Computer Graphics

- Shadow Algorithms -

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Recap: Shadows

- **Lightsource contributes to shading if the lightsource is visible from the sampling point**
- **Contributions of lightsources are added**

```
Color shade( Point surfacePosition, Direction toCamera )
{
    Color outgoing = black;
    for ( light : lightsources )
        if ( ! occluded( surfacePosition, light.position ) )
        {
            Color incoming = light.illuminate( surfacePosition );
            Direction toLight = light.position – surfacePoint;
            outgoing += brdf( incoming, toCamera, toLight );
        }
    return totalColor;
}
```

Recap: Visibility Queries

- **Visibility queries**
  - Simplified ray tracing operations
- **Normal ray-scene intersection:**
  - Find first intersection with scene
- **Visibility Query:**
  - Find any intersection with scene (slightly faster)
- **Rasterization context**
  - Ray-scene intersection operation is not available
  - No access to other triangles from within the pipeline

Shadowing in Rasterization

- **Direct (subtractive) shadow rendering (historic)**
  - Render scene without shadows
  - „Add“ shadows later by subtracting light (e.g. via geometry)
  - No consistent interpretation in terms of rendering equation

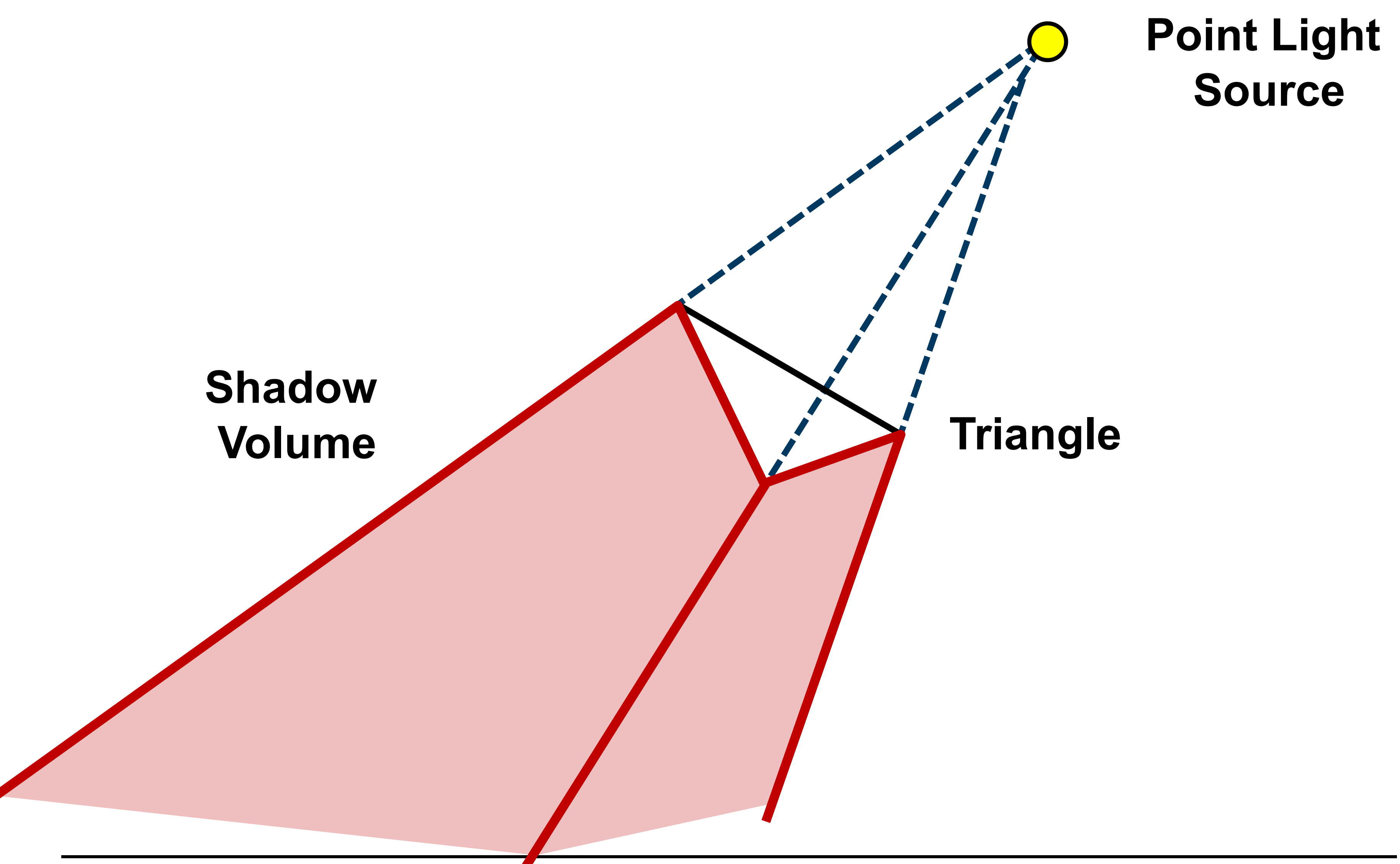
- **Shadow Volumes (Hard Shadows)**
  - Precompute volume representation of light visibility
  - Use visibility information during rendering

- **Shadow Maps (Hard Shadows)**
  - Precompute a discrete representation of light visibility
  - Use visibility information during rendering

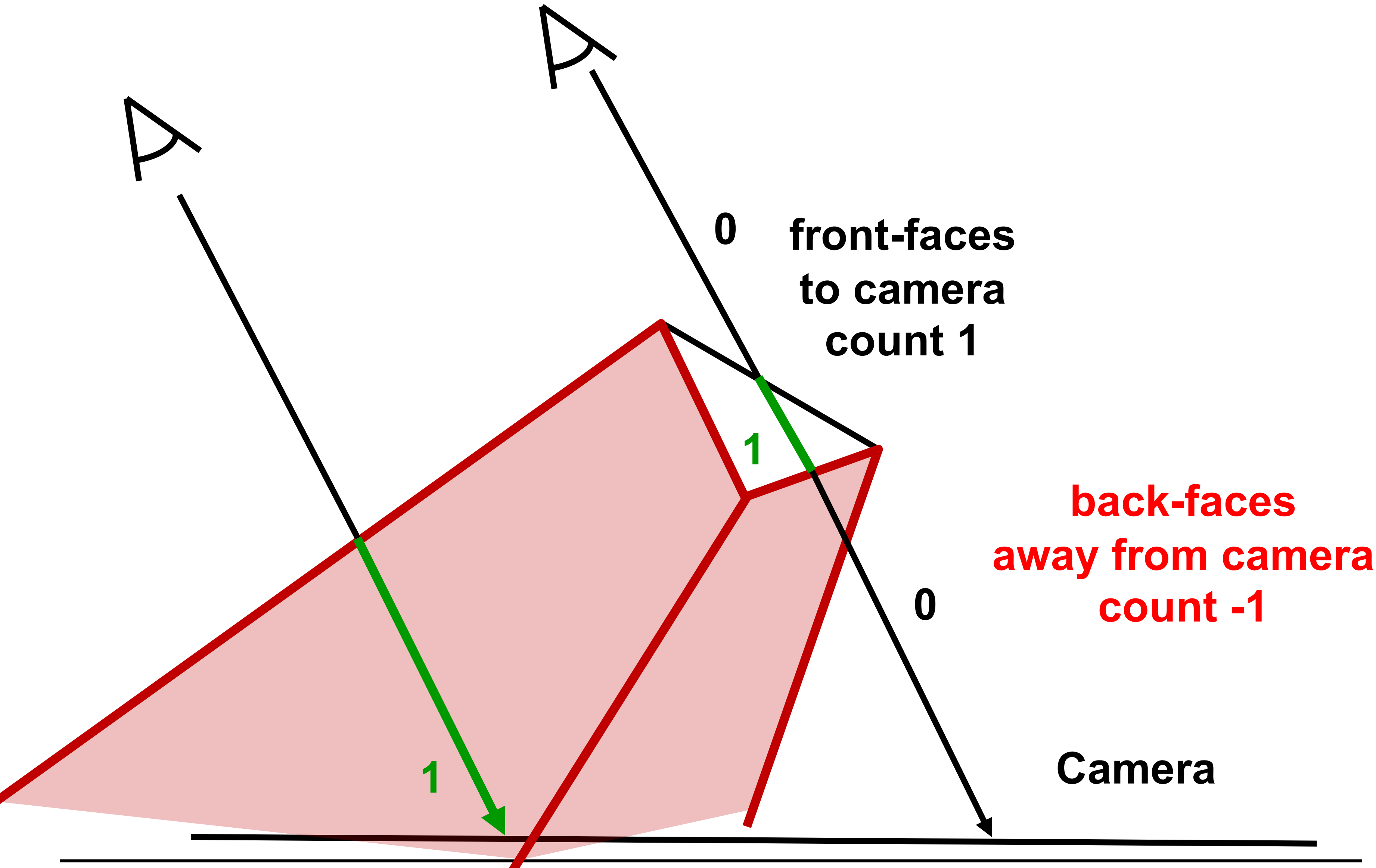
- **Hybrid Rendering Techniques (Soft Shadows)**
  - Use cone-tracing in a scene approximation

