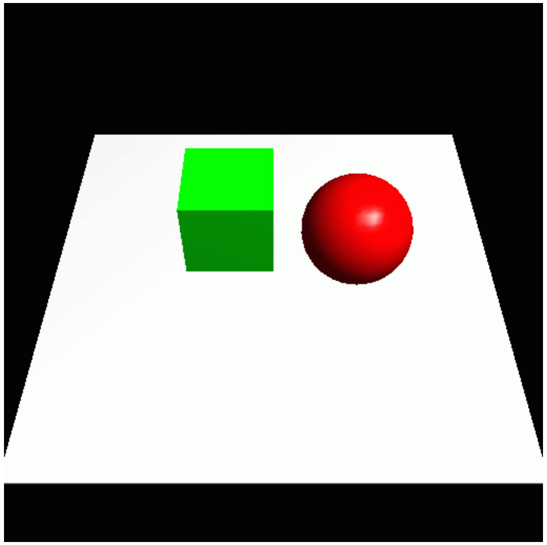
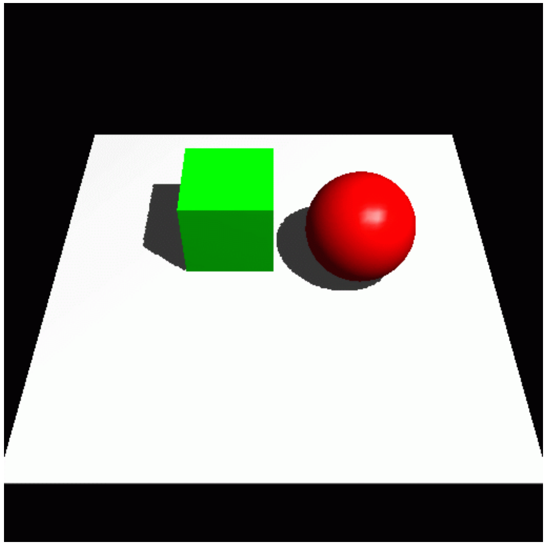
Outline

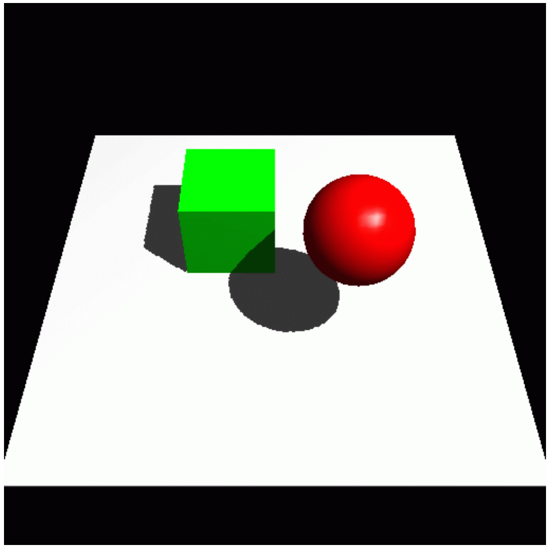
- introduction
- projection shadows
- shadow maps
- shadow volumes
- conclusion

Motivation

- shadows help to
  - improve the realism in rendered images
  - illustrate spatial relations between objects

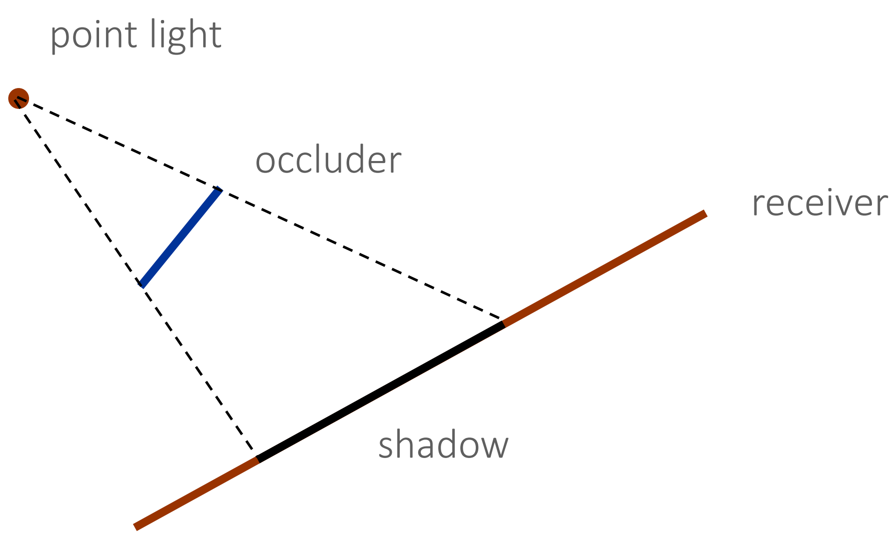


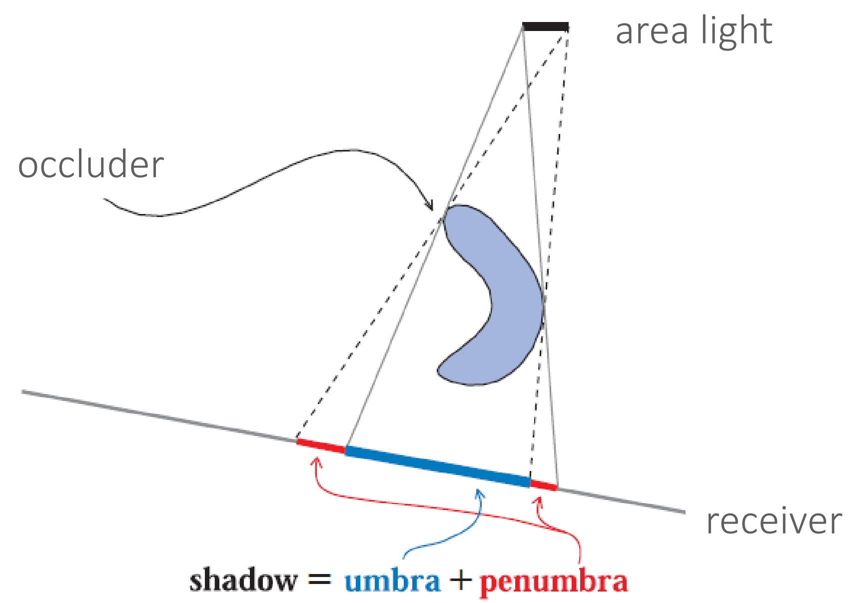




Goal

- determination of shadowed parts in 3D scenes



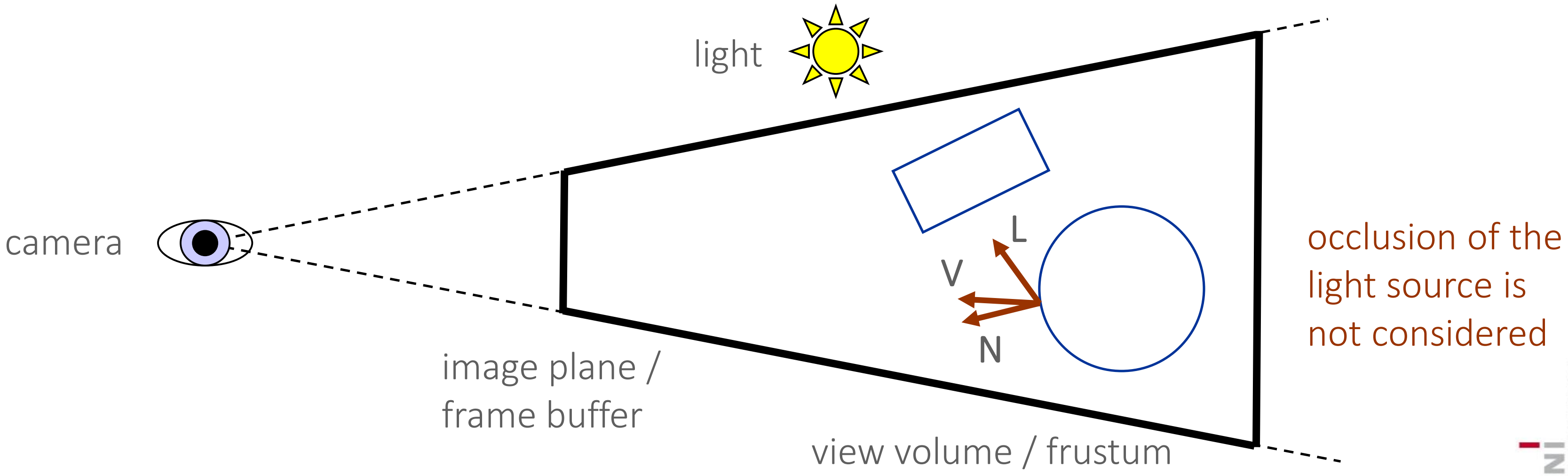


- only the geometry is considered

[Akenine-Moeller et al.: Real-time Rendering]

