Real-Time Rendering (Echtzeitgraphik)

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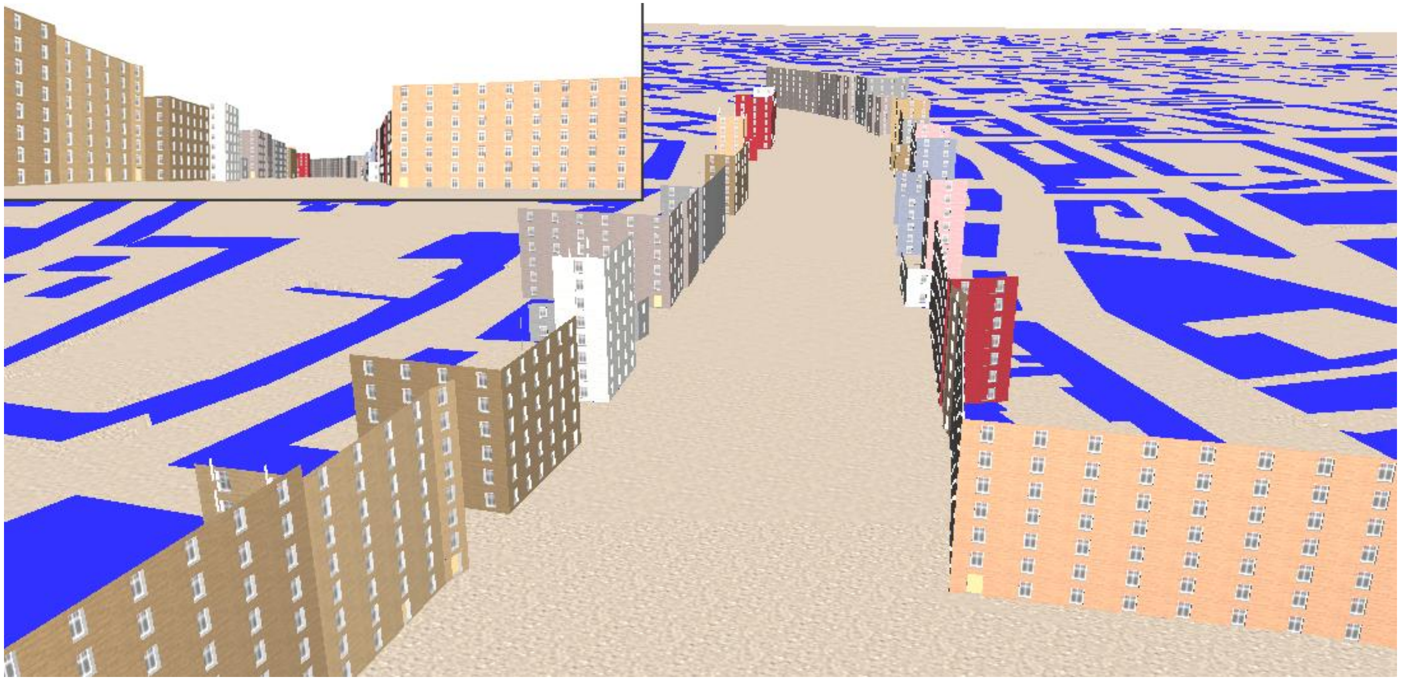
Visibility



Overview

- Basics about visibility
- Basics about occlusion culling
- View-frustum culling / backface culling
- Occlusion culling
  - From a point
    - Object space / image space
  - From a region
    - Cells – portals / extended projections
    - Point sampling / line space

What Can You Learn from this Lecture

- **Terminology** and **problems** of visibility computation
- **Principles** of existing algorithms

- Goal: judge existing algorithms, design your own visibility algorithms

Visibility is Researched in …

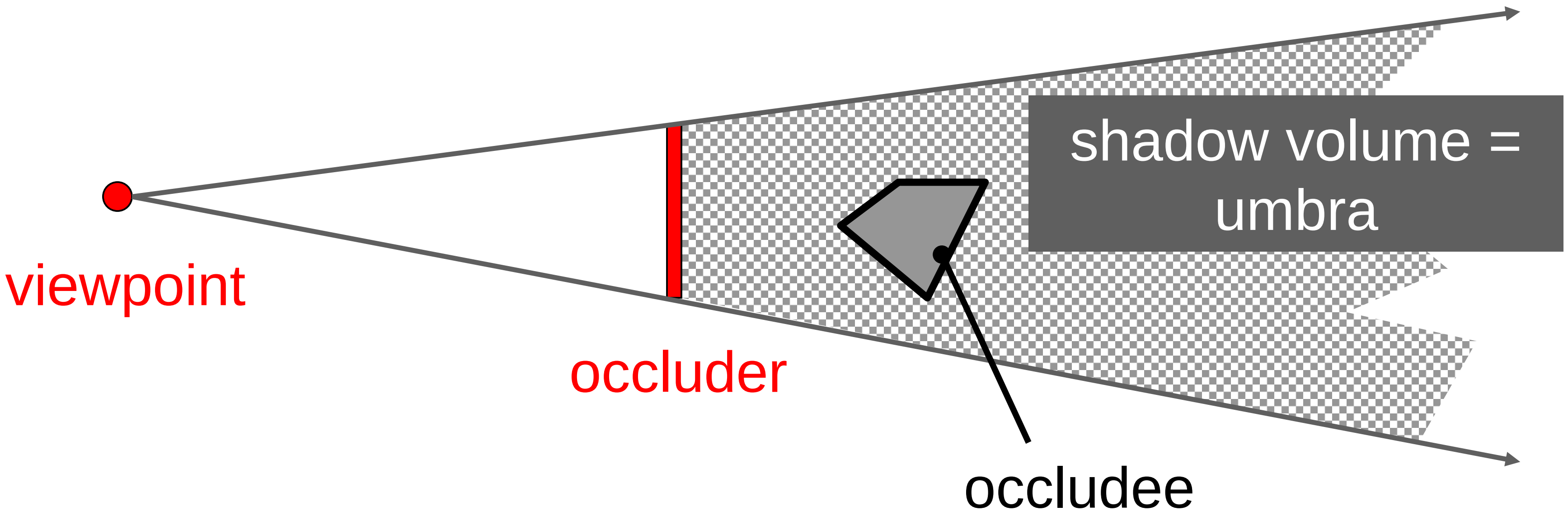
- **Computer graphics**
- Computational geometry
- Computer vision
- Robotics
- Architecture
- GIS
- …

Applications in Computer Graphics

- **Occlusion culling**
- Shadows
- Global illumination
- Hidden-surface removal
- Viewpoint selection
- Image-based rendering
- …