SHADOW VOLUMES

Shadow Volumes



Shadow Volumes



Shadow Volume Algorithm

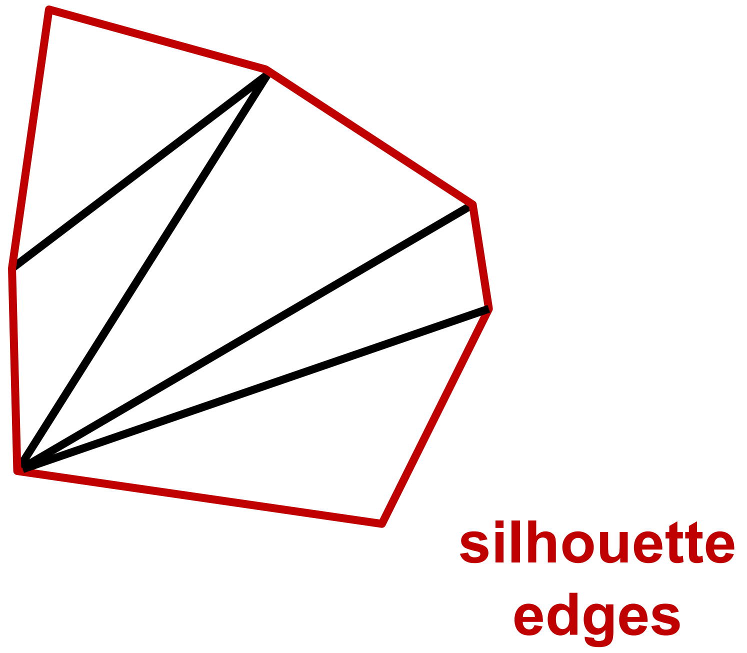
1. fill z-buffer as seen from camera (disable writing to FB)
2. fill color buffer to black
3. for (light : lightsources)
    4. initialize stencil buffer to zero
    5. compute all front facing shadow volume surfaces
    6. render to stencil buffer with value 1
    7. compute all back facing shadow volume surfaces
    8. render stencil buffer with value -1
    9. render scene from camera only, adding illum where shadow volume buffer != 0

Properties

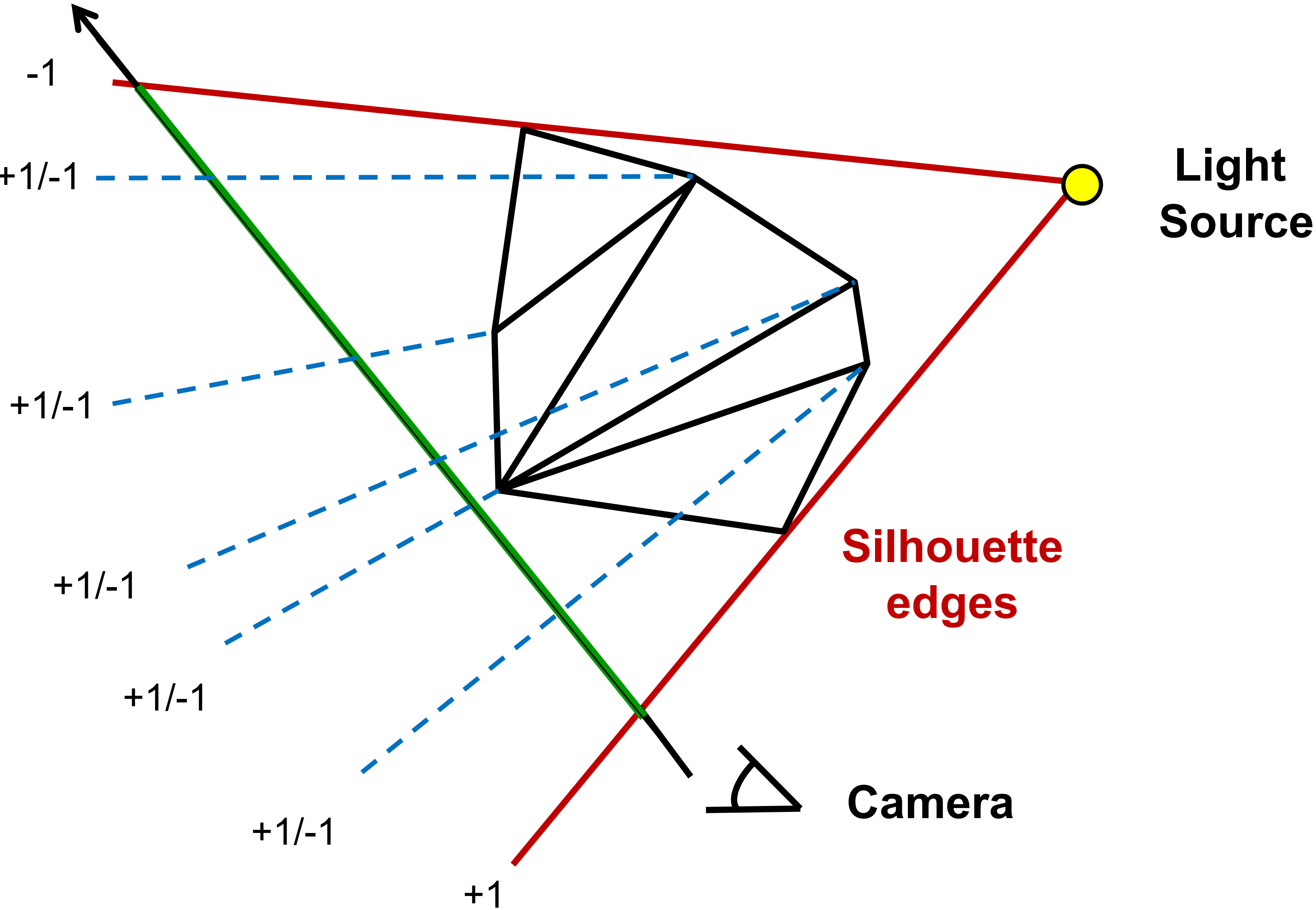
- **Pro**
  - Per pixel accurate shadows without aliasing problems
  - Maps moderat well to hardware
- **Con**
  - Needs major changes to how scene is rendered
- **Performance**
  - Generate 3 faces per triangle-light combination
  - Poor performance for geometrically complex shadow casters
  - Very bandwidth intensive

Optimization: Silhouettes

- **Mesh as seen from light source**
- **Only silhouette edges are relevant**



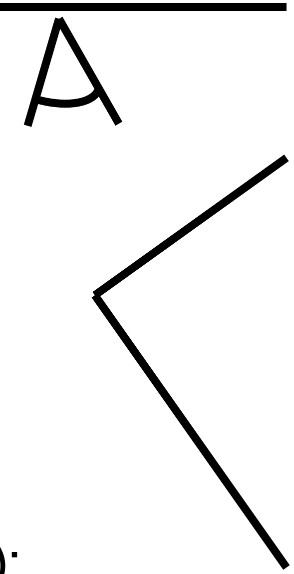
Optimization: Silhouettes



Finding silhouettes

- **Brute force approach (convex objects)**

```
for ( light: scene )
        for ( edge : mesh )
        {
                normal1 = edge.face1.normal;
                normal2 = edge.face2.normal;
                camera = directionToCamera;
                direction1 := sign( dotProduct(normal1, camera) );
                direction2 := sign( dotProduct(normal2, camera) );
                isSilhouette[light, edge] := (direction1 != direction2);
        }
```



  - Finding general silhouettes is a difficult topic in itself
  - Possible optimization
    - Edges between planer triangles can be disregarded