Context

- shadow algorithms are not standard functionality of the rasterization-based rendering pipeline
- rendering pipeline
  - generates 2D images from 3D scenes (camera, light, objects)
  - evaluates lighting models using local information
  - spatial relations among objects are not considered



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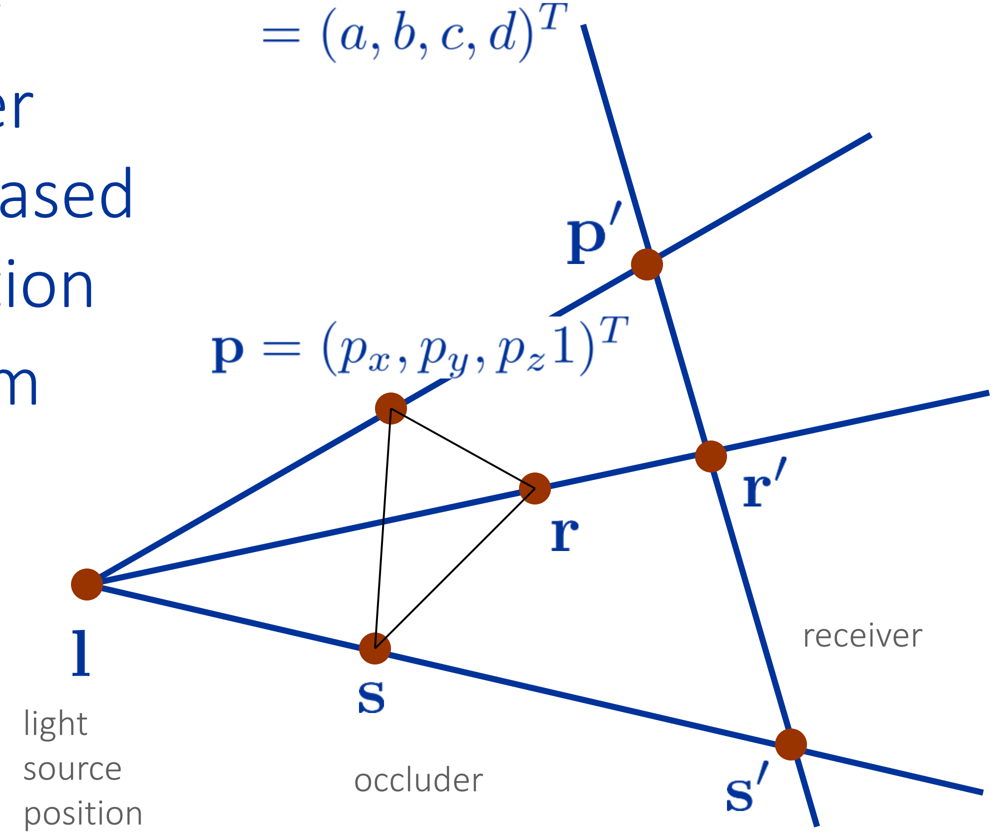
Projection Shadows

- project the primitives of occluders onto a receiver plane (ground or wall) based on the light source location
- projected primitives form the shadow geometry
- projection matrix
  $\mathbf{P} = \mathbf{l}\mathbf{n}^T - (\mathbf{n} \cdot \mathbf{l})\mathbf{I}_4$

$$\mathbf{n} = \{ax + by + cz + d = 0\} = (a, b, c, d)^T$$

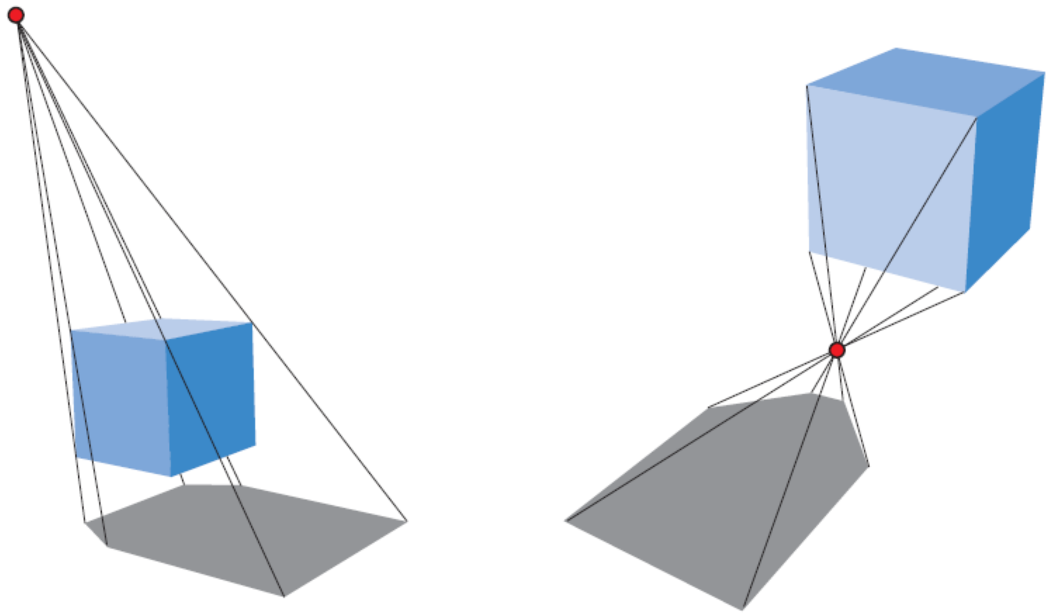


Projection Shadows Implementation

- draw the receiver plane
  - increment stencil where the receiver is rendered
- disable depth test
- draw shadow geometry (projected occluders) for stencil=1
- enable depth test
- draw occluders

Projection Shadows
Issues

- restricted to planar receivers
- no self-shadowing
- antishadows



[Akenine-Moeller et al.: Real-time Rendering]