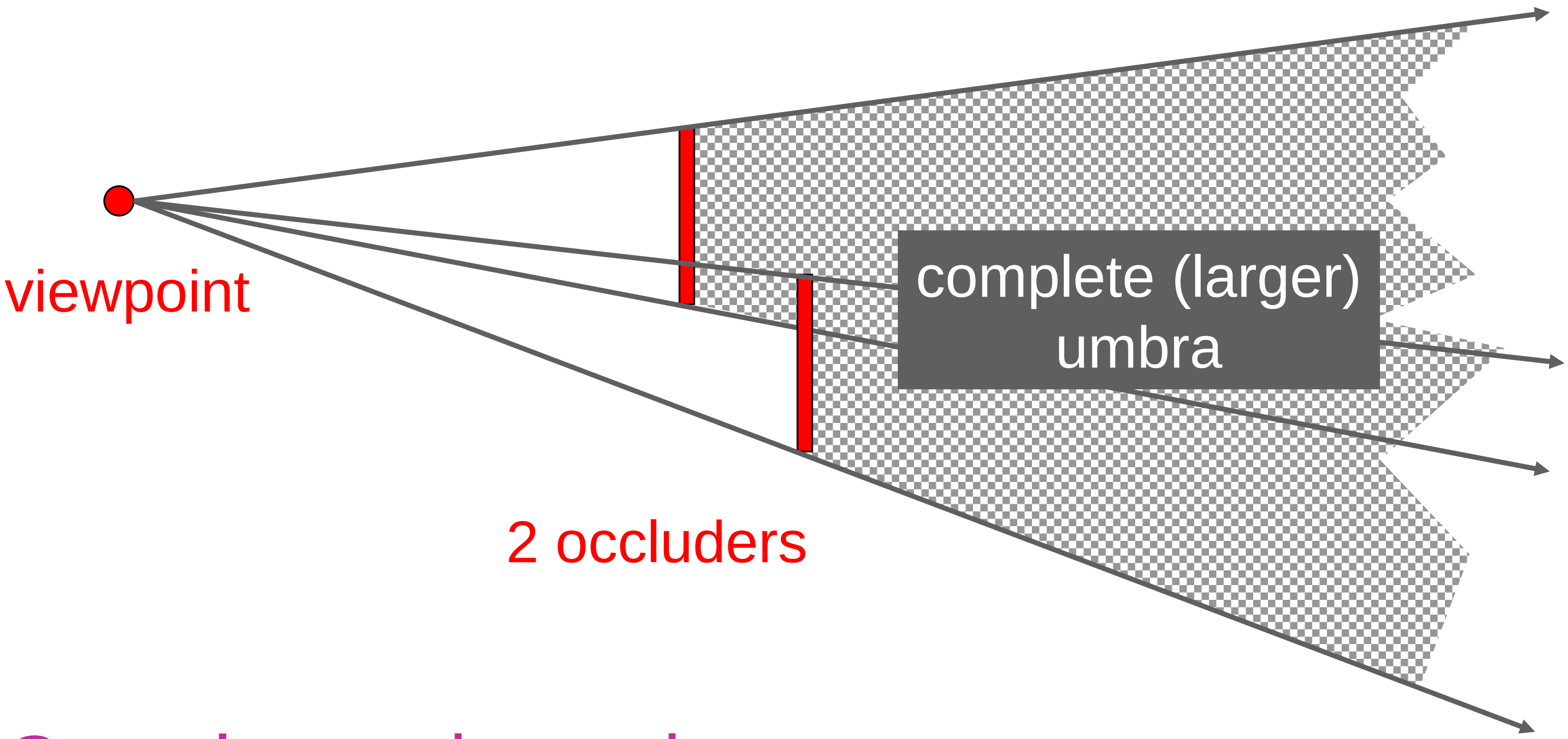
Basics of Visibility

Visibility from a Point



- Terms: occluder, occludee, shadow volume = umbra

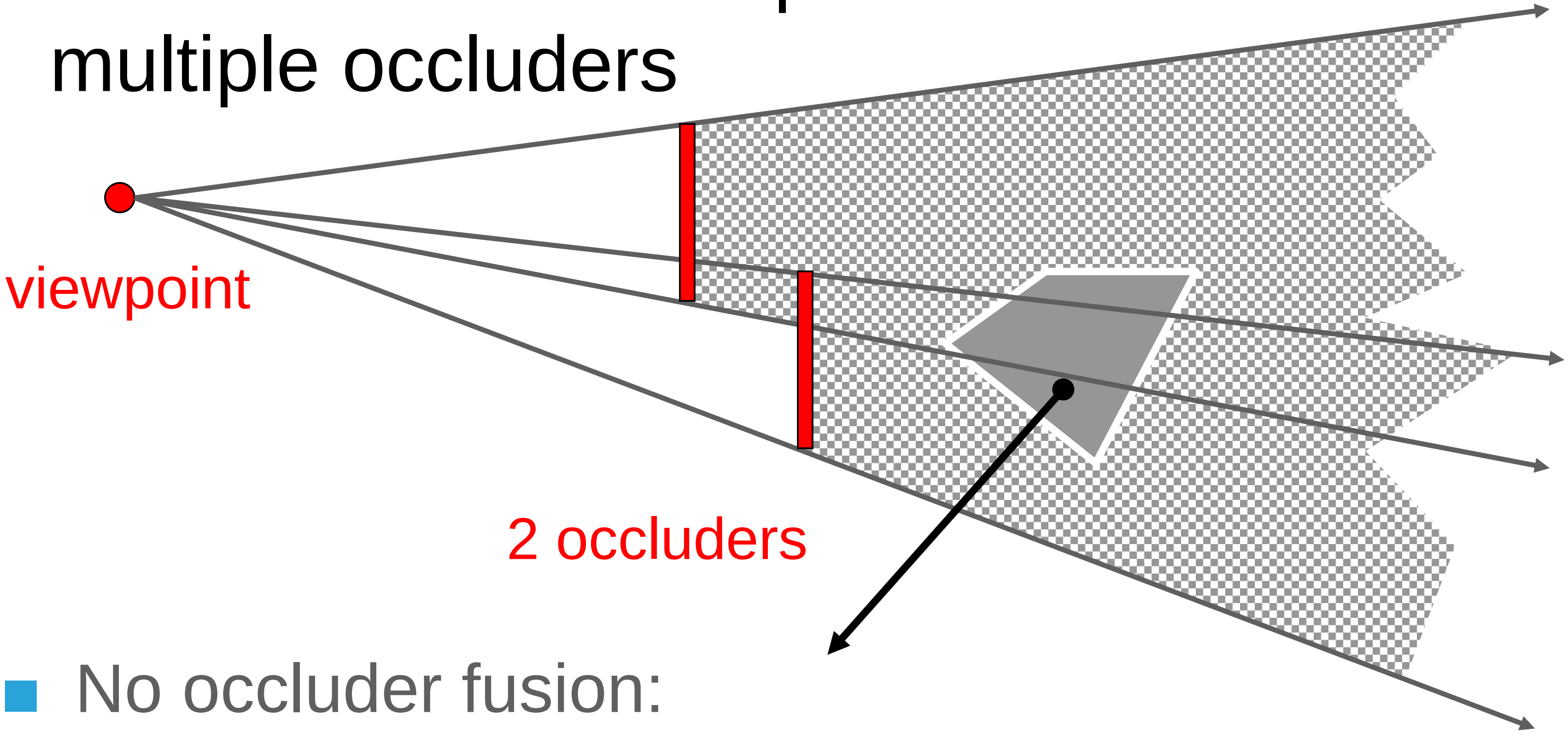
Visibility from a Point



- Complete point umbra
  for occluders $occ_1, \ldots, occ_n$ =
  union of all individual umbrae

Occluder Fusion

- **Occluder fusion**: exploit combined effect of multiple occluders



- No occluder fusion:
- Test against individual umbrae → visible
- Occluder fusion:
  - Test against **complete umbra** → invisible

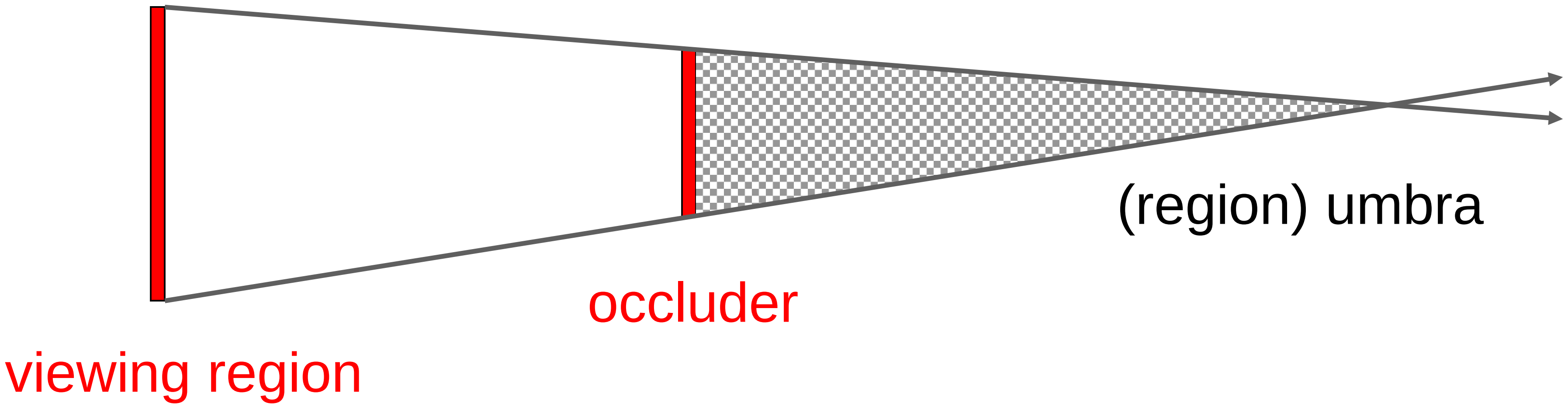
Simple Algorithm for Point Visibility

- Umbra data structure (UDS) = empty
- For each occluder occ_i
  - Calculate umbra U_i
  - Add U_i to UDS
- Test the scene against the UDS to see what is visible / occluded

- Examples for UDS: BSP-tree, z-buffer, …

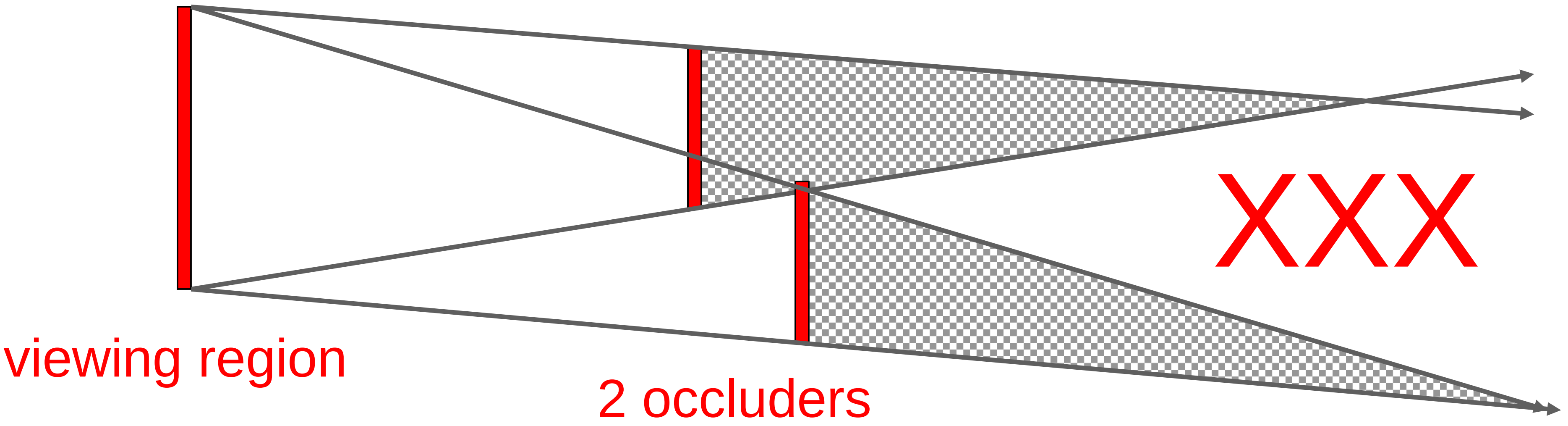
Visibility from a Region

(Example in 2D)



Visibility from a Region

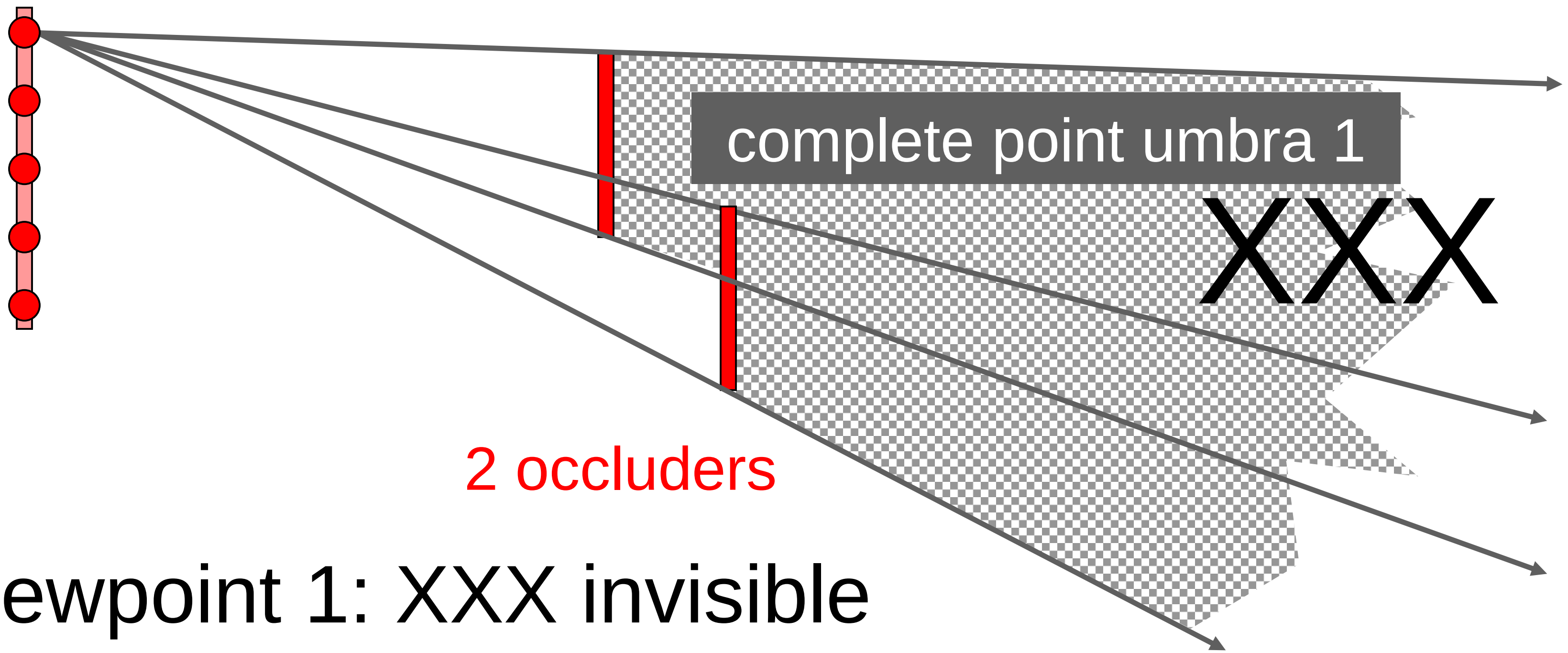
- Goal: find complete (region) umbra!