Further Reading

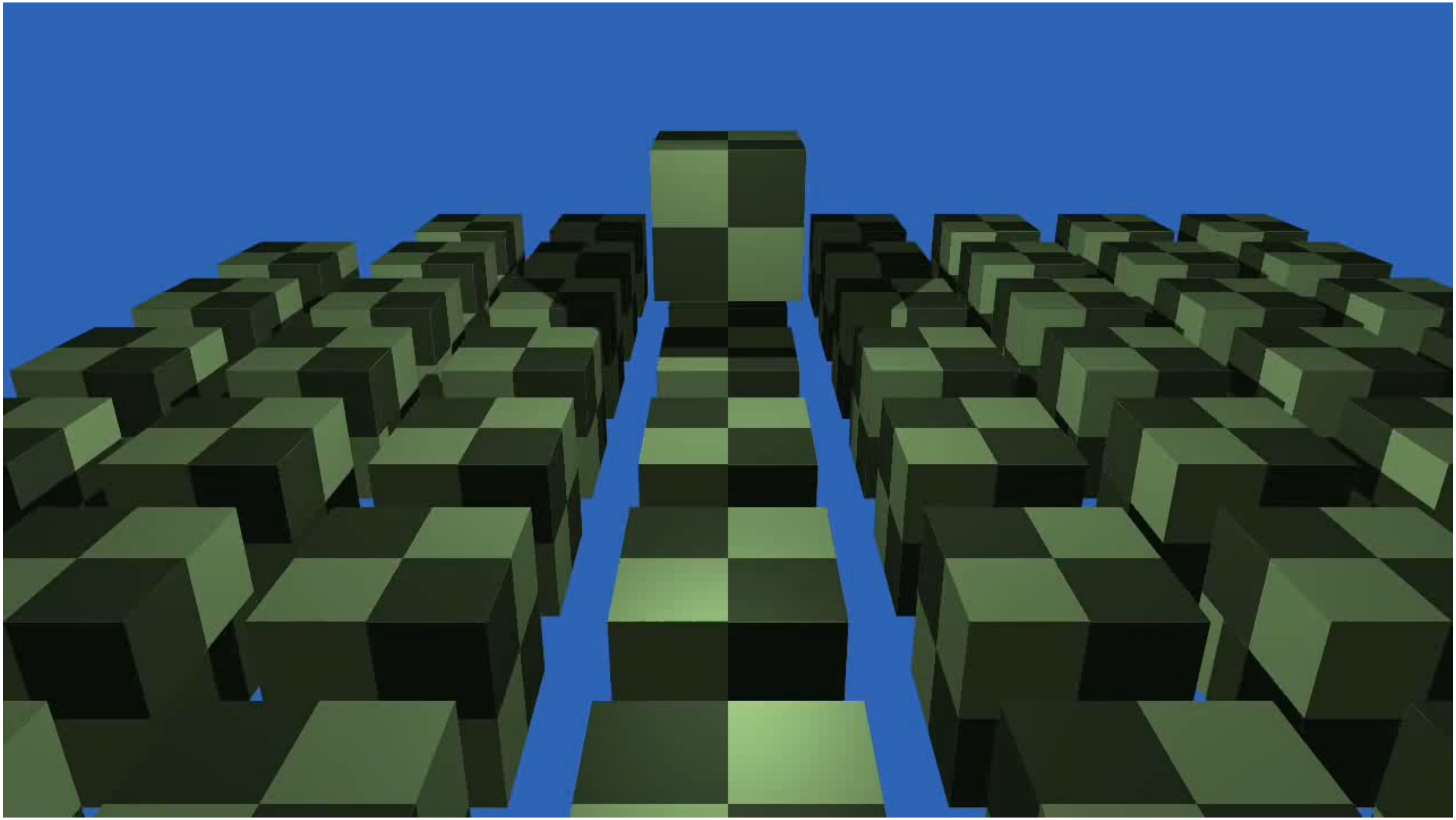
Approximate approach:

Markosian, Lee et. al. *Real-Time Nonphotorealistic Rendering*, Proceedings of SIGGRAPH 1997, pp. 415-420

Using Gauss Maps:

Gooch, Amy, et. al. *„A Non-Photorealistic Lighting Model for Automatic Technical Illustrations“*, Proceedings of SIGGRAPH 1998, pp. 447-452