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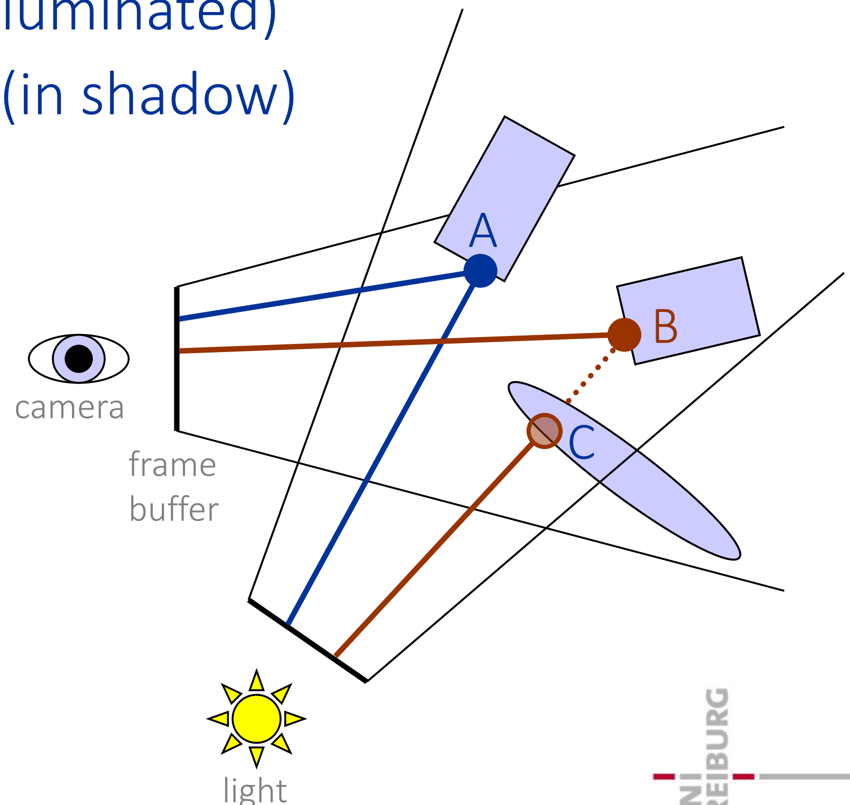
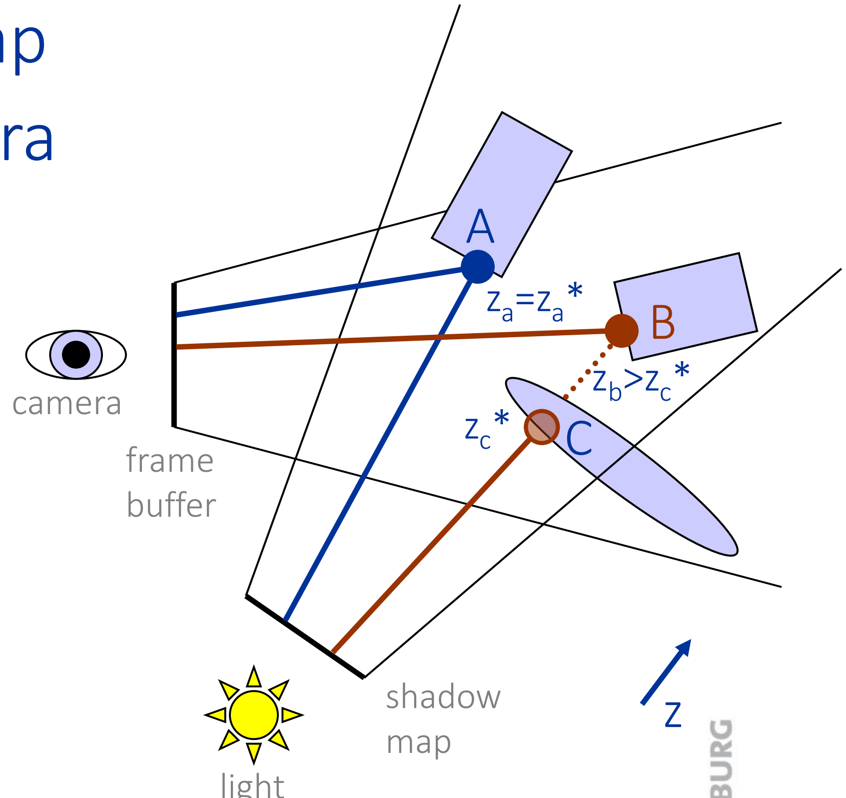
Concept

- see shadow casting as a visibility problem
- scene points are
  - visible from the light source (illuminated)
  - invisible from the light source (in shadow)
- resolving visibility is standard functionality in the rendering pipeline (z-buffer algorithm)



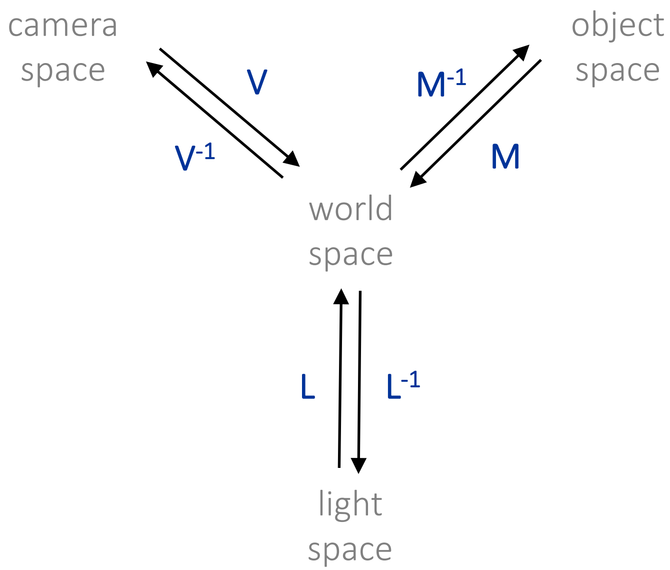
Algorithm

- render scene from the light source
- store all distances to visible (illuminated) scene points in a shadow map
- render scene from the camera
- compare the distance of rendered scene points to the light with stored values in the shadow map
- if both distances are equal, the rendered scene point is illuminated

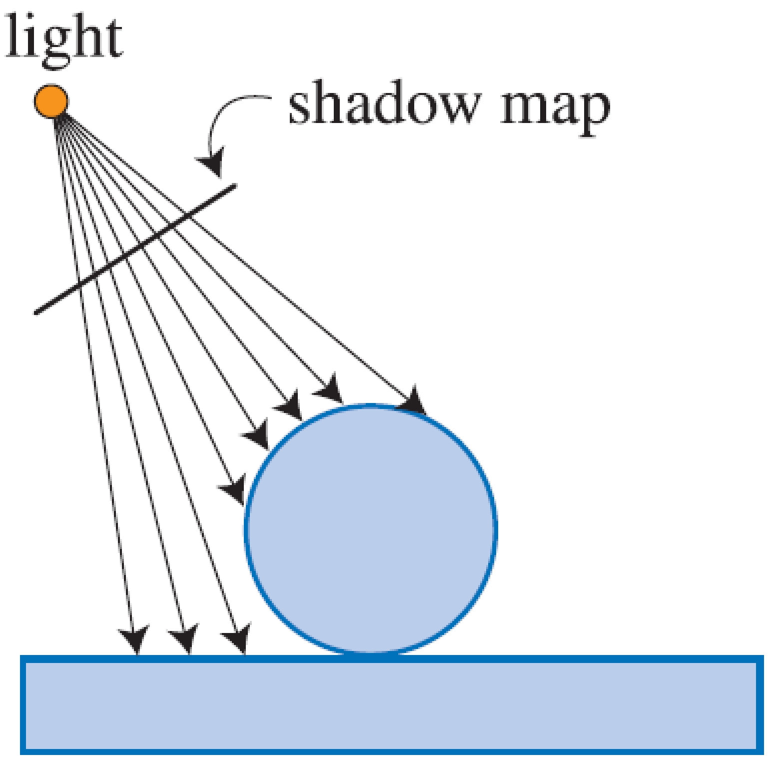


Coordinate Systems

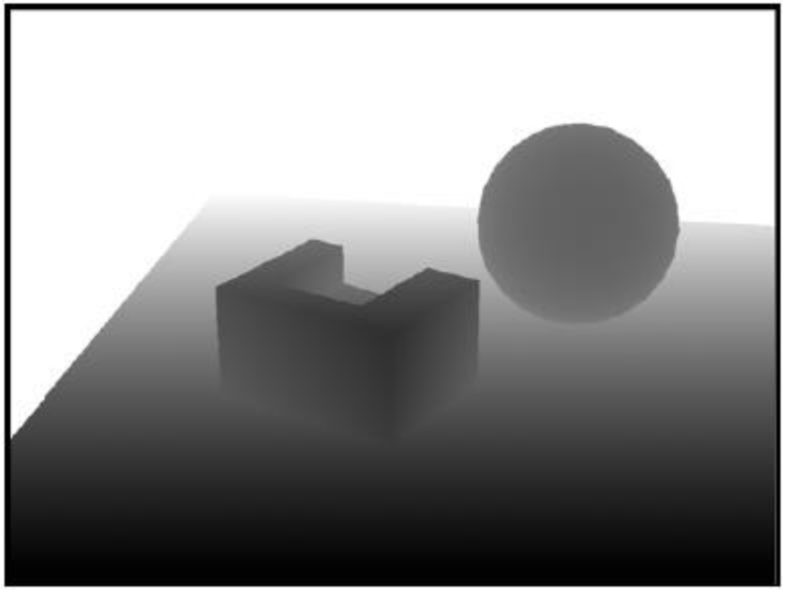
- in the second rendering pass, for each fragment, its position in the shadow map has to be determined
  - convert the 3D position of a fragment to object space
  - apply modelview transform of the light $\mathbf{L^{-1}M}$
  - apply projective transform of the light $\mathbf{P_{light}}$
  - homogenization and screen mapping
  - mapping to texture space
  - results in $(x', y', z', 1)^T$
  - $z' >$ shadowMap $(x', y') \rightarrow$ point in shadow