- Try: union of (region) umbrae…

Visibility from a Region

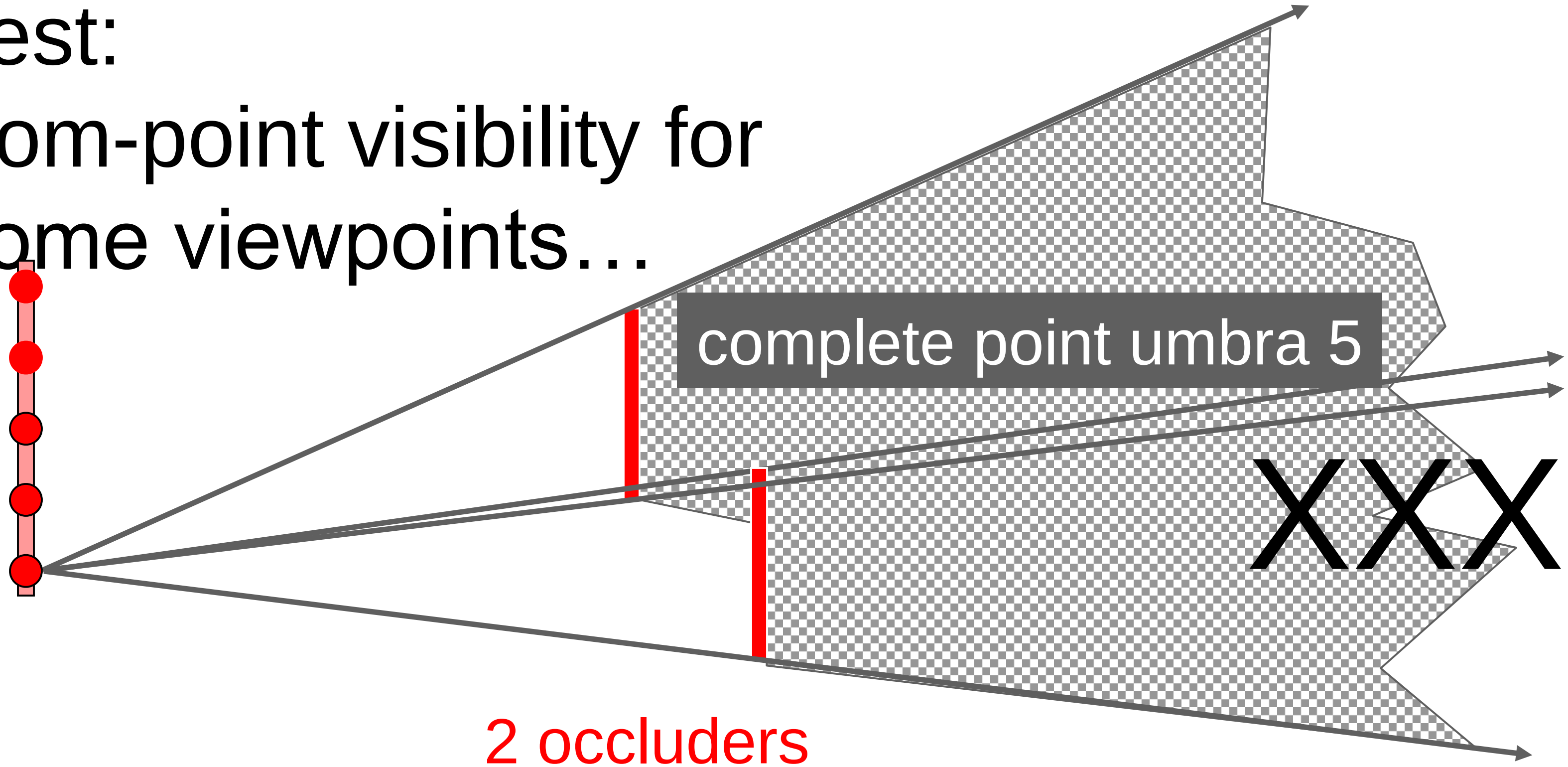
- Test:
  from-point visibility for some viewpoints…