Shadow Volumes Example

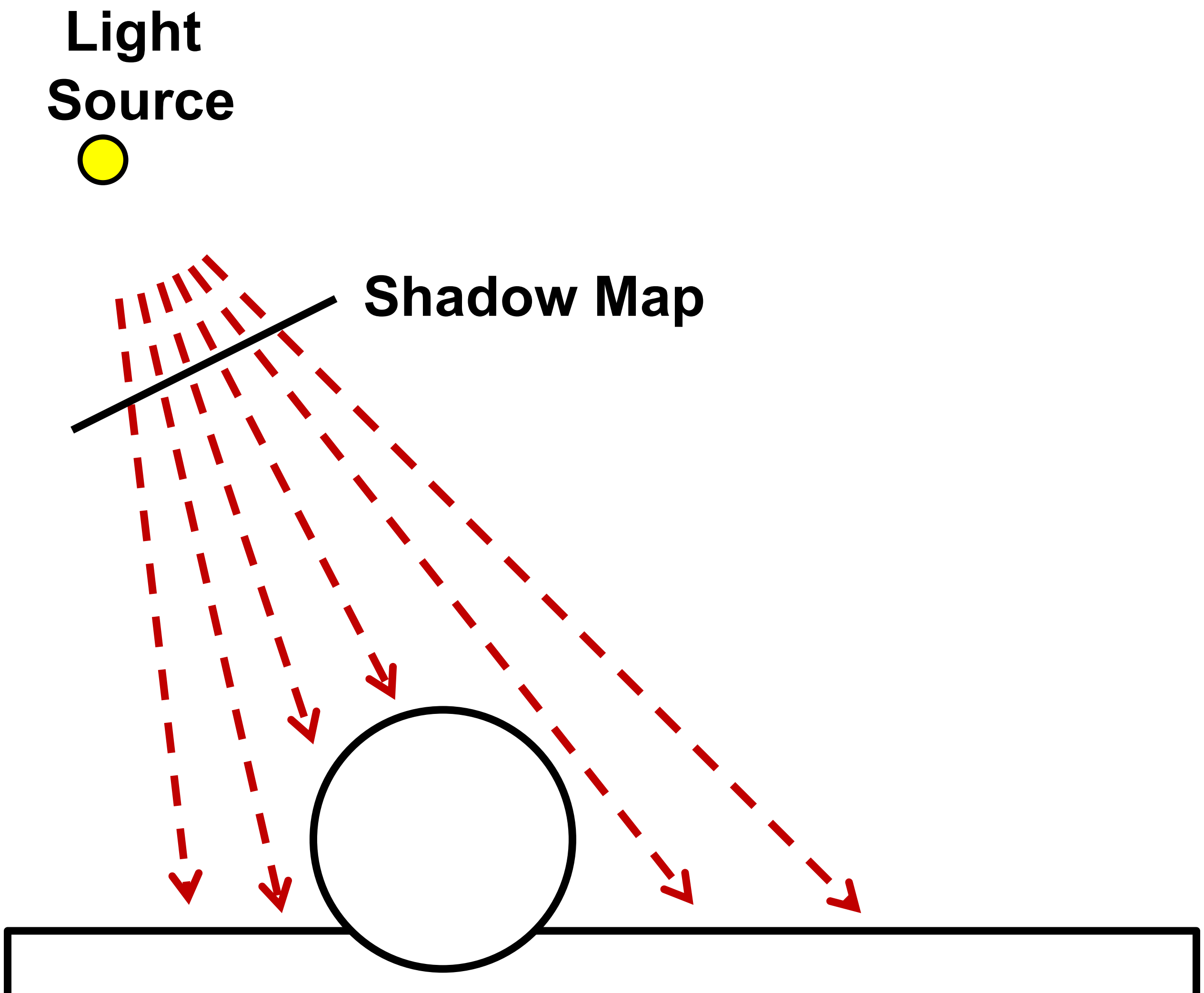


SHADOW MAPS

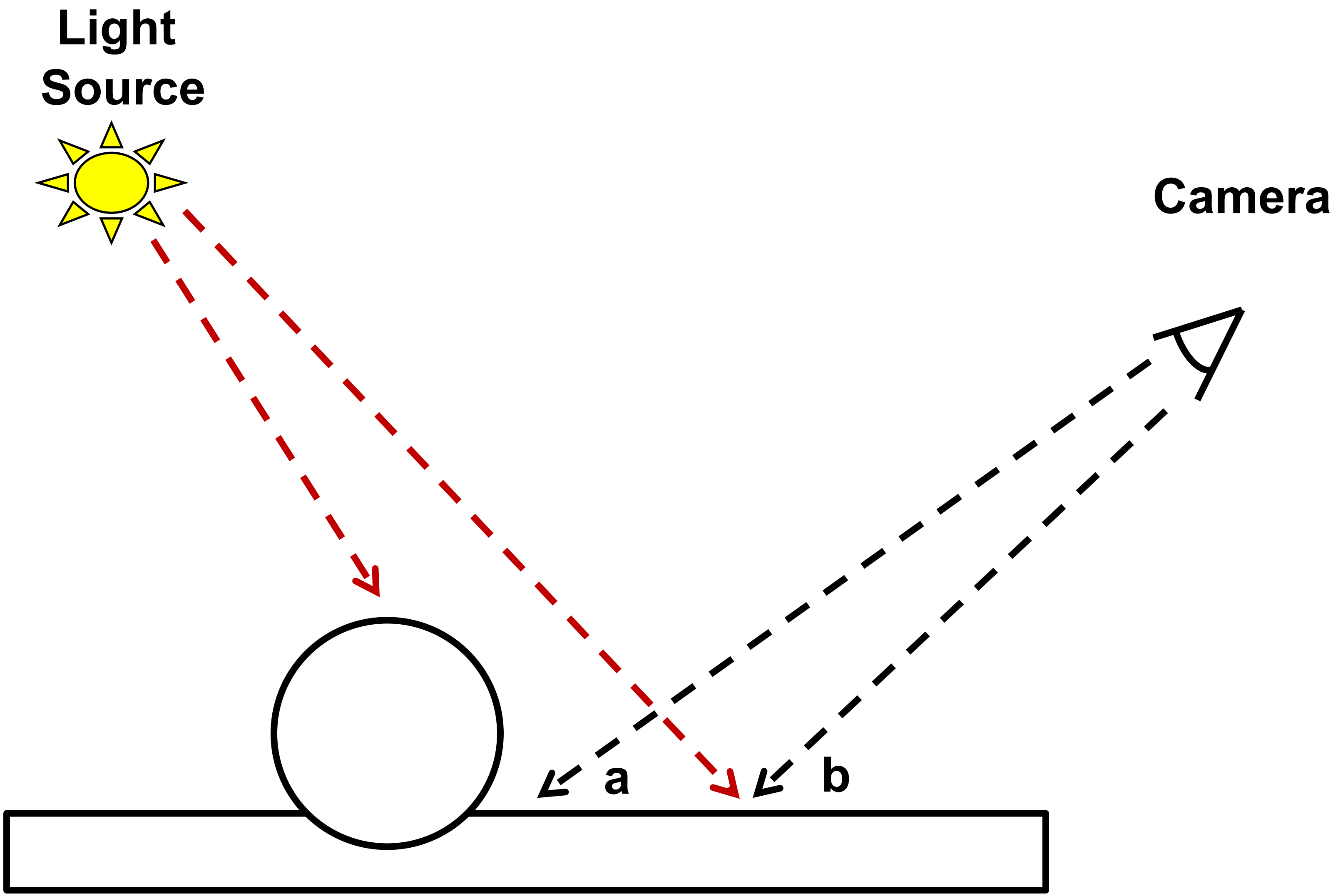
Shadow Mapping

- **Idea: Use Z-Buffer to store occlusion information**
- **First pass: Render scene from position of light source**
  - For each pixel: Store distance from lightsource to object
  - Resulting data structure is called shadow map
- **Second pass: Render scene from position of camera**
  - For each pixel: Compare distance to lightsource with corresponding pixel in shadow map

Shadow Mapping



Shadow Mapping



Properties

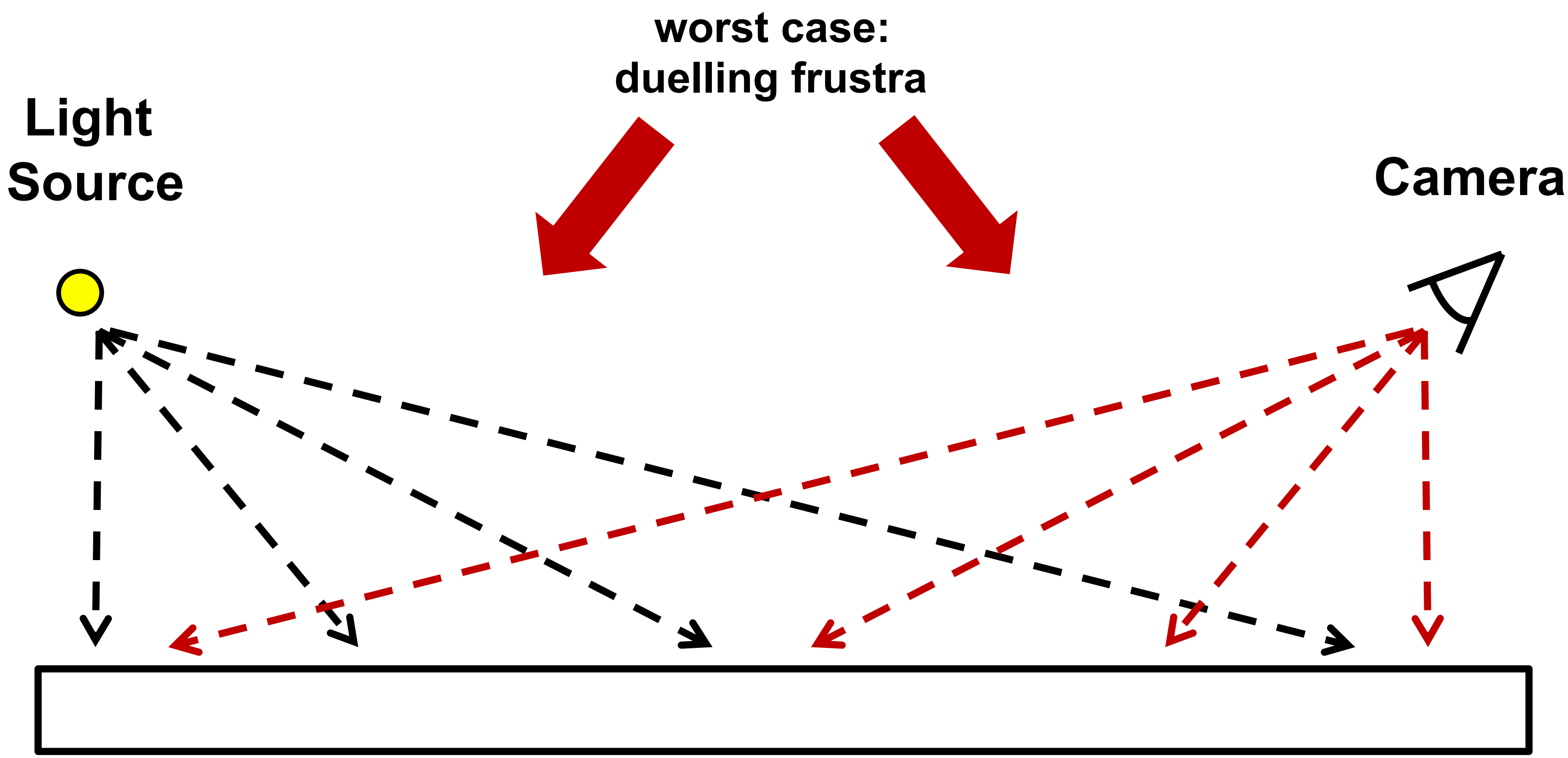
- **Pro**
  - Very flexible: can handle arbitrary shadow casters
  - Can handle semi-transparent shadow casters
  - Maps well to hardware

- **Con**
  - Aliasing problems occur as shadow map samples are in general not at same positions as camera samples
  - Aliasing is a principal problem of shadow maps – can be reduced but not avoided
  - Difficult question where to place the shadow map

- **Performance**
  - One additional render pass per light source
  - Moderate memory consumption for shadow maps