Shadow Map Generation



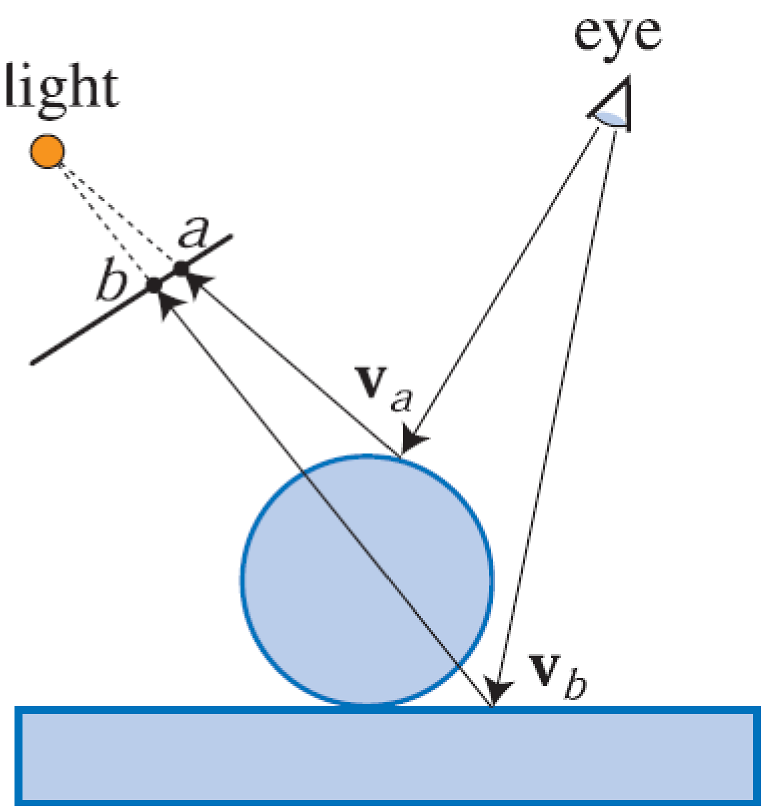
scene is rendered from the position of the light source



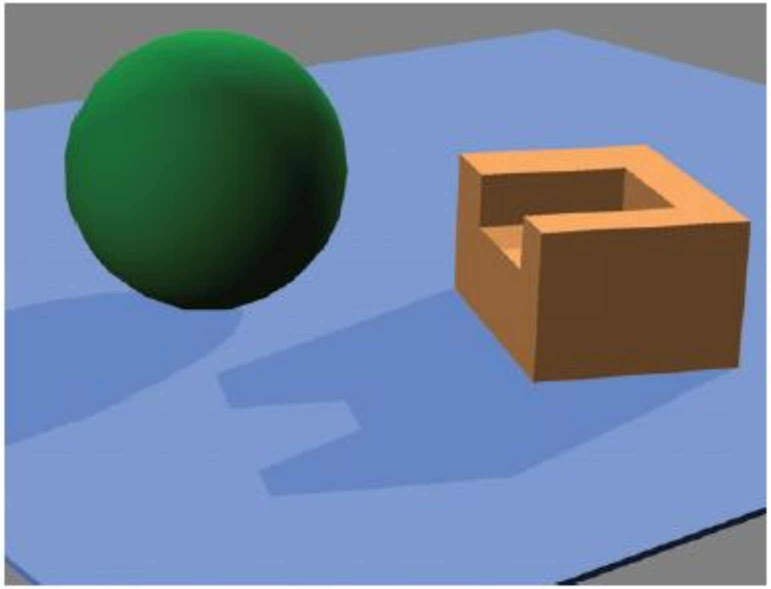
shadow map. a texture that represents distances of illuminated surface points to the light source.

[Akenine-Moeller et al.: Real-time Rendering]

Scene Rendering



in the second rendering pass, v_a and v_b are rendered. v_a is represented in the shadow map (illuminated). v_b is occluded and not represented in the shadow map (in shadow).



in a second rendering pass, the camera view is generated. For each fragment, it is tested whether it is represented in the shadow map or not.

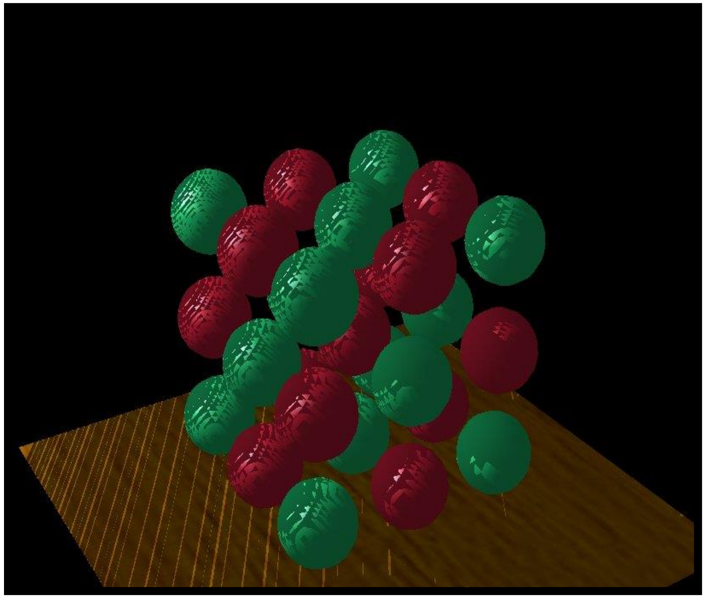
[Akenine-Moeller et al.: Real-time Rendering]

Algorithm

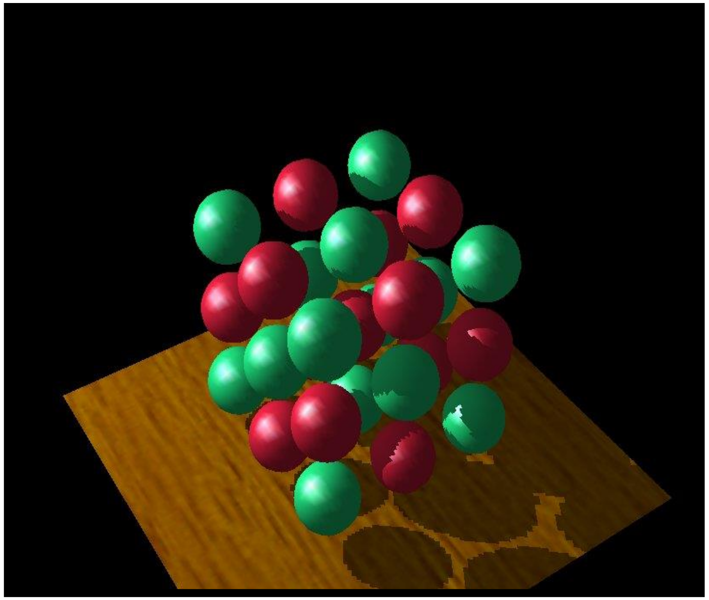
- use two depth buffers
  - the “usual” depth buffer for the view point
  - a second depth buffer for the light position (shadow map)
- render the scene from the light position into the shadow map
- render the scene from the view position into the depth buffer
  - transform depth buffer values to shadow map values
  - compare transformed depth buffer values and shadow map values to decide whether a fragment is shadowed or not

Aliasing

- discretized representation of depth values can cause an erroneous classification of scene points
- offset of shadow map values reduces aliasing artifacts



no offset



correct offset

[Mark J. Kilgard]