- Viewpoint 1: XXX invisible

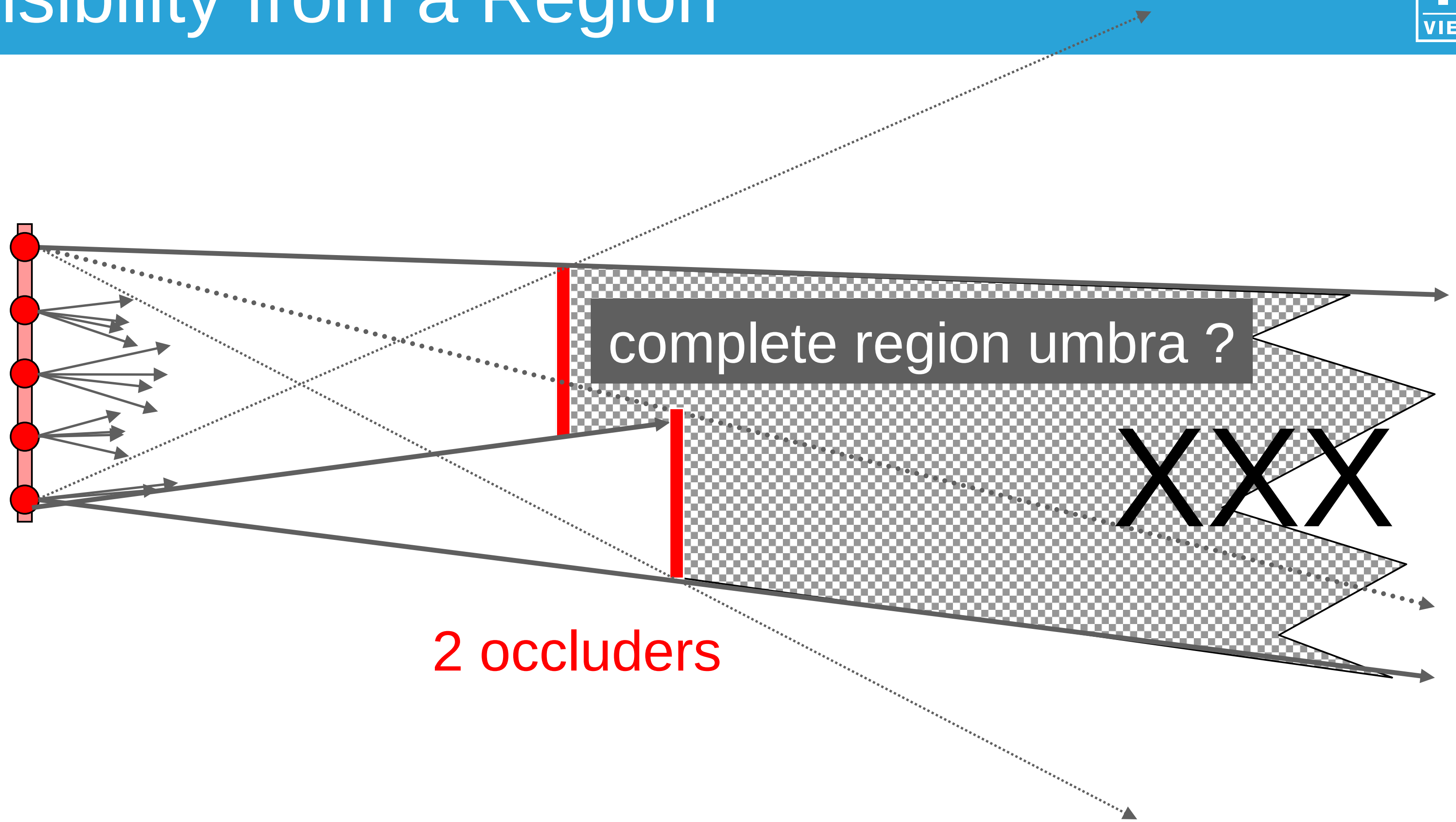
Visibility from a Region

- Test:
  from-point visibility for some viewpoints…



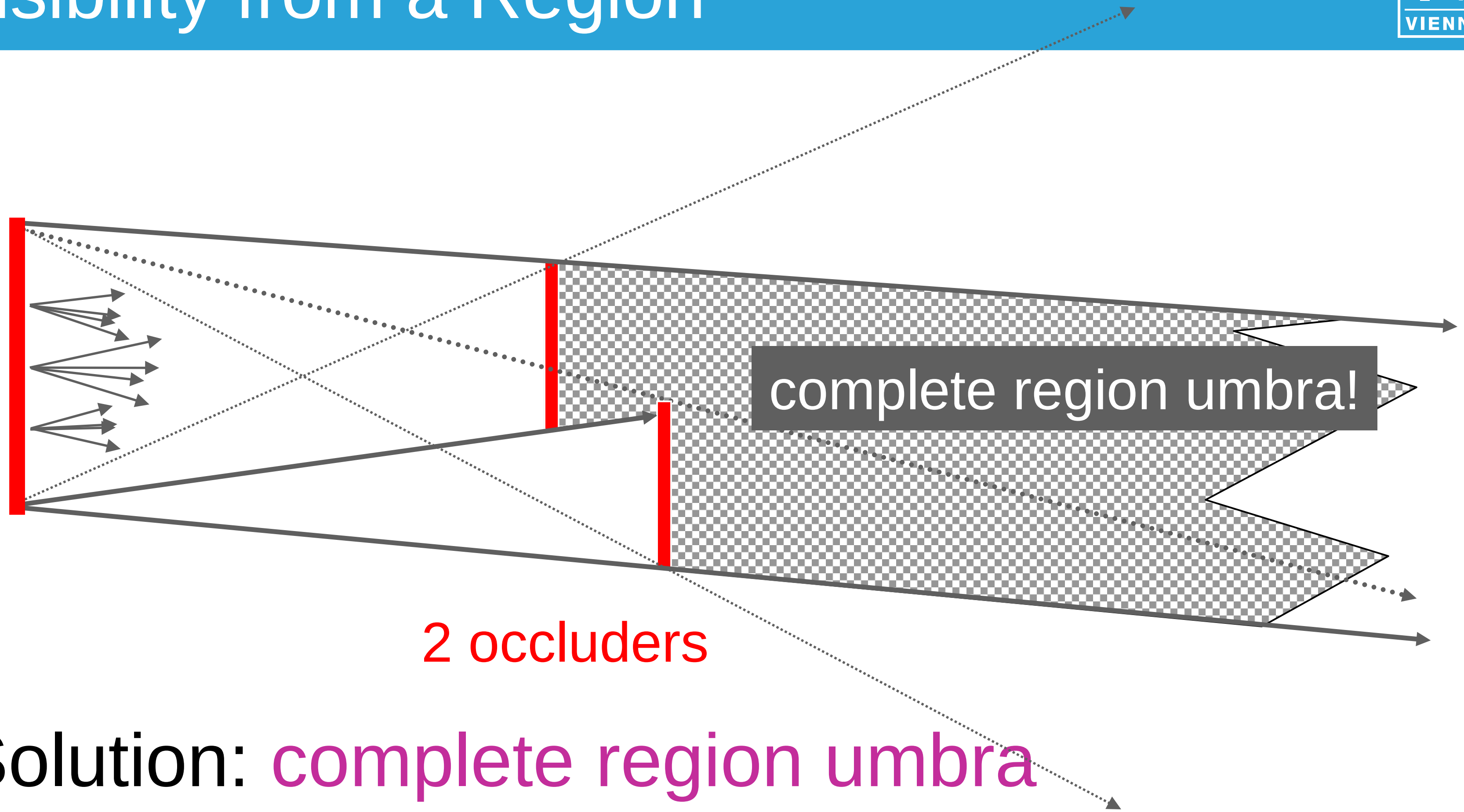
- Viewpoint 5: XXX invisible

Visibility from a Region



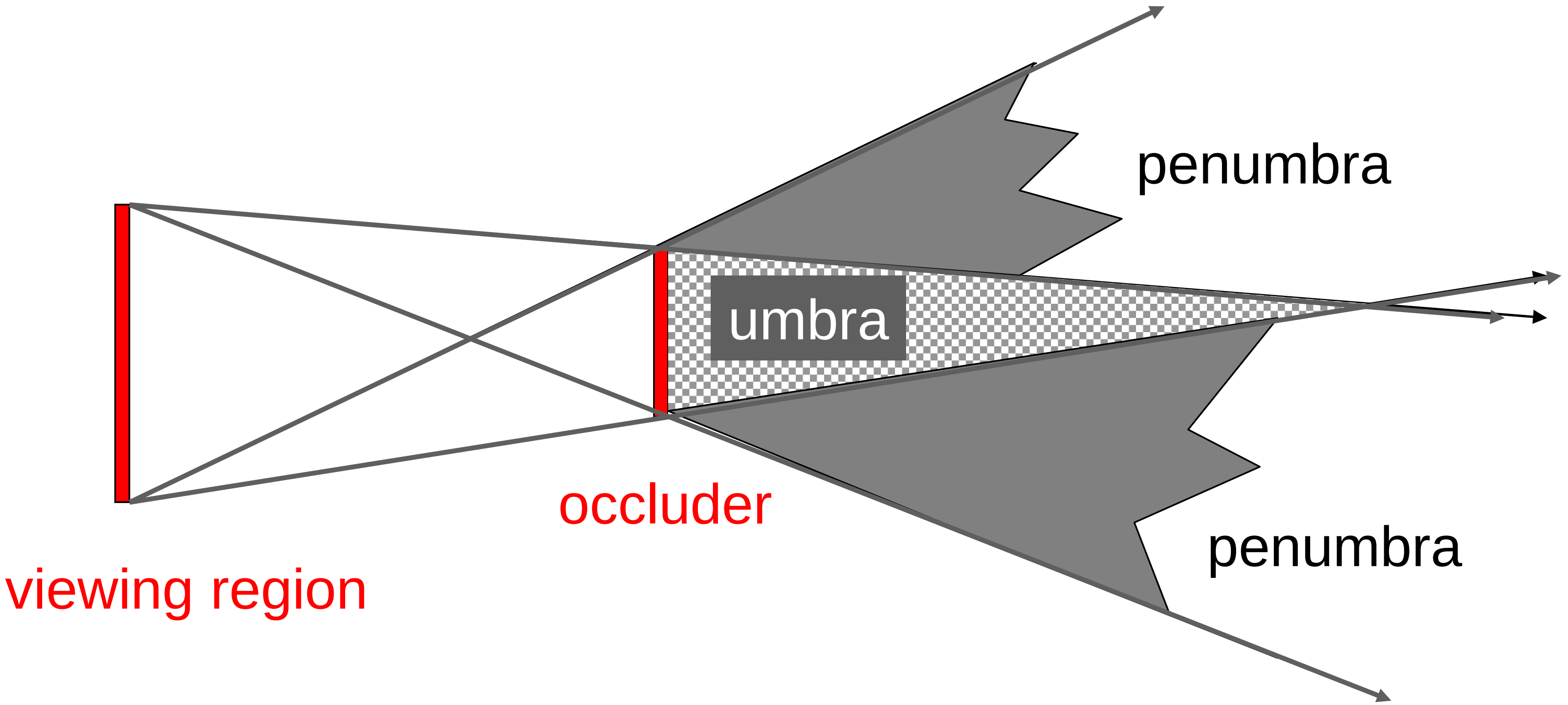
- XXX is always occluded → suggests: complete region umbra is **more** than union of individual region umbra

Visibility from a Region



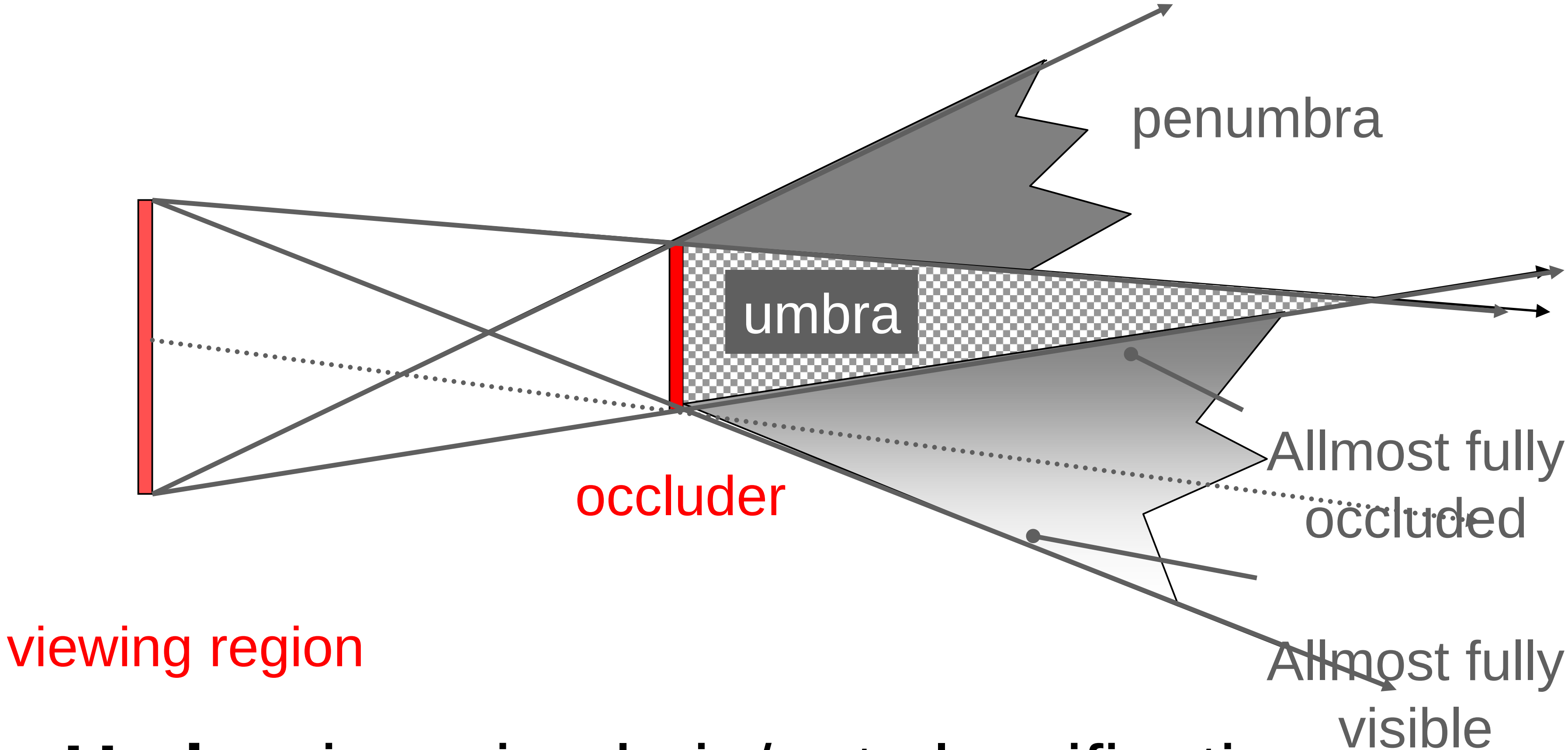
- Solution: complete region umbra for occluders occ_1, …, occ_n = **intersection** of **complete point umbrae** for all viewpoints in region!

Important Terms 1: Umbra / Penumbra



- The area (volume) in full shadow is the **umbra**, the grey area the **penumbra**.

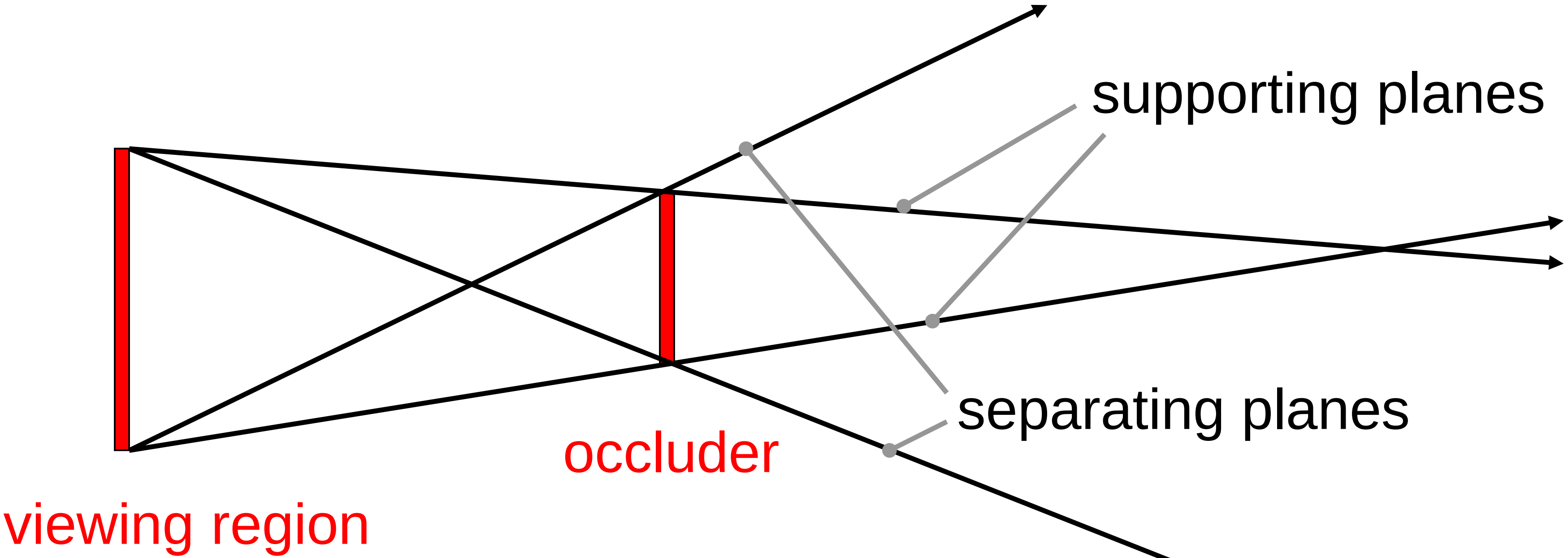
Umbra / Penumbra



- **Umbra** is a simple in/out classification
- **Penumbra** additionally encodes which parts of the viewing region are visible