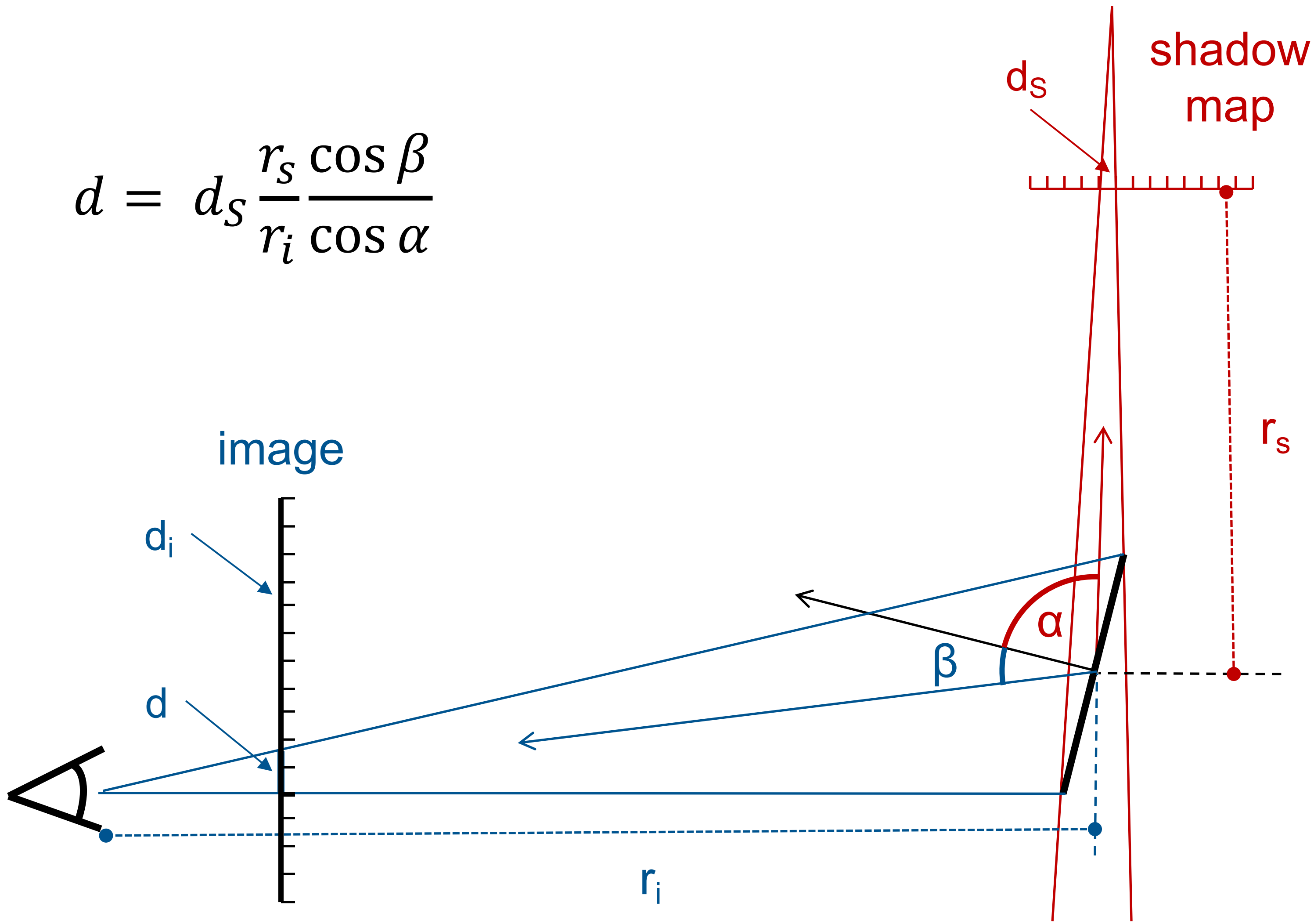
Dueling Frustra and Aliasing

- **Types of Aliasing**
  - Projective aliasing: light ray almost parallel to surface
  - Perspective aliasing: perspective shortening of view frustrum