Sampling

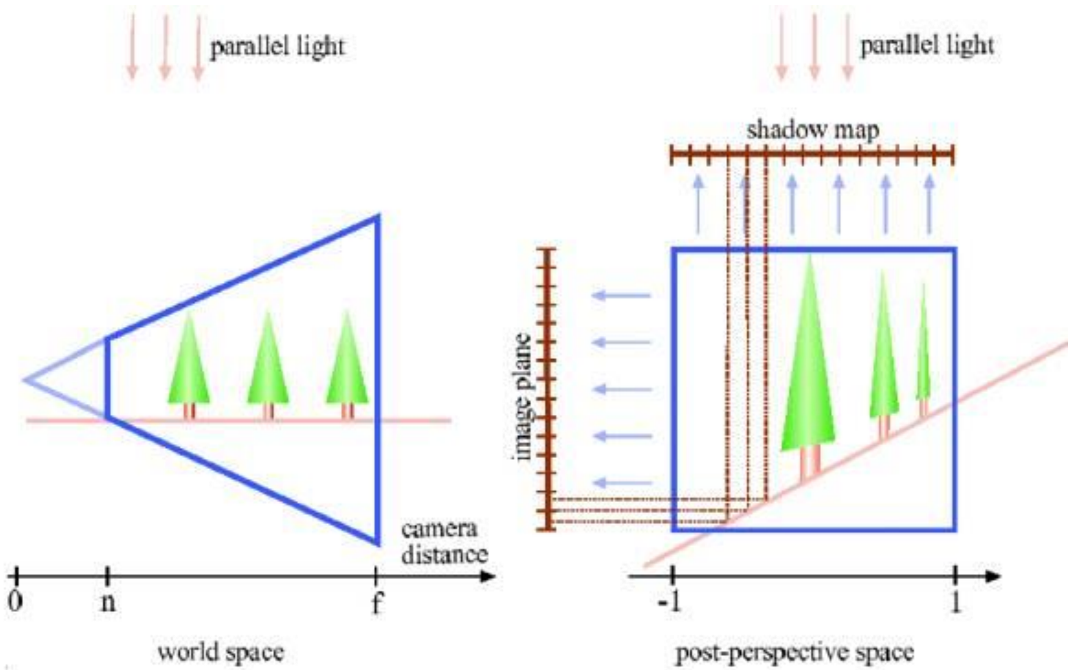
- in large scenes, sampling artifacts can occur
- uniform sampling of the shadow map can result in non-uniform resolution for shadows in a scene
- shadow map resolution tends to be too coarse for nearby objects and too high for distant objects

block artifacts

[Stamminger, Drettakis]

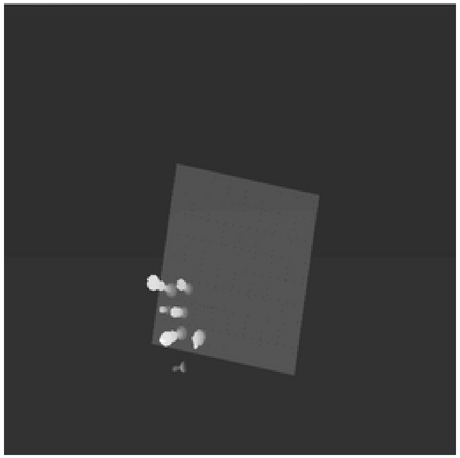
Sampling
Perspective Shadow Maps

- scene and light are transformed using the projective transformation of the camera
- compute the shadow map in post-perspective space

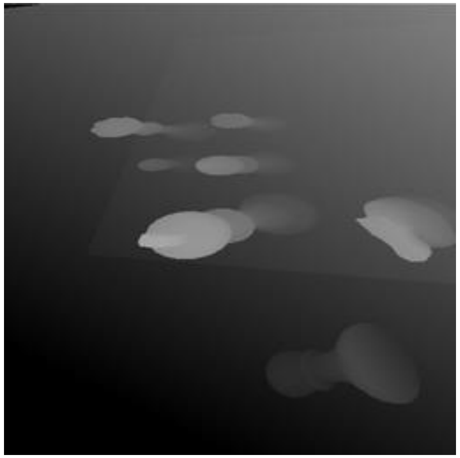
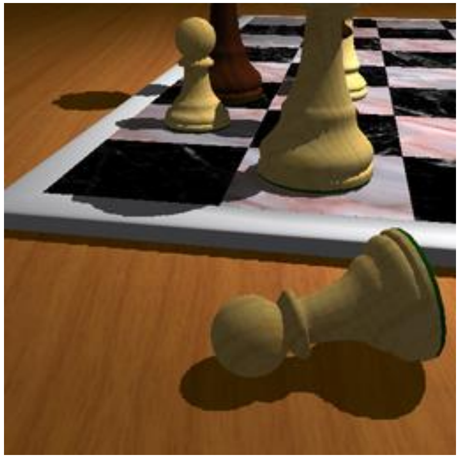


[Stamminger, Drettakis]

Sampling
Perspective Shadow Maps




uniform shadow map

perspective shadow map

[Stamminger, Drettakis]

Summary

- image-space technique with two rendering passes
- no knowledge of the scene geometry is required
- works best for distant spot light sources
- light looks at the scene through
  a single view frustum
  - scene geometry outside the view frustum is not handled
- aliasing artifacts and sampling issues

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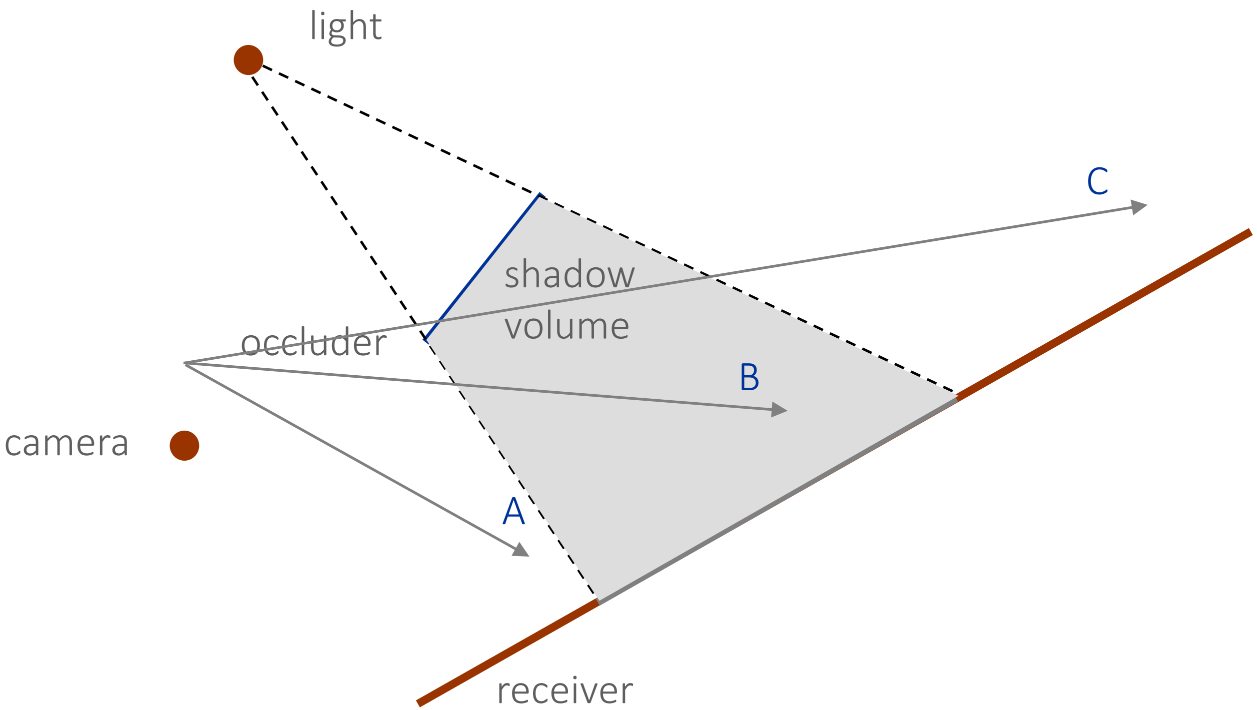
Concept