Important Terms 2:

Supporting / Separating Planes

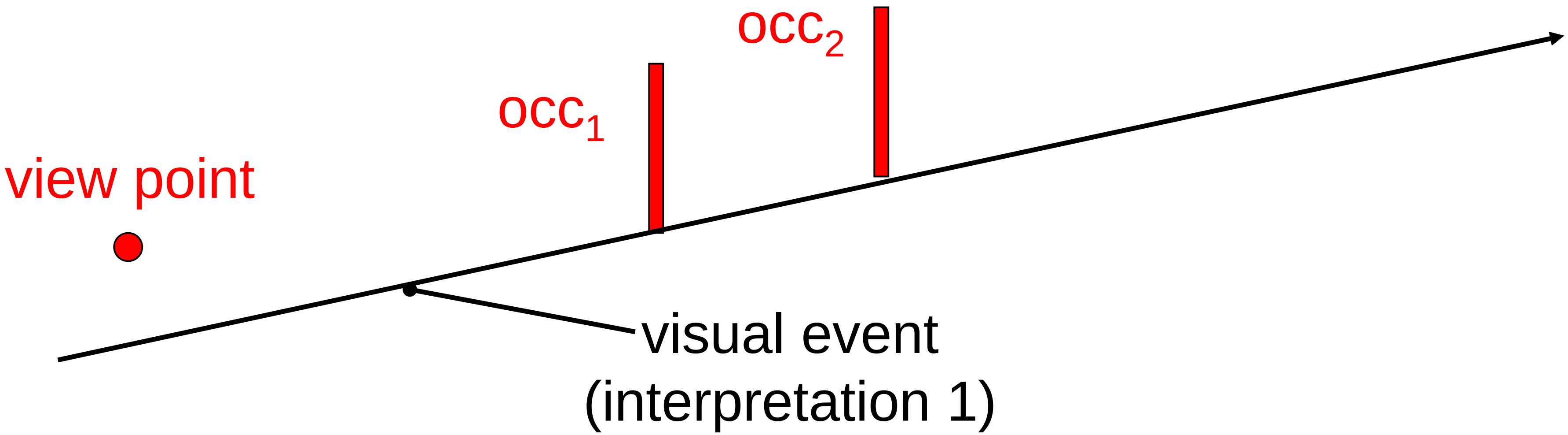


Supporting / Separating Planes

- Planes between two polyhedra defined by:
  - Edge of one polyhedron (view cell/occluder)
  - Vertex of other polyhedron (view cell/occluder)
- **Supporting planes**
  - Example: bound umbra of one occluder
  - Polyhedra on **same** side of plane
- **Separating planes**
  - Example: bound penumbra of one occluder
  - Polyhedra on **opposite** sides of plane

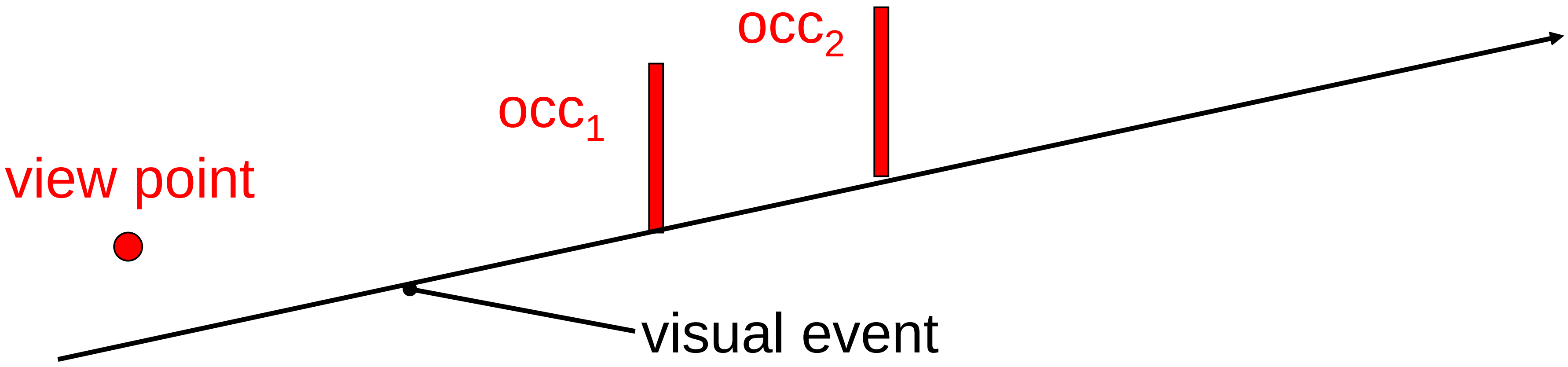
Important Terms 3: Visual Events

- Surfaces where visibility changes when a point crosses it
- Interpretation 1: point is viewpoint
  - Visual events bound regions of constant visibility
- Interpretation 2: point is “viewed point”
  - Visual events are the shadow boundaries

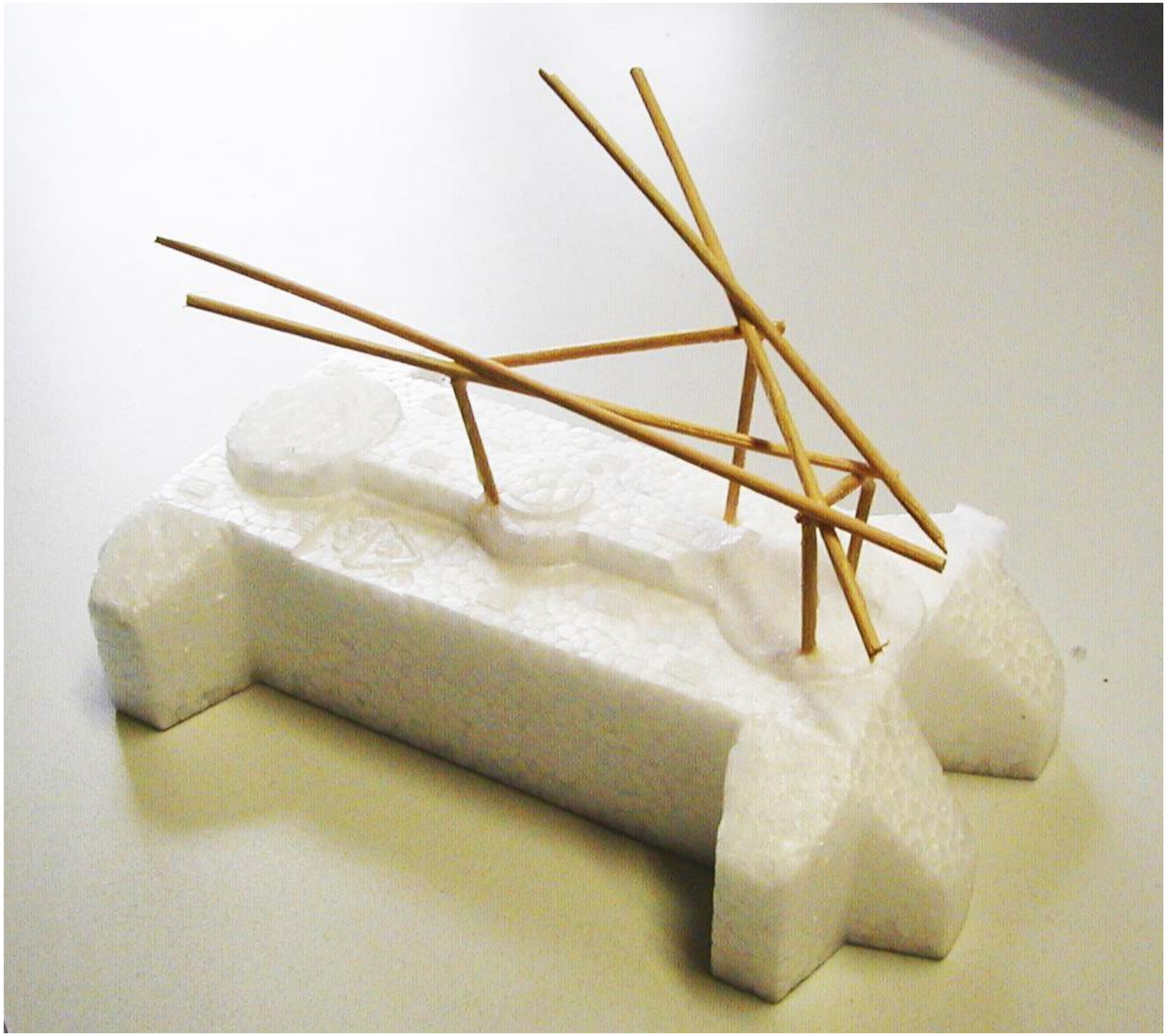


Visual Events

- Visual event types:
  - Vertex-Edge (VE): supporting/separating planes
  - Edge-Edge-Edge (EEE): curved surfaces!