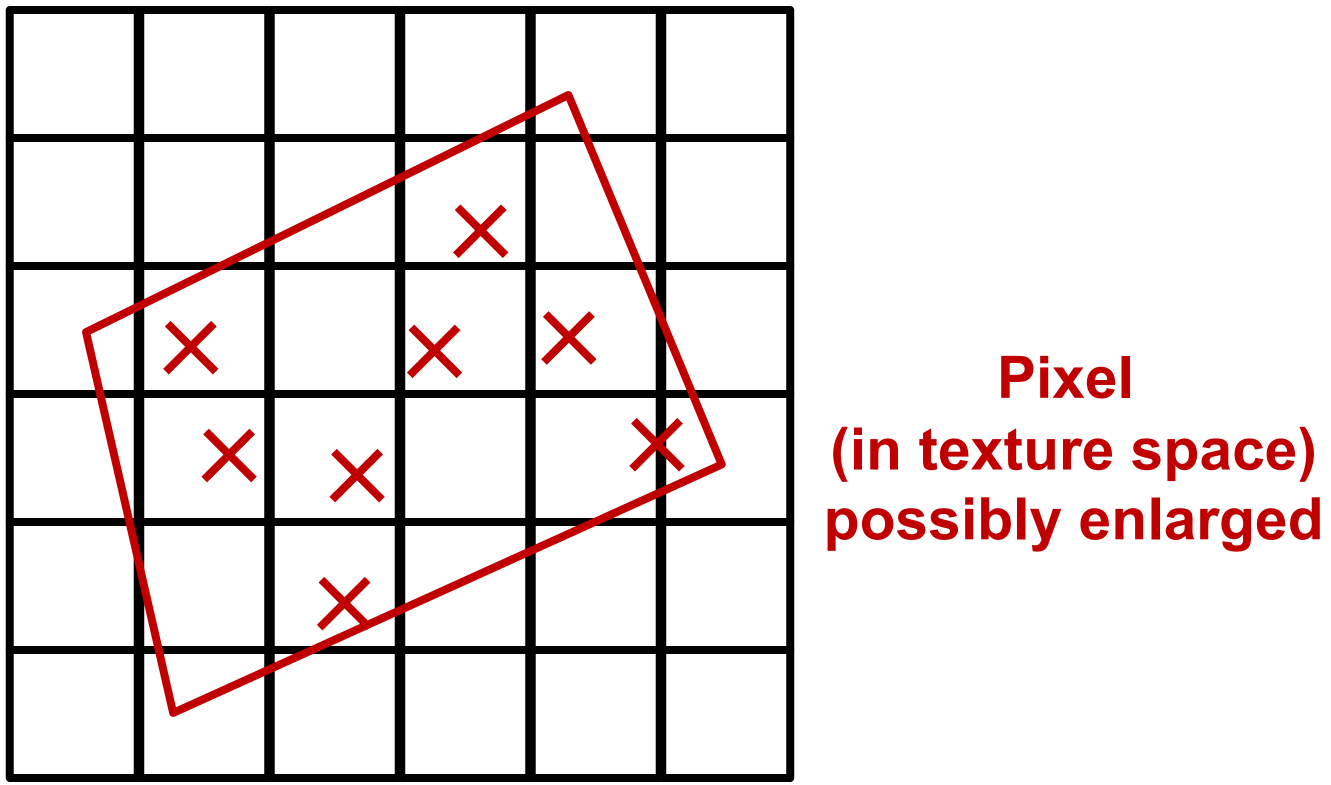
Quantifying Sampling Error

$$d = d_S \frac{r_s}{r_i} \frac{\cos\beta}{\cos\alpha}$$



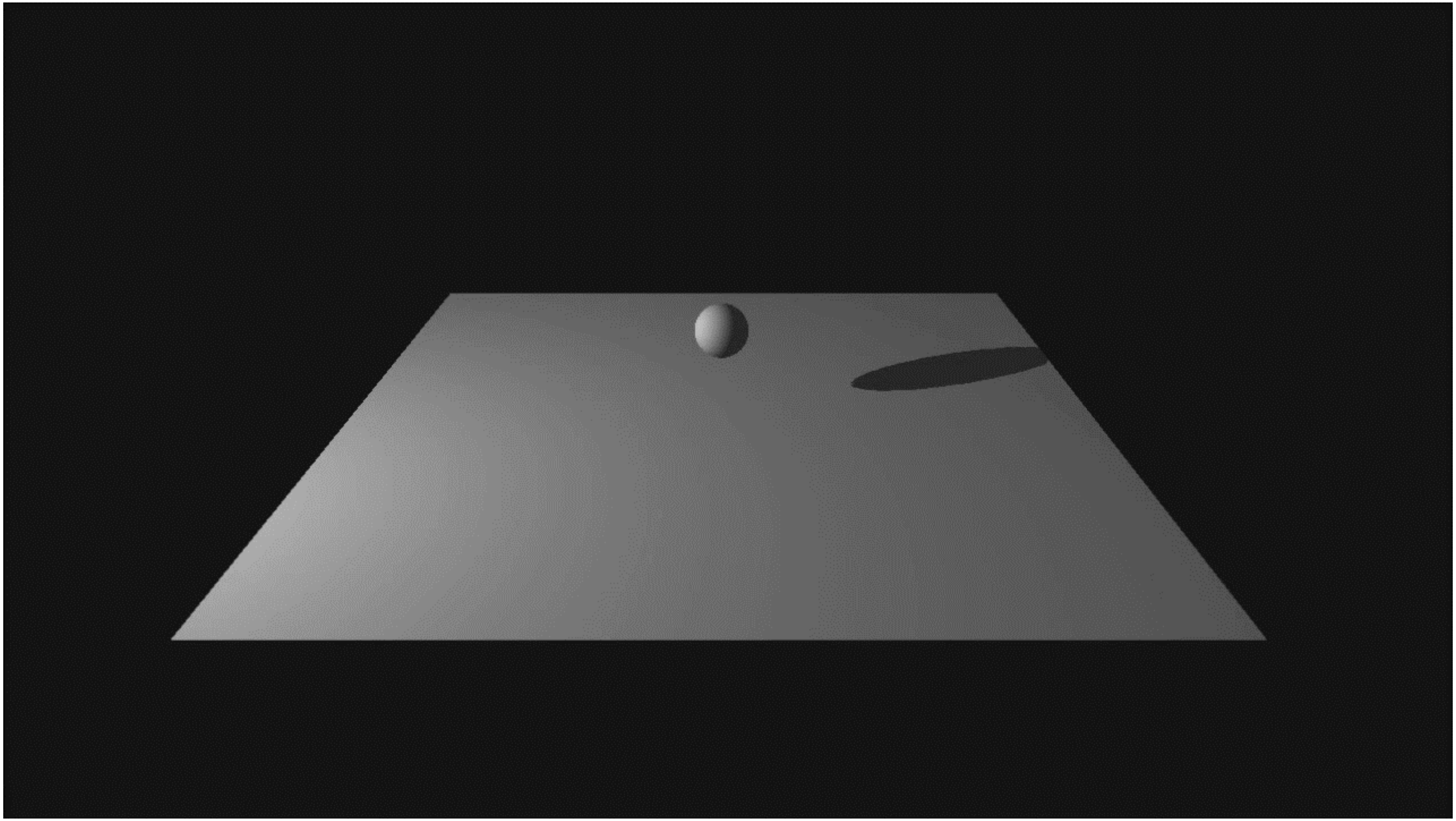
Shadow Map Filtering

- **Percentage-Closer Filtering**
  - Map area representing pixel to texture space
  - Stochastically sample pixel to find percentage of surface in light



Shadow Map

Percentage-Closer Filtering



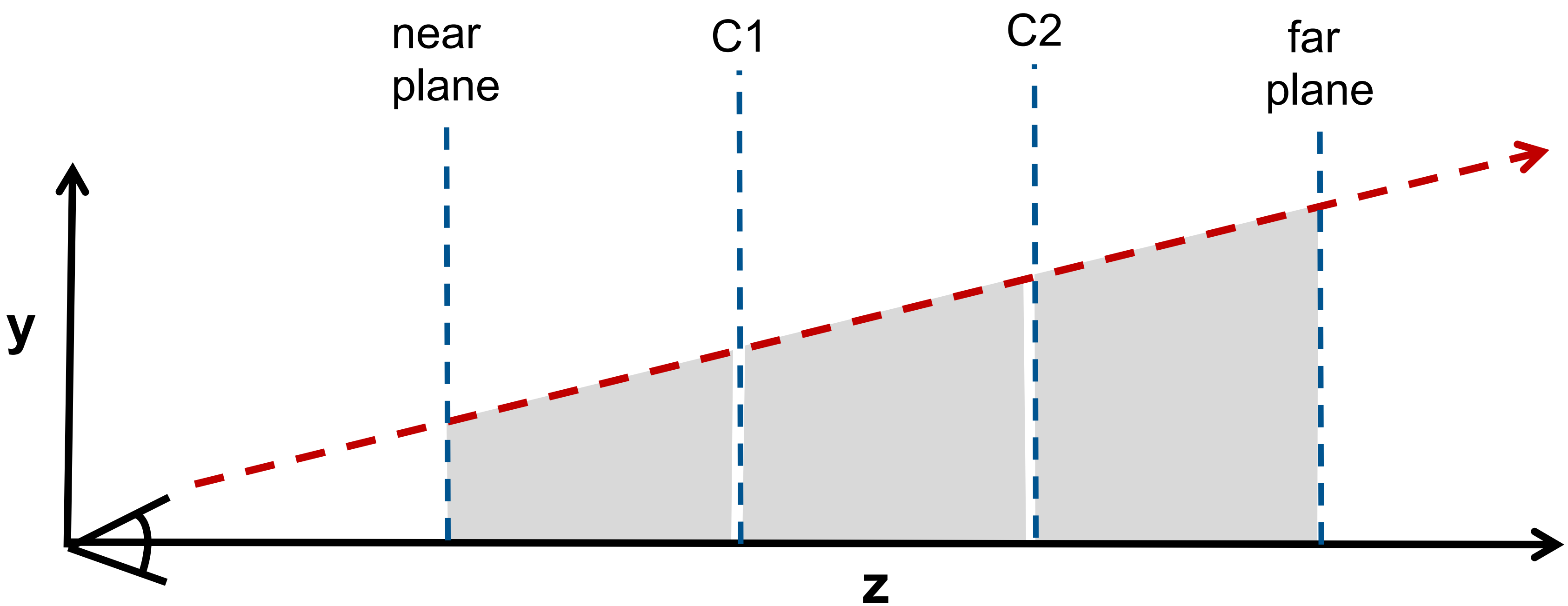
Properties

- **Pro**
  - Display undersampled data in shadow map in a less disturbing way
  - Fools our perception: Blurring easily mistaken for penumbra in many situations

- **Con**
  - Not geometrically correct soft shadows with penumbra, just blurred, undersampled shadow map
  - Computationally more expensive than normal shadow maps expensive

Parallel Split Shadow Maps (PSSM)

- **Shadow map reparametrization**
  - Optimize distribution of shadow map texels
- **Idea of PSSM: Split depth range**
  - Use different shadow map for every layer



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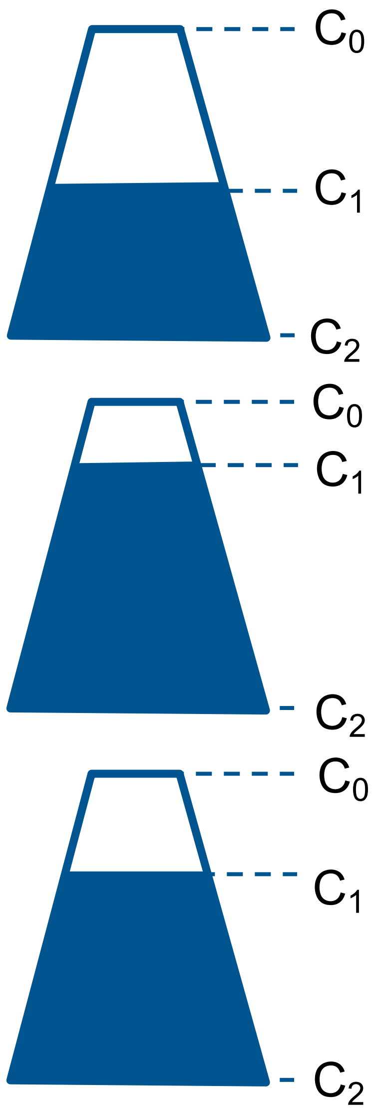
Split Plane Positioning



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

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

$$C_i = \frac{C_i^{log} + C_i^{uniform}}{2}$$

Properties

- **Pro**
  - All advantages of shadow maps
  - n=3 or 4 mostly solves issues with perspective shadow map aliasing
- **Con**
  - Projective aliasing remains a problem
- **Performance**
  - n additional render pass per light source
    (but can use multiple render targets)
  - n times memory consumption for shadow maps
    (but can compensate by reducing resolution due to better usage)

Further Reading

Perspective Shadow Maps:

Marc Stamminger and George Drettakis, *Perspective Shadow Maps*, Proceedings of SIGGRAPH 2002, pp. 557-562

Volumetric Objects:

Tom Lokovic and Eric Veach *„Deep Shadow Maps“*, Proceedings of SIGGRAPH 2000, pp. 385-392

HYBRID RENDERING

Hybrid Rendering Techniques

- **Rasterization for primary rendering**
  - Efficiently maps to hardware
  - Resolve visibility using z-buffer

- **Ray-tracing for lighting computation**
  - Ray-scene intersection often too slow for real-time applications
  - Particularly true when sampling large area lights or large opening angles (=many rays per pixel are needed for soft shadows)

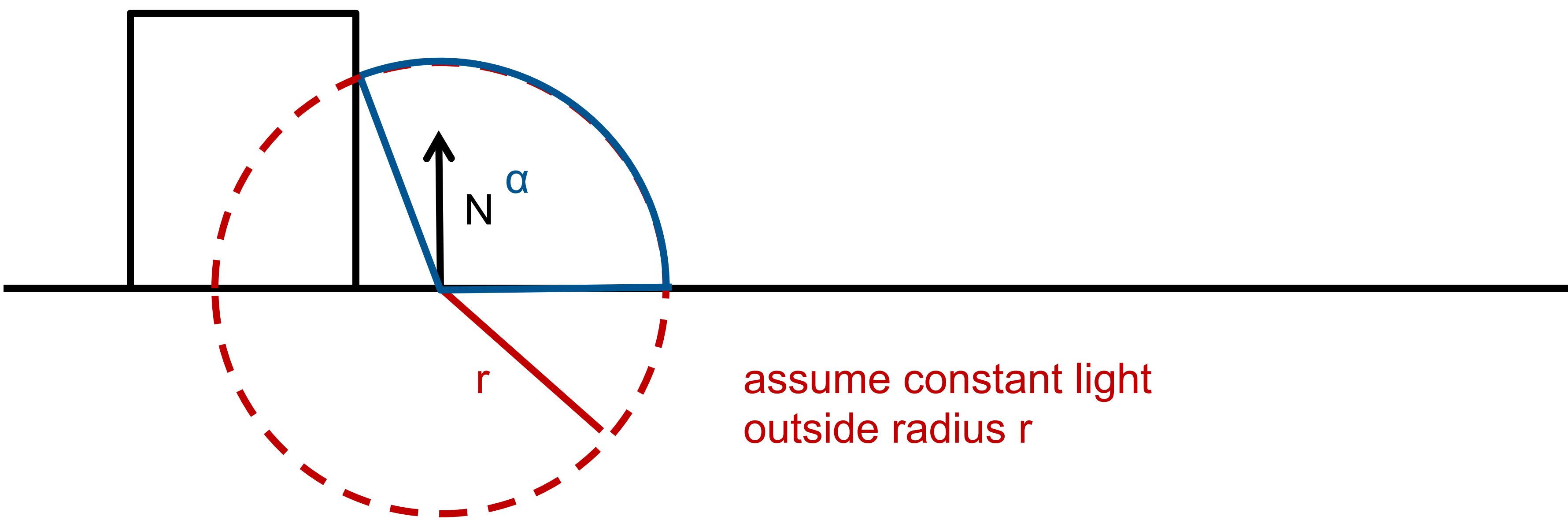
- **Core idea**
  - Approximate large number of ray-scene intersections by a small number (often one) cone-scene intersections
  - Intersect against approximate representation of scene that allows fast cone intersection
  - Sufficiently accurate for many lighting purposes

Overview of Techniques

- **Screen Space Ambient Occlusion**
  - Consider z-buffer as a surface that approximates the scene
  - Use ray-tracing in the z-buffer to determine ambient occlusion
- **Sparse Voxel Octree Cone Tracing**
  - Convert entire scene to a view-dependent sparse voxel representation
  - Build mip-map like pyramid over the voxel structure
  - Use „diagonal ray-tracing“ in the voxel pyramid to approximate cone-scene intersection
- **Distance Field Ray Traced Shadows**
  - Build view-dependent voxelized scene representation where voxel contains the distance to the nearest mesh
  - Can be used as acceleration structure for approximate ray-tracing
  - Can be used to calculate ambient occlusion

Ambient Occlusion

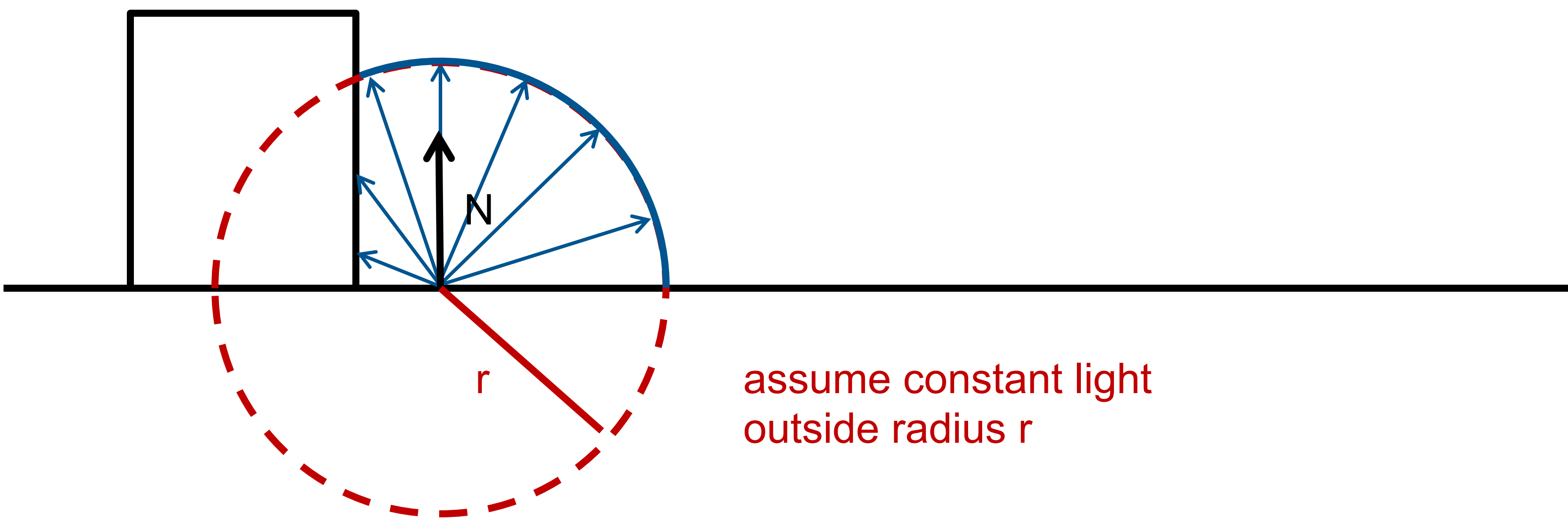
- **Calulates shadows against assumed constant ambient illumination**
  - Idea: in most environments, multiple light bounces lead to a very smooth component in the overall illumination
  - For this component, incident light on a point is proportional to the part of the environment (opening angle) visible from the point
  - Describes well contact shadows, dark corners