- employ a polygonal representation of the shadow volume
- point-in-volume test



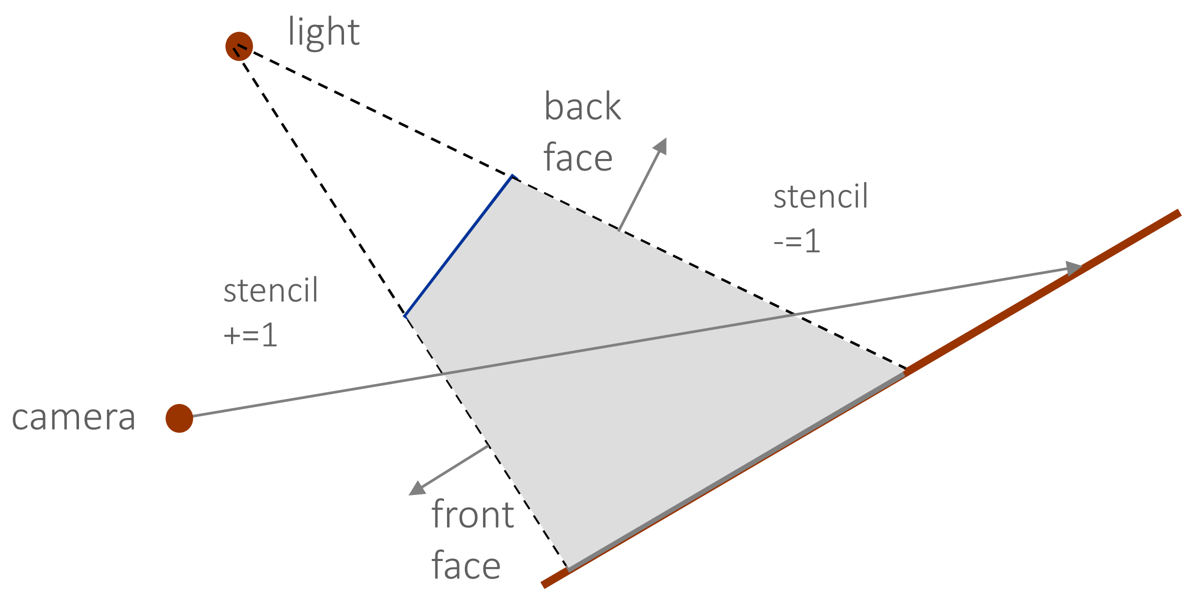
A is illuminated, ray does not intersect the shadow volume

B is in shadow, ray enters the shadow volume

C is illuminated, ray enters and leaves the shadow volume

Implementation Issues

- classification of shadow volume polygons into front and back faces
  - rays enter the volume at front faces / leave it at back faces
- stencil buffer values count the number of intersected front and back faces



Algorithm (Z-pass)

- render scene to initialize depth buffer
  - depth values indicate the closest visible fragment
- stencil enter / leave counting approach
  - render shadow volume twice using face culling
    - render front faces and increment stencil when depth test passes (count occluding front faces)
    - render back faces and decrement stencil when depth test passes (count occluding back faces)
  - do not update depth and color
- finally,
  - if pixel is in shadow, stencil is non-zero
  - if pixel is illuminated, stencil is zero

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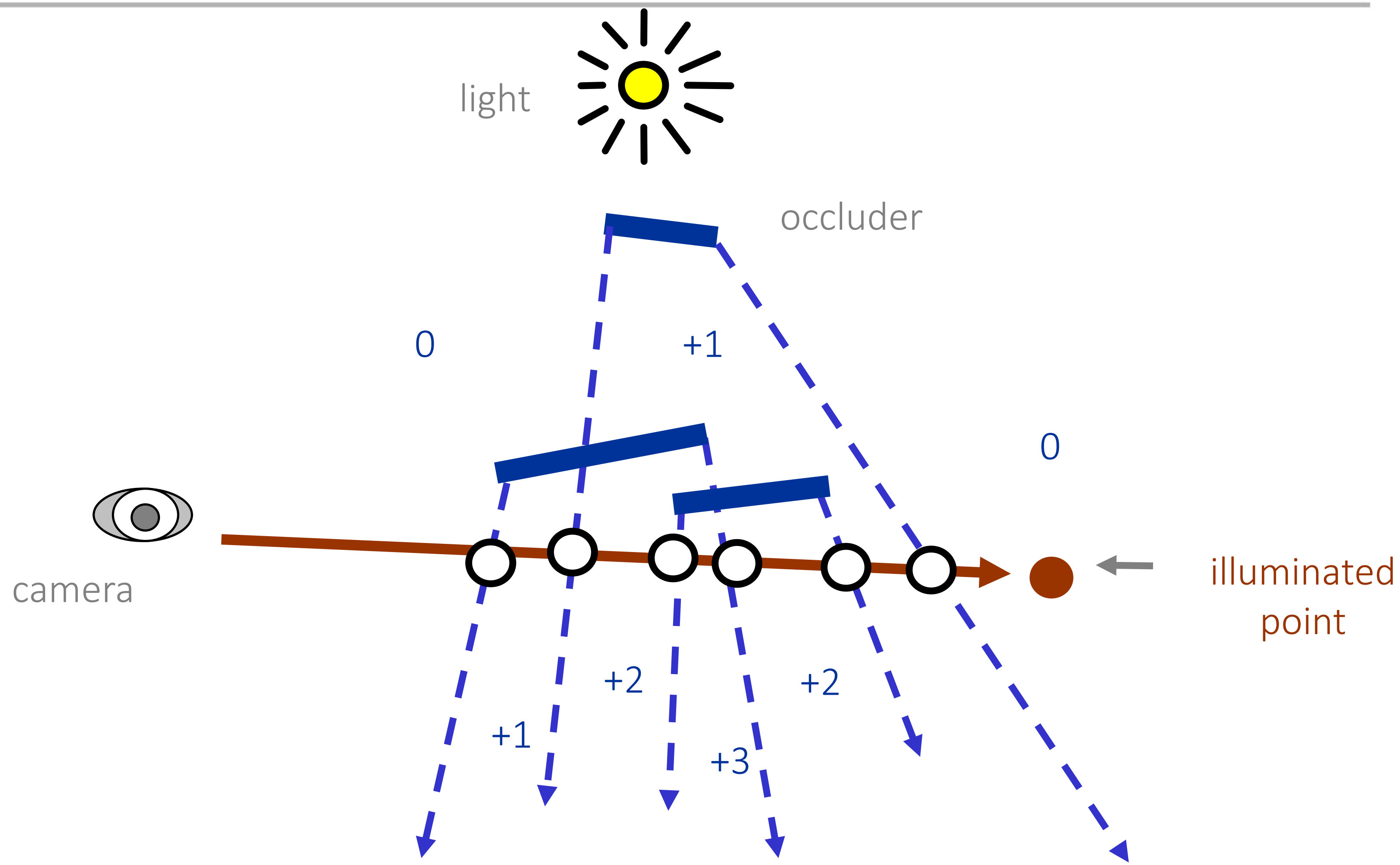
Implementation

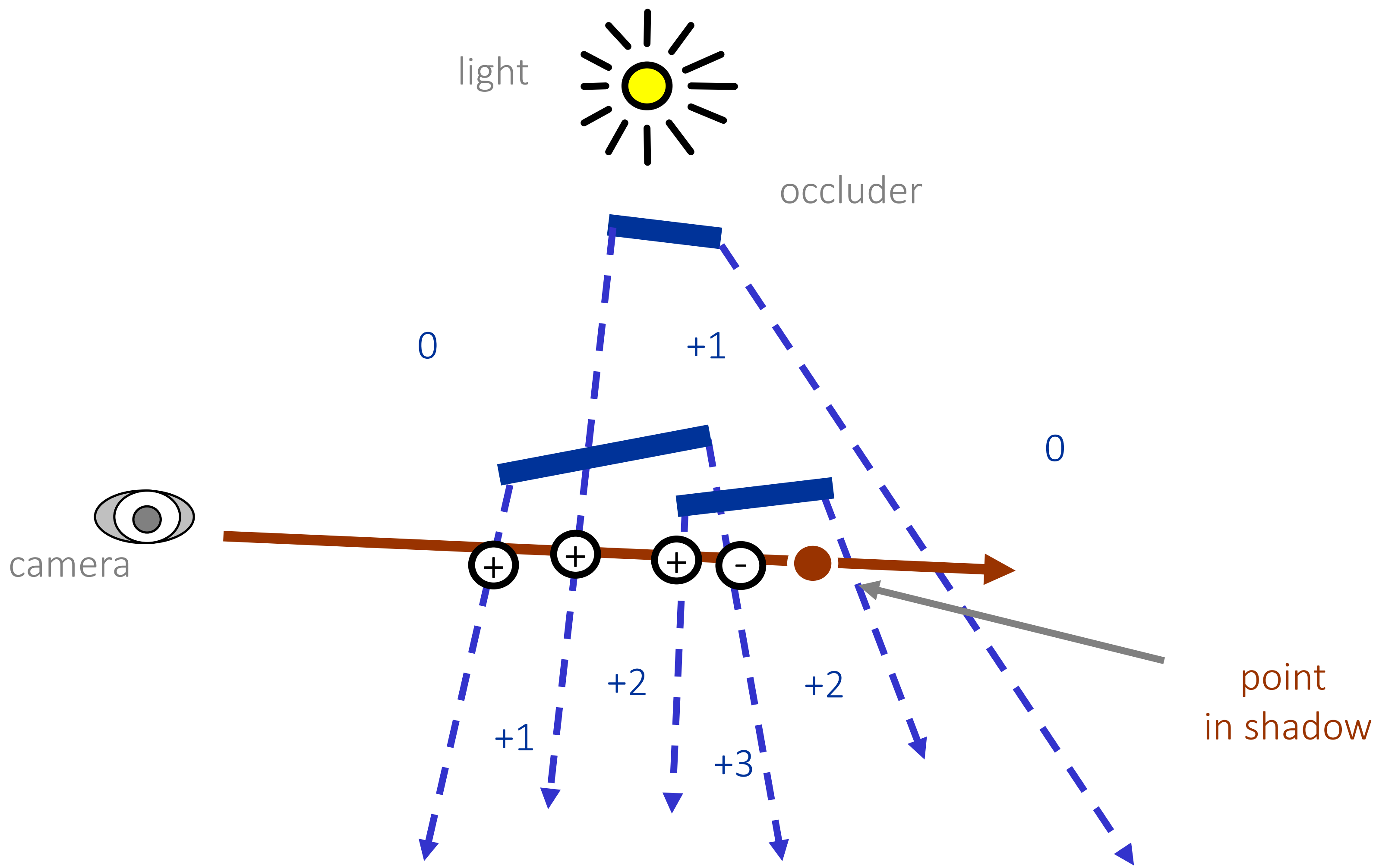
- render the scene with only ambient lighting
- render front facing shadow volume polygons (without depth and color update) to determine how many front face polygons are in front of the depth buffer pixels
- render back facing shadow volume polygons (without depth and color update) to determine how many back face polygons are in front of the depth buffer pixels
- render the scene with full shading where stencil is zero