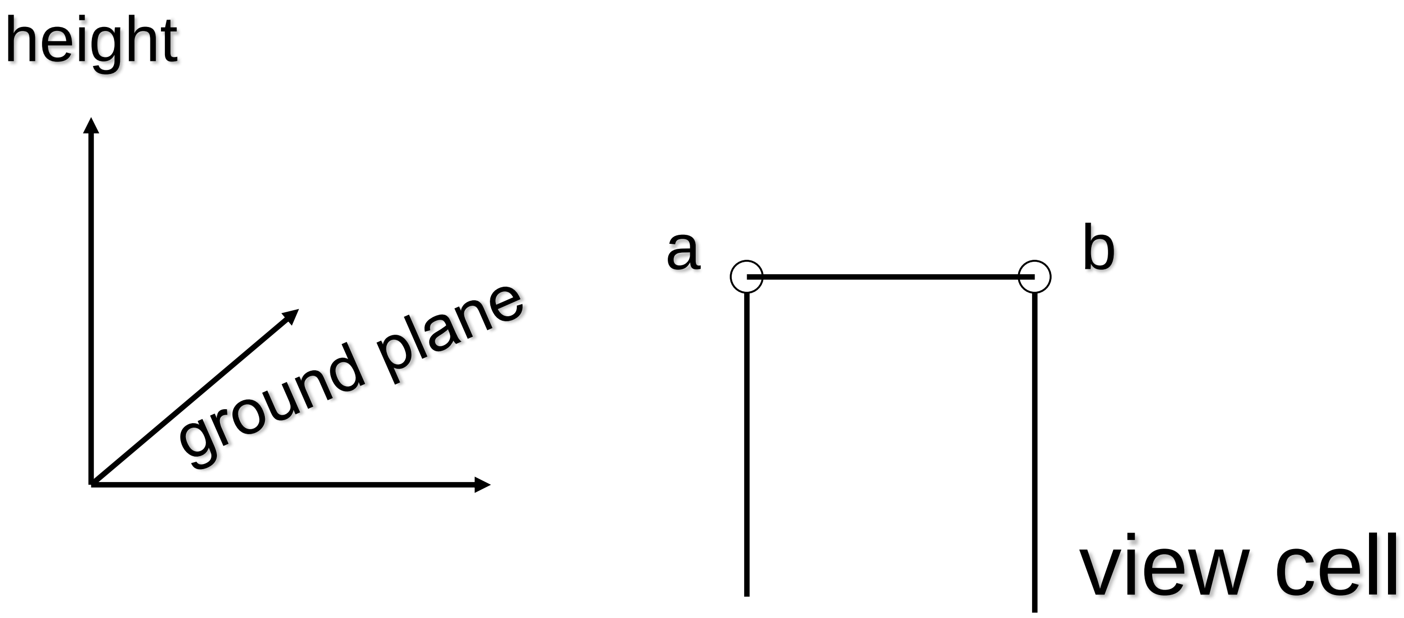


Visual Events / Shadow Boundaries



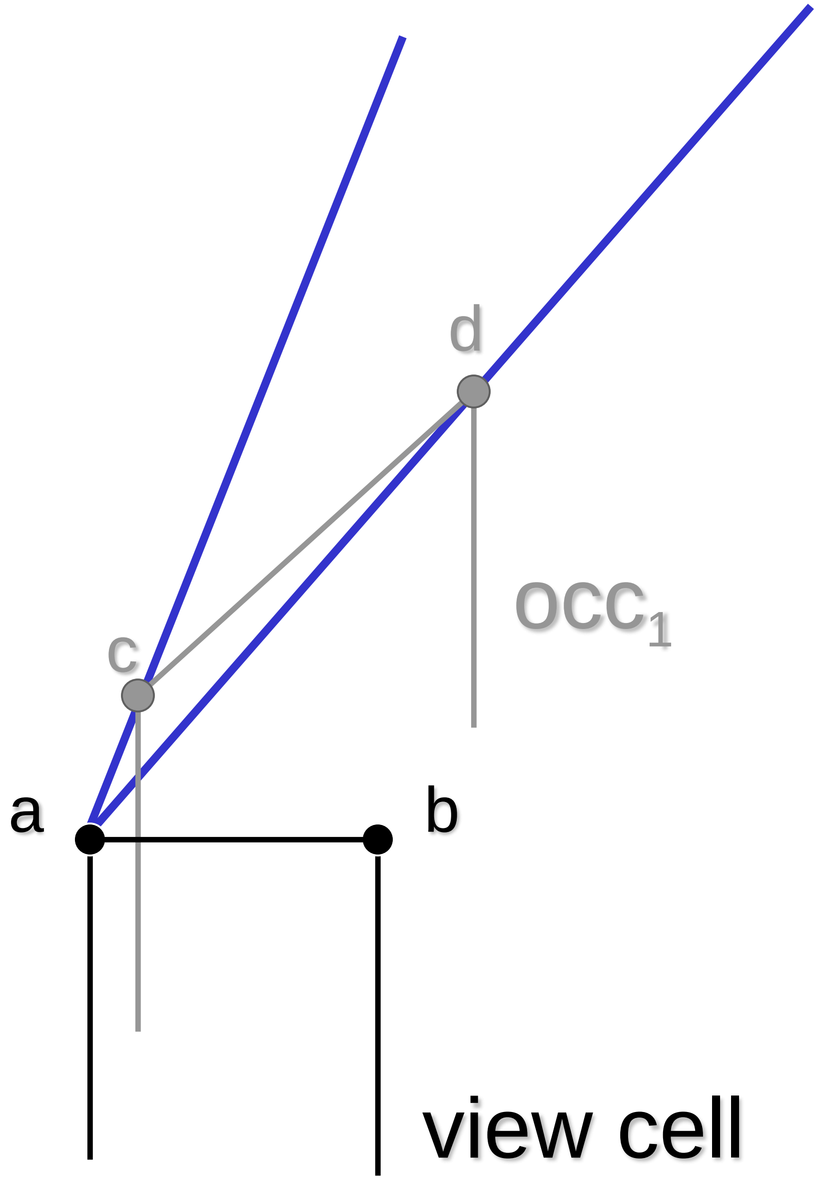
Shadow Boundaries

- Visual events, interpretation 2
  - View cell always participates



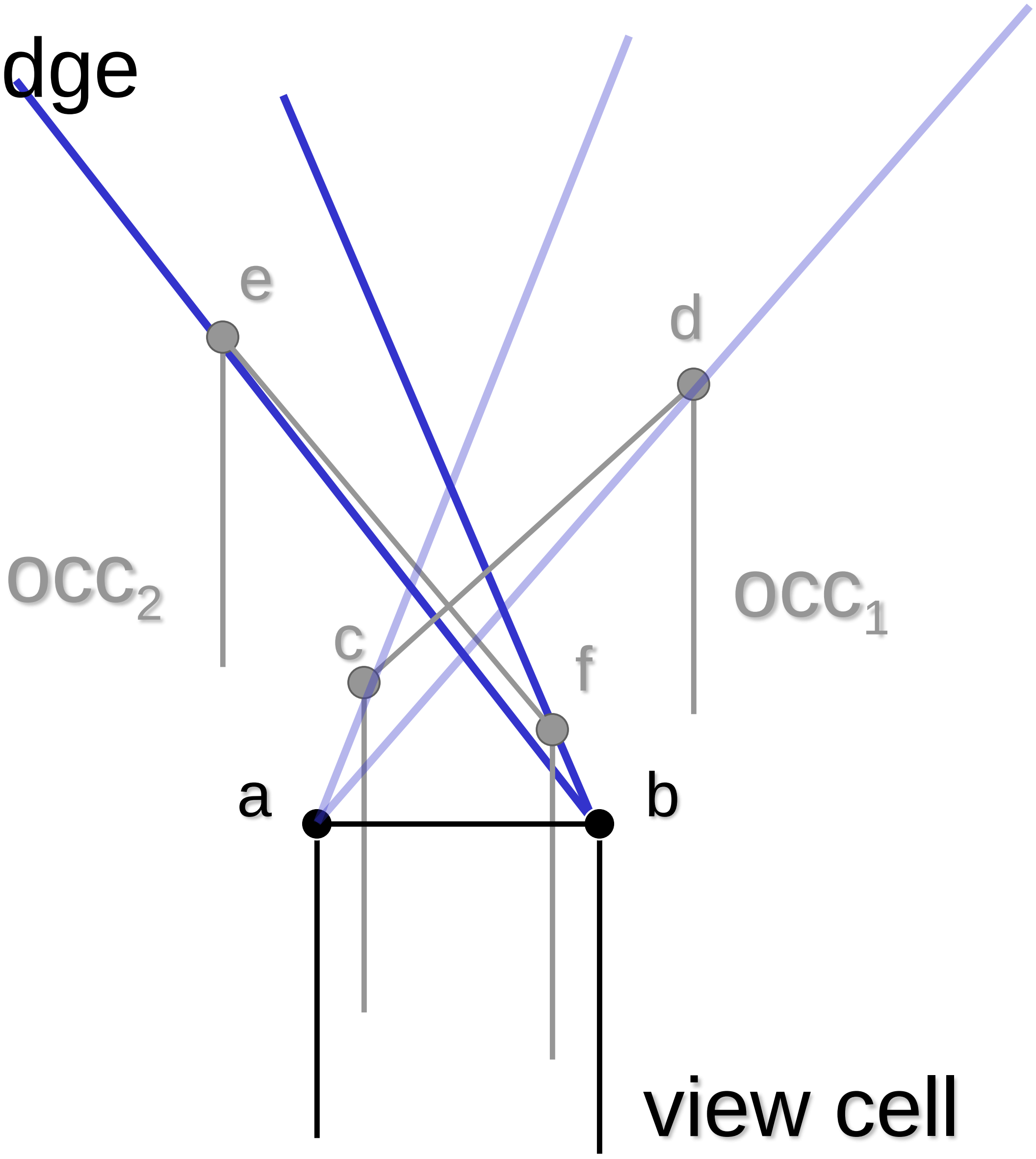
Shadow Boundaries

- Vertex/edge