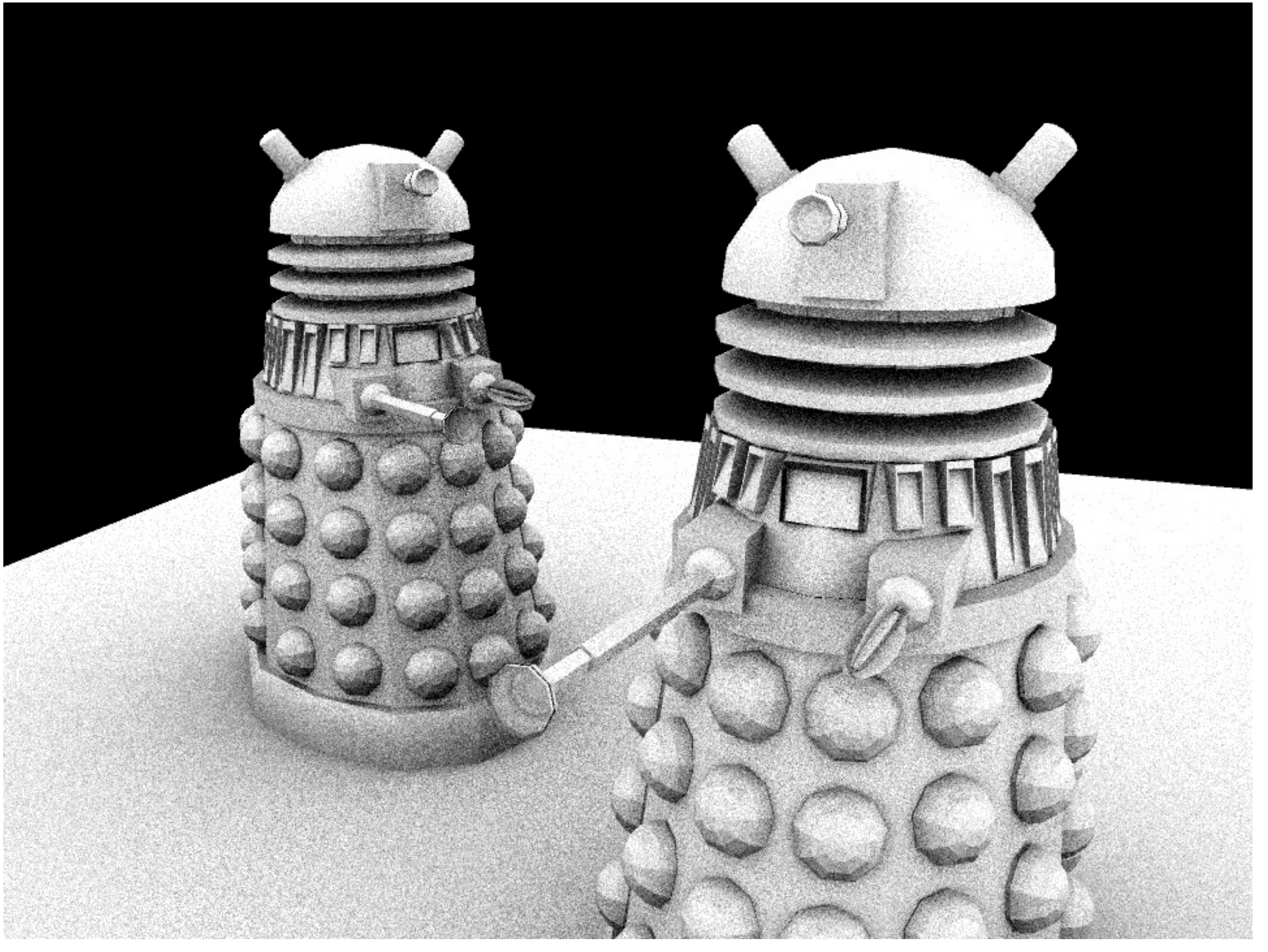
Ambient Occlusion

AO Using Ray-Tracing

- **Computation using Ray-Tracing straight forward**
  - Start at point P
  - Sample N directions (D_1-D_N) from upper hemisphere
  - Shoot shadow rays from P to D_i with maximum length r
  - Count how many rays reach the environment
  - Gives correct result in the limit, but requires many rays to avoid noise (i.e., slow)



AO Using Ray-Tracing

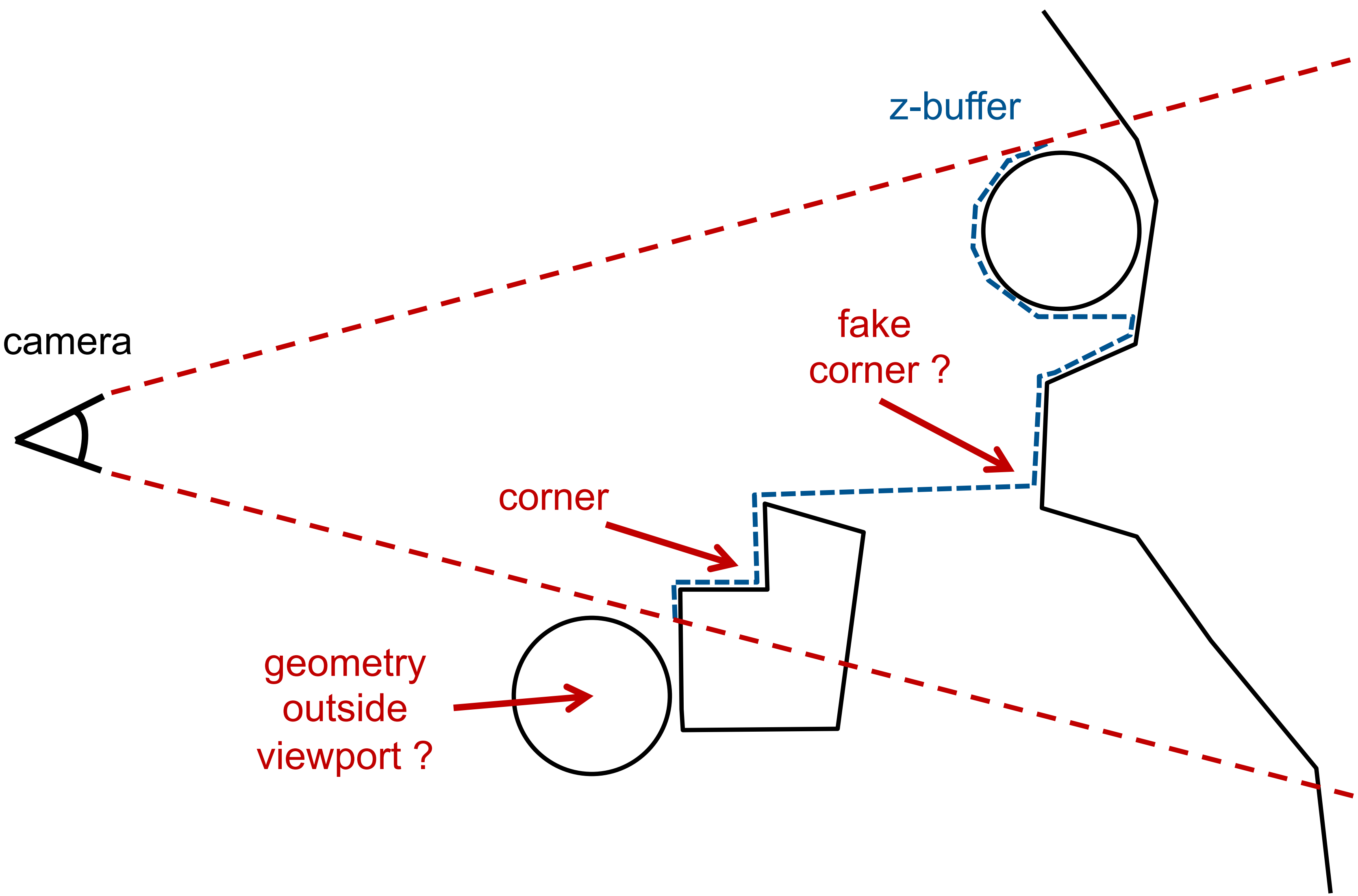


Screen Space Ambient Occlusion

- **Can we approximate ambient occlusion in real-time?**
- **Ray-scene intersection too slow**

- **Idea: Use z-buffer as scene approximation**
  - Horizontal and vertical position give position of point in x,y-direction (camera space)
  - Z-buffer content gives position of point in z-direction (camera space)
  - Contains discrete representation of all visible geometry
  - Use ray-tracing against this simplified scene

Screen Space Ambient Occlusion



Properties

- **Pro**
  - Allows approximate computation of ambient occlusion in real-time on consumer hardware
  - Replaced „ambient term“ of Phong model in most real-time applications (practically highly relevant)

- **Con**
  - Relies on scene approximation that may generate artifacts

Further Reading

Tobias Ritschel, Thorsten Grosch, Hans-Peter Seidel, "*Approximating Dynamic Global Illumination in Image Space*", ACM SIGGRAPH Symposium on Interactive 3D Graphics and Games 2009

Louis Bavoil, Miguel Sainz and Rouslan Dimitrov, „Image-Space Horizon-Based Ambient Occlusion“, Presentation at SIGGRAPH 2008

Louis Bavoil, Miguel Sainz, *"Multi-Layer Dual-Resolution Screen-Space Ambient Occlusion"*, Presentation at SIGGRAPH 2009

Recap

- **Today**
  - Re-visited shadows from a rasterization perspective
  - Shadow volumes
  - Shadow maps, parallel split shadow maps
  - Screen space ambient occlusion

- **Next Lecture**
  - Sparse Voxel Octree Cone Tracing
  - Distance Field Ray Traced Shadows