Example



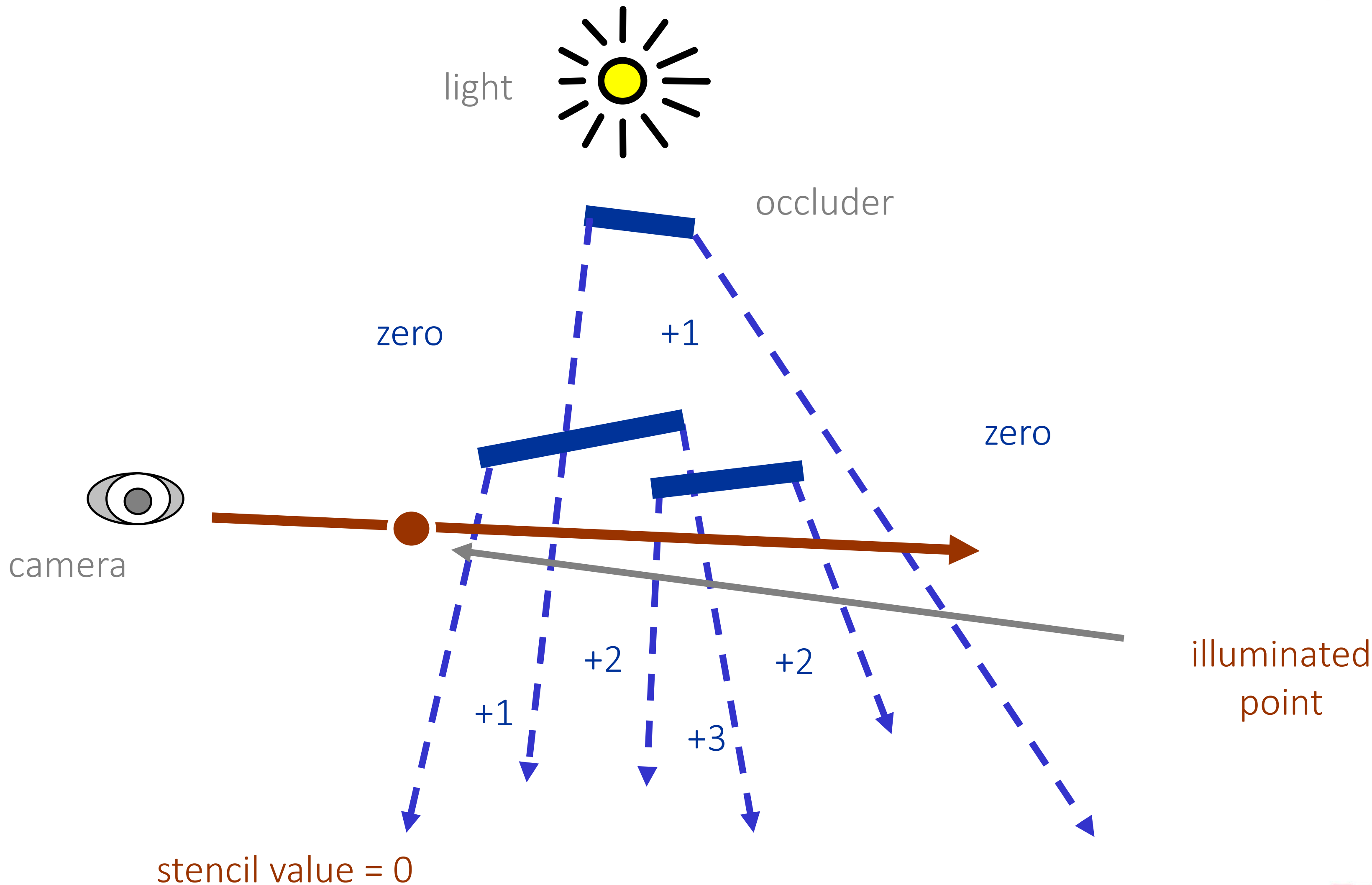
stencil value = +1+1+1-1-1-1 = 0

Example

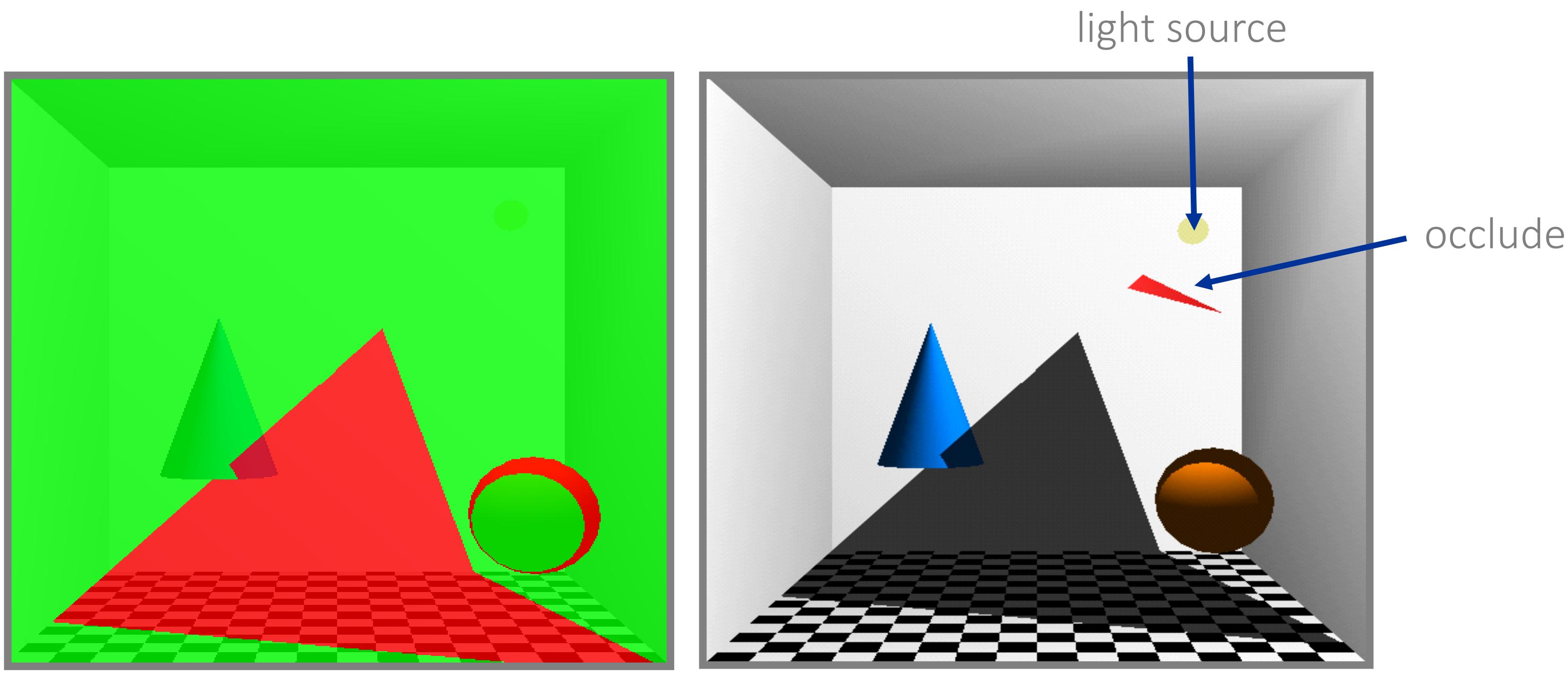


stencil value = +1+1+1-1 = 2

Example


light
occluder
zero
+1
zero
camera
+2
+2
+1
+3
illuminated point
stencil value = 0