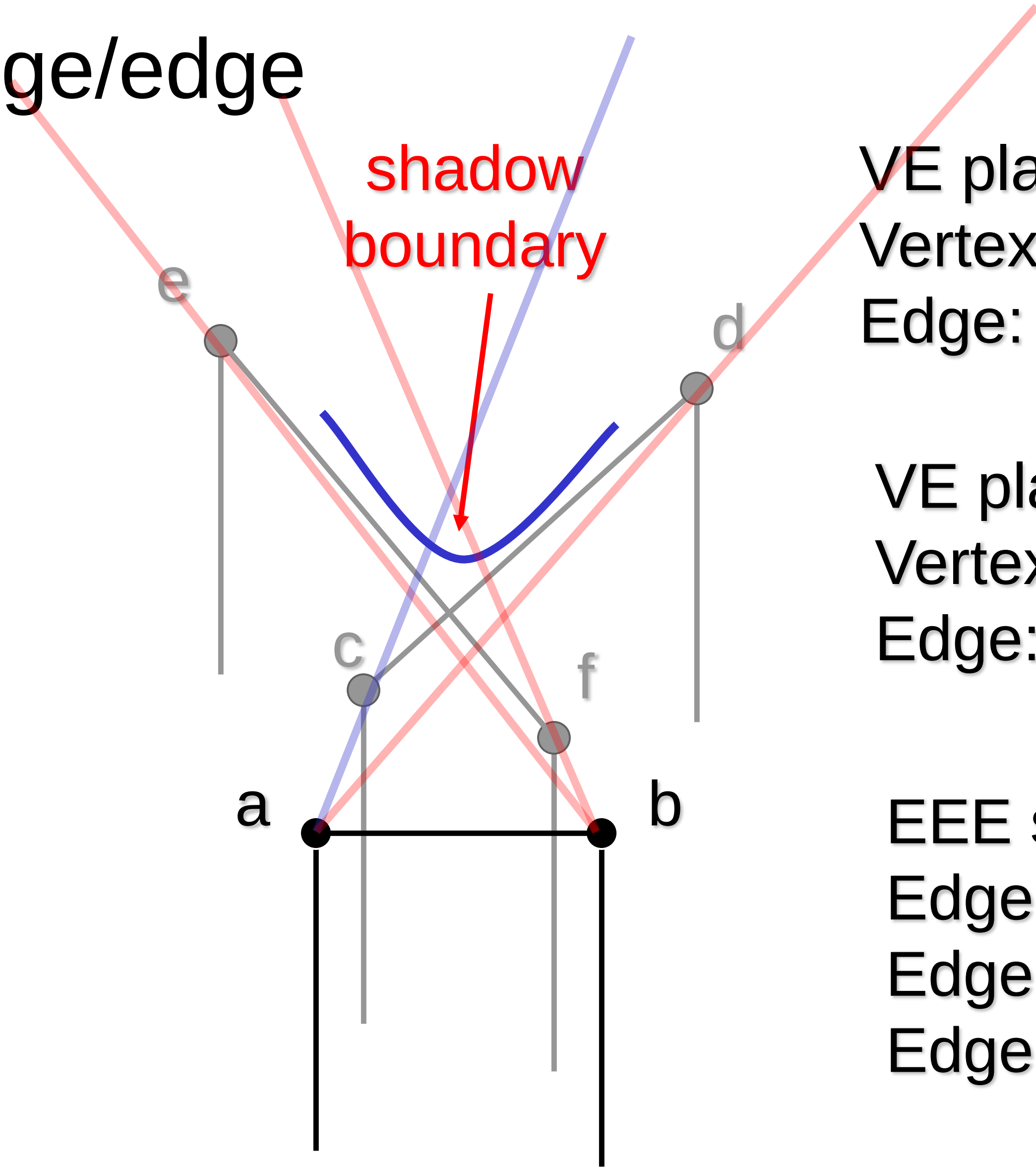
Shadow Boundaries

- Vertex/edge



Shadow Boundaries

- Edge/edge/edge



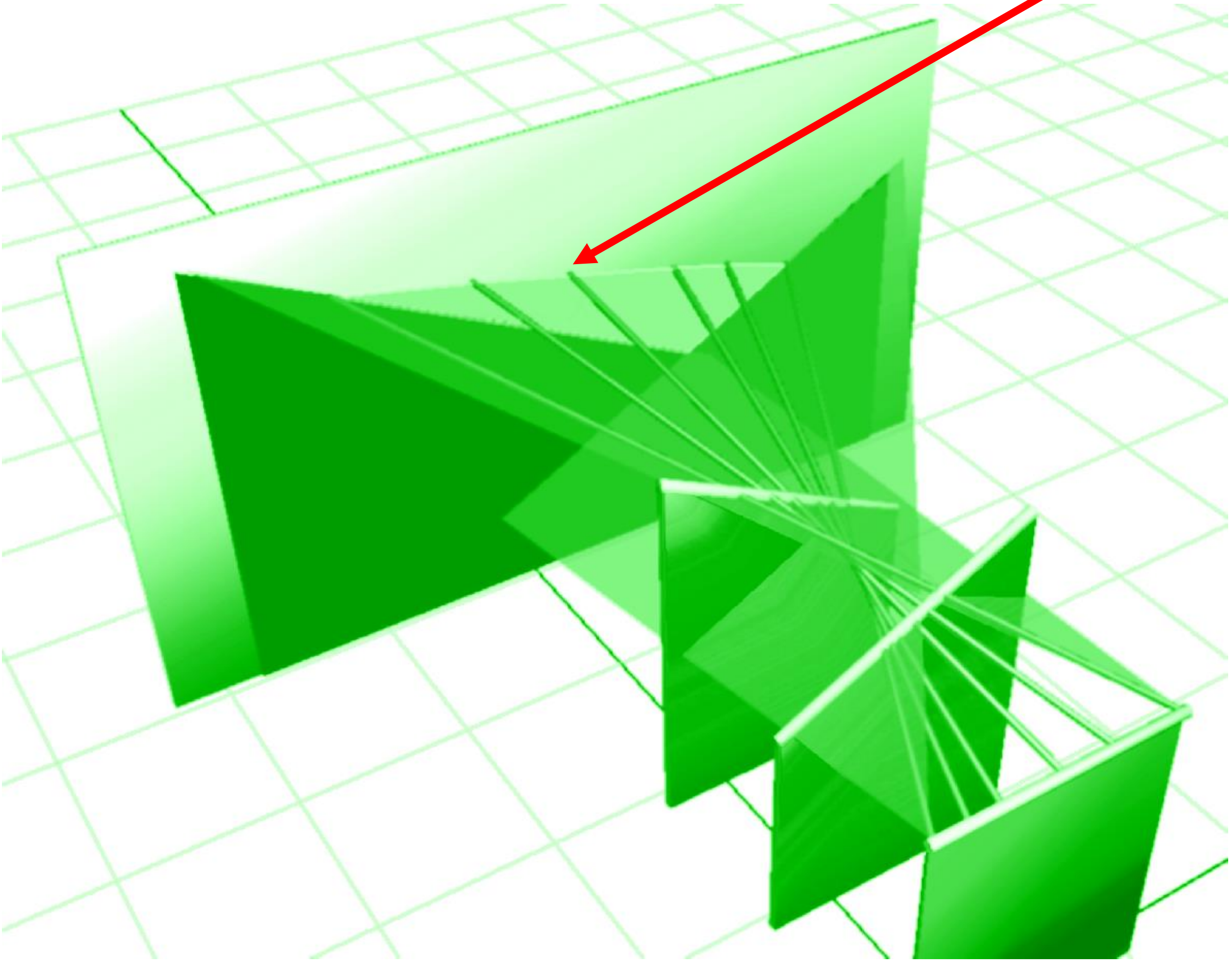
VE plane:
Vertex: a
Edge: cd

VE plane:
Vertex: b
Edge: ef

EEE surface:
Edge: cd
Edge: ef
Edge: ab

Shadow Boundaries

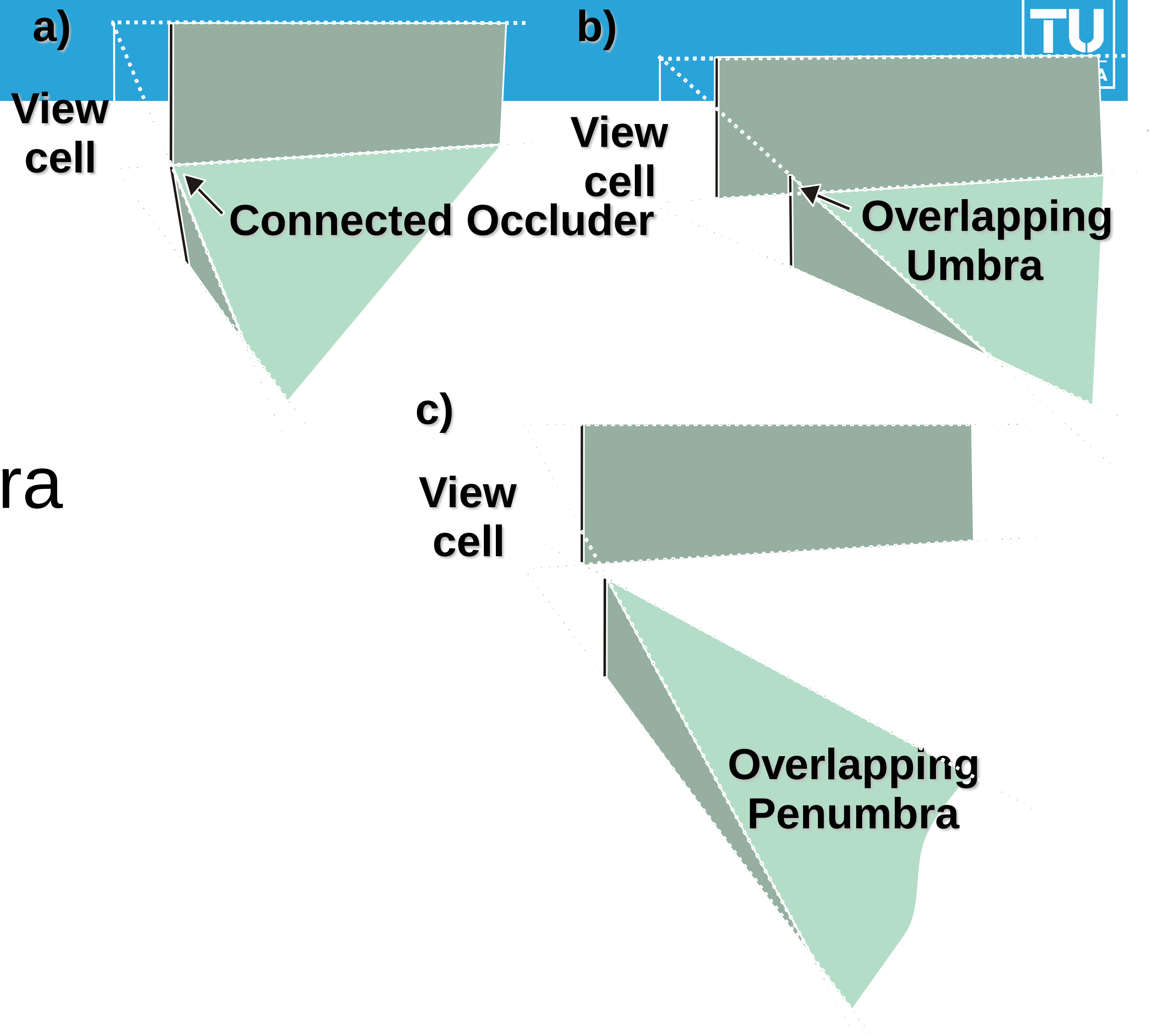
curved!