Example

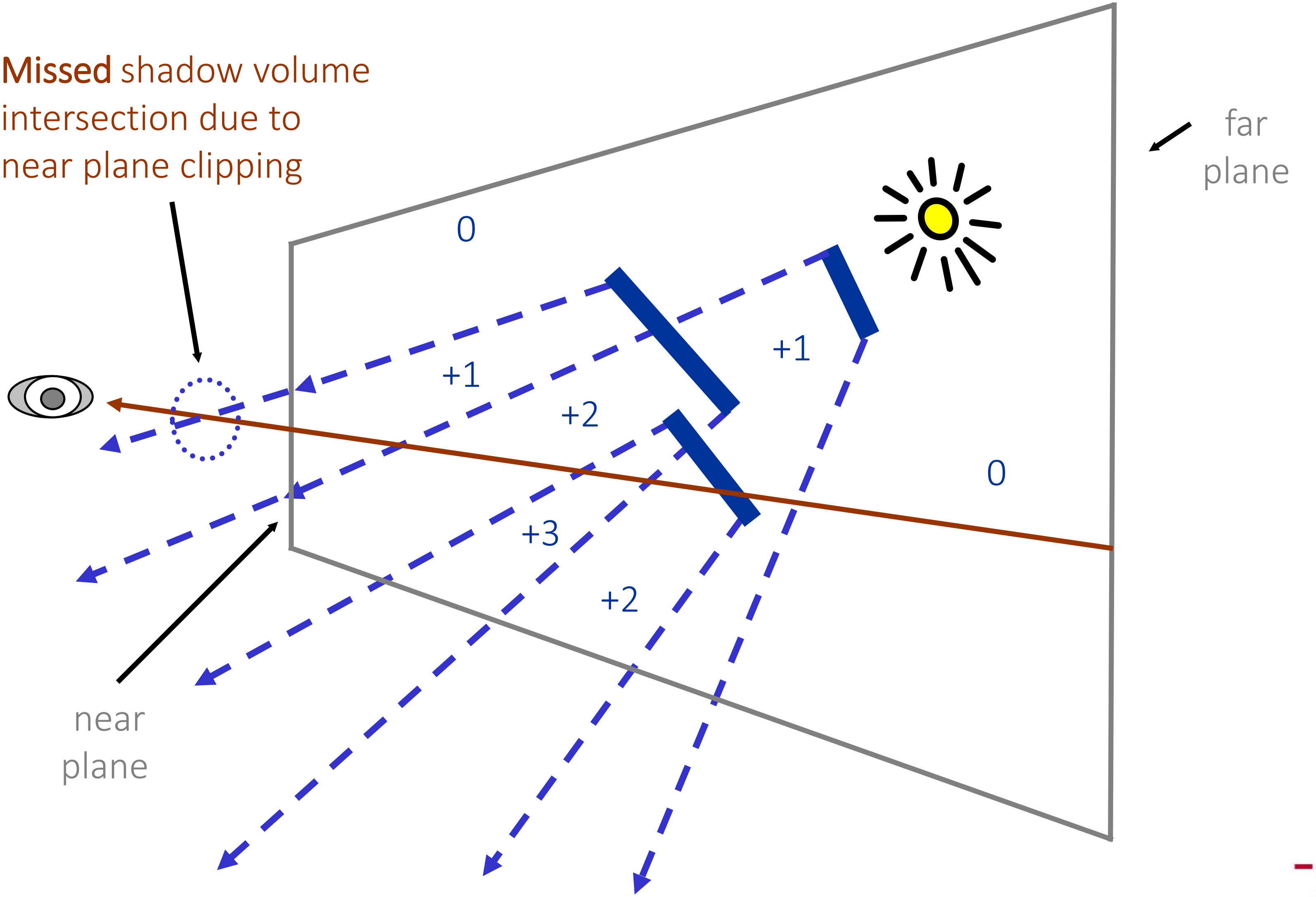


rendered scene

stencil value = 1
stencil value = 0

Missed Intersections

Missed shadow volume intersection due to near plane clipping



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Solutions

- Z-fail
  - counts the difference of
    occluded front and back faces
  - misses intersections behind the far plane
- Z-fail with depth clamping
  - do not clip primitives at the far plane
  - clamp the actual depth value to the far plane
- Z-fail with far plane at infinity
  - adapt the perspective projection matrix

Algorithm (Z-fail)

- render scene to initialize depth buffer
  - depth values indicate the closest visible fragment
- stencil enter / leave counting approach
  - render shadow volume twice using face culling
    - render back faces and increment stencil when depth test fails (count occluded back faces)
    - render front faces and decrement stencil when depth test fails (count occluded front faces)
  - do not update depth and color
- finally,
  - if pixel is in shadow, stencil is non-zero
  - if pixel is illuminated, stencil is zero

Improving Z-fail

- depth clamping
  - do not clip primitives to the far plane
  - draw primitives with a maximum depth value instead (clamp the actual depth value to the far plane)
- extend the shadow volume to infinity
- set the far plane to infinity (matrices in OpenGL form with negated values for n and f)

$$\begin{pmatrix} \frac{2n}{r-l} & 0 & \frac{r+l}{r-l} & 0 \\ 0 & \frac{2n}{t-b} & \frac{t+b}{t-b} & 0 \\ 0 & 0 & -\frac{f+n}{f-n} & -\frac{2fn}{f-n} \\ 0 & 0 & -1 & 0 \end{pmatrix} \quad f \to \infty \quad \Rightarrow \begin{pmatrix} \frac{2n}{r-l} & 0 & \frac{r+l}{r-l} & 0 \\ 0 & \frac{2n}{t-b} & \frac{t+b}{t-b} & 0 \\ 0 & 0 & -1 & -2n \\ 0 & 0 & -1 & 0 \end{pmatrix}$$

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Summary

- projection shadows
  - restricted to planar receivers, no self-shadowing
- shadow maps
  - image-space technique, two rendering passes
  - works correct, if all relevant objects are "seen" by the light
  - sampling issues
- shadow volumes
  - requires a polygonal representation of the shadow volume
  - multiple rendering passes
  - clipping of shadow volume polygons has to be addressed

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References

Shadow Maps

- Williams, "Casting Curved Shadows on Curved Surfaces", *SIGGRAPH*, 1978.
- Brabec, Annen, Seidel, "Practical Shadow Mapping", *Journal of Graphics Tools*, 2002.
- Stamminger, Drettakis, "Perspective Shadow Maps", *SIGGRAPH*, 2002.
- Wimmer, Scherzer, Purgathofer, "Light Space Perspective Shadow Maps", *Eurographics Symposium on Rendering*, 2004.

Shadow Volumes

- Crow, "Shadow Algorithms for Computer Graphics", *SIGGRAPH*, 1977.
- Heidmann, "Real Shadows, Real Time", *Iris Universe*, 1991.
- Diefenbach, "Multi-pass Pipeline Rendering: Interaction and Realism through Hardware Provisions", *PhD thesis, University of Pennsylvania*, 1996.
- McGuire, Hughes, Egan, Kilgard, Everitt, "Fast, Practical and Robust Shadows", *Technical Report, NVIDIA*, 2003.