Occlusion Culling from a Region: Theoretical Approaches

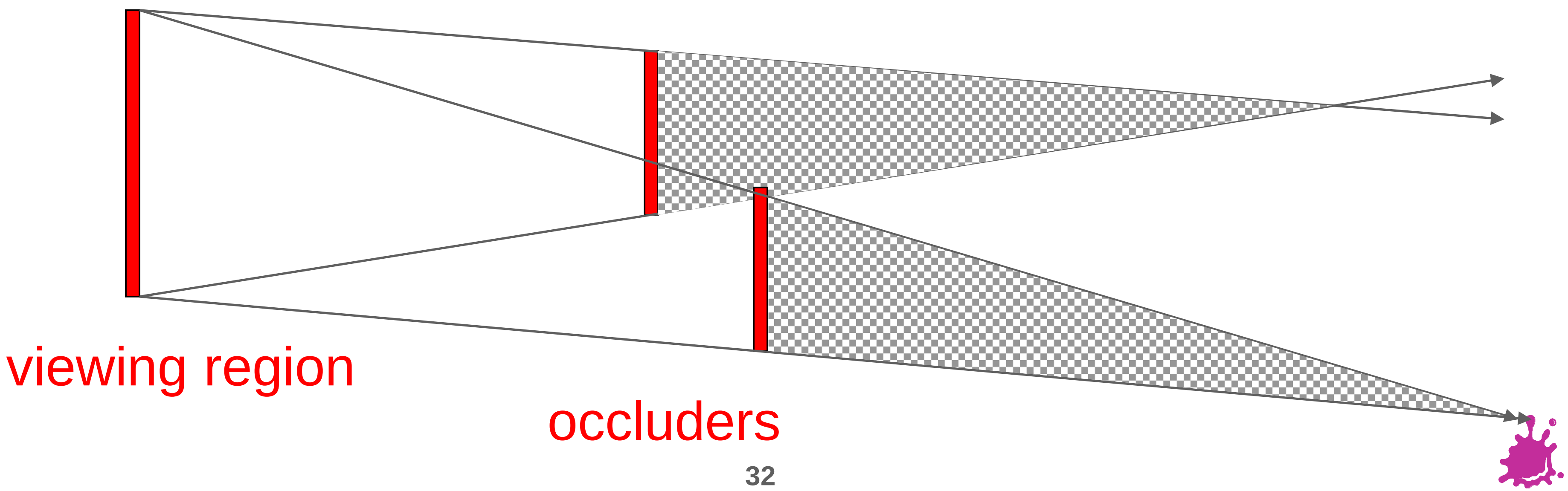
- Recall: complete region umbra = intersection of complete point umbrae
- But: impossible to calculate!
- Approach: look at ways to merge penumbrae
  - Complete region umbra =
    union of individual region umbrae +
    all regions where penumbrae merge to umbra
- Problem: How to store Penumbra?

3 ways how penumbrae merge to umbra



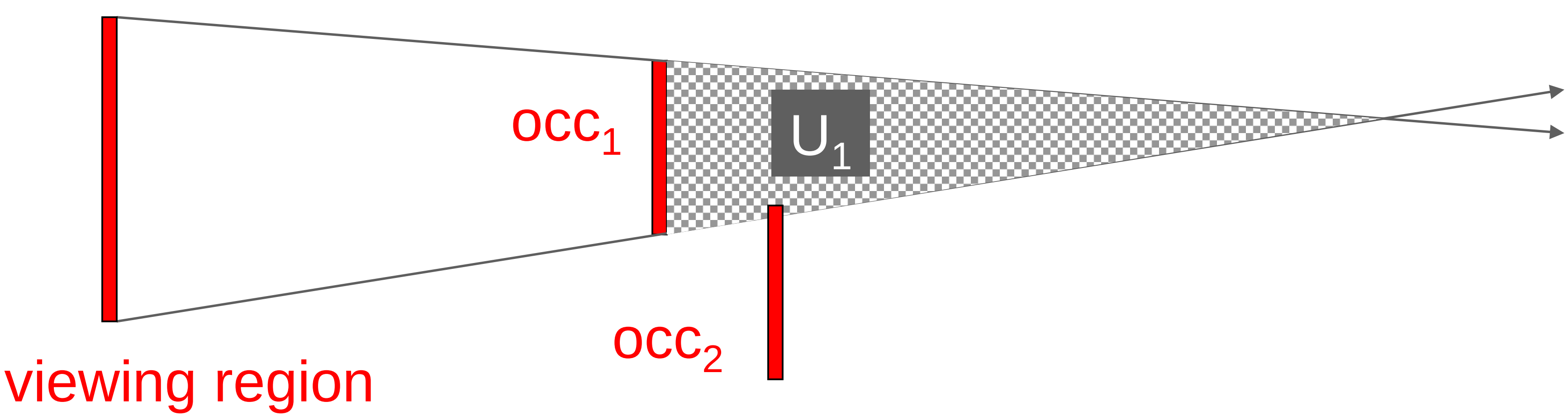
Occlusion Culling from a Region I

- Idea I: ignore problem completely
- Umbra data structure (UDS) = empty
- for each occluder occ_i
  - Calculate umbra U_i
  - Add U_i to UDS
- Test the scene against the UDS (union of U_i)



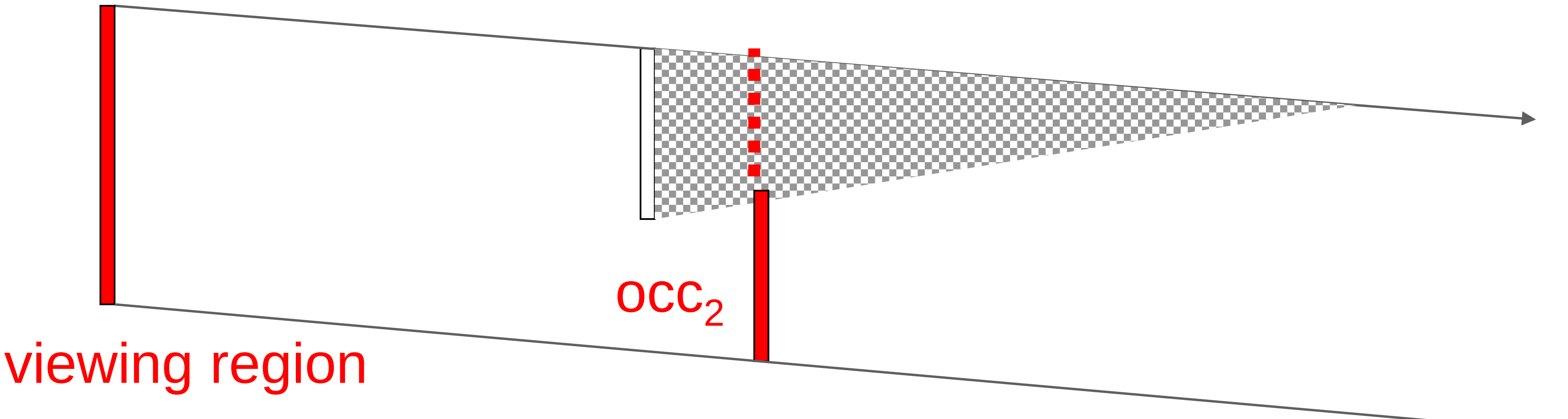
Occlusion Culling from a Region II

- Idea II: detect overlapping umbrae (case b)
- UDS = empty
- front-to back: for each occluder occ_i



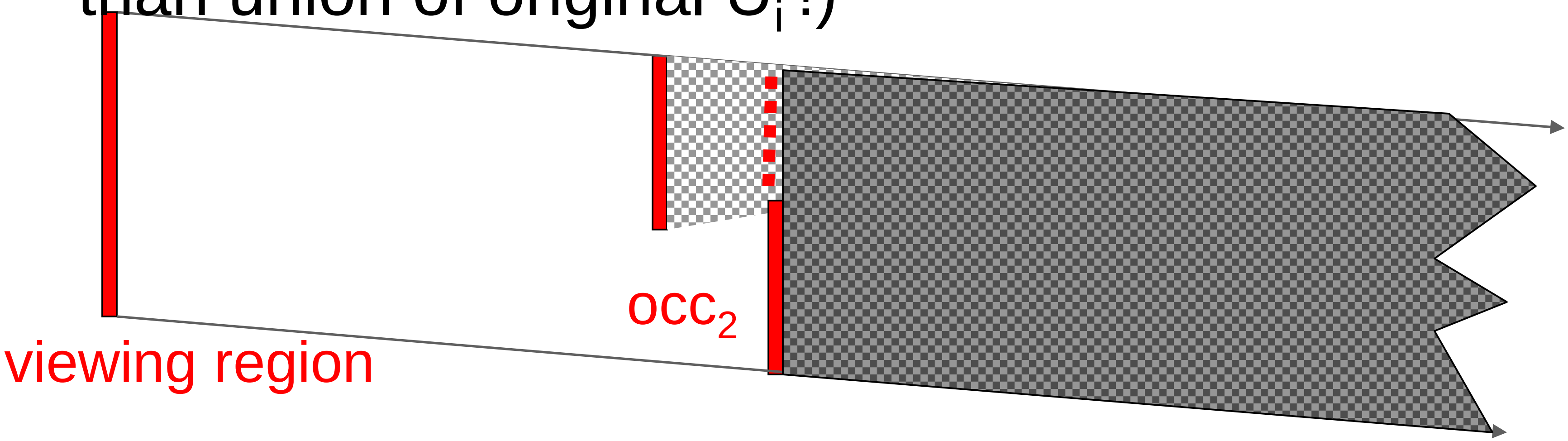
Occlusion Culling from a Region II

- Idea II: detect overlapping umbrae
- UDS = empty
- front-to back: for each occluder occ_i
  - **Extend occluder into existing umbra**
  - Calculate (extended) umbra U_i
  - Add U_i to UDS



Occlusion Culling from a Region II

- Idea II: detect overlapping umbrae
- UDS = empty
- front-to back: for each occluder occ_i
  - **Extend occluder into existing umbra**
  - Calculate (extended) umbra U_i
  - Add U_i to UDS
- Test the scene against UDS (which is now more than union of original U_i !)

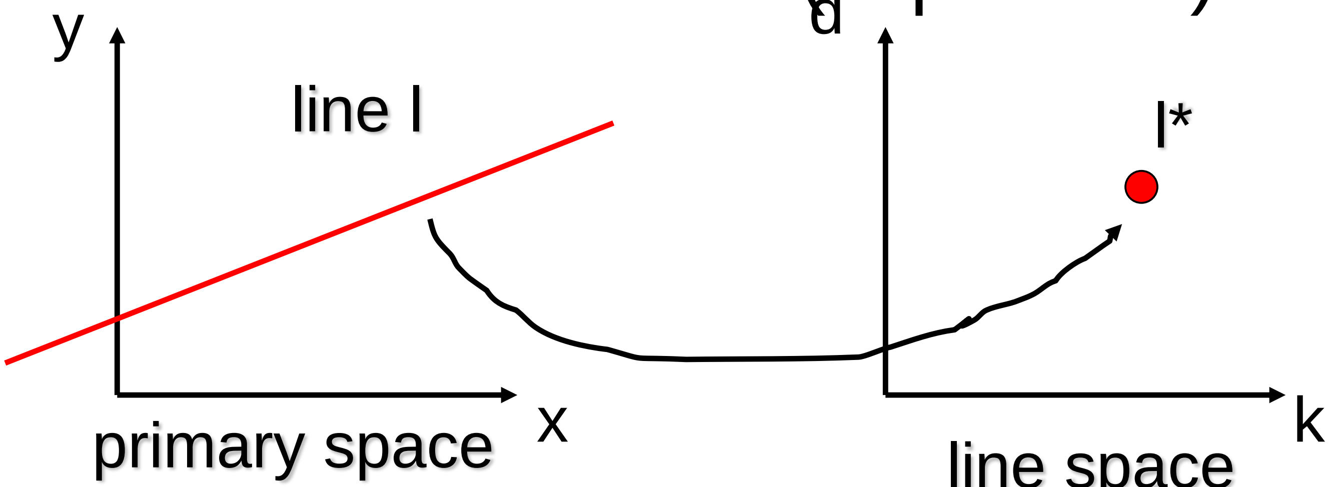


Occlusion Culling from a Region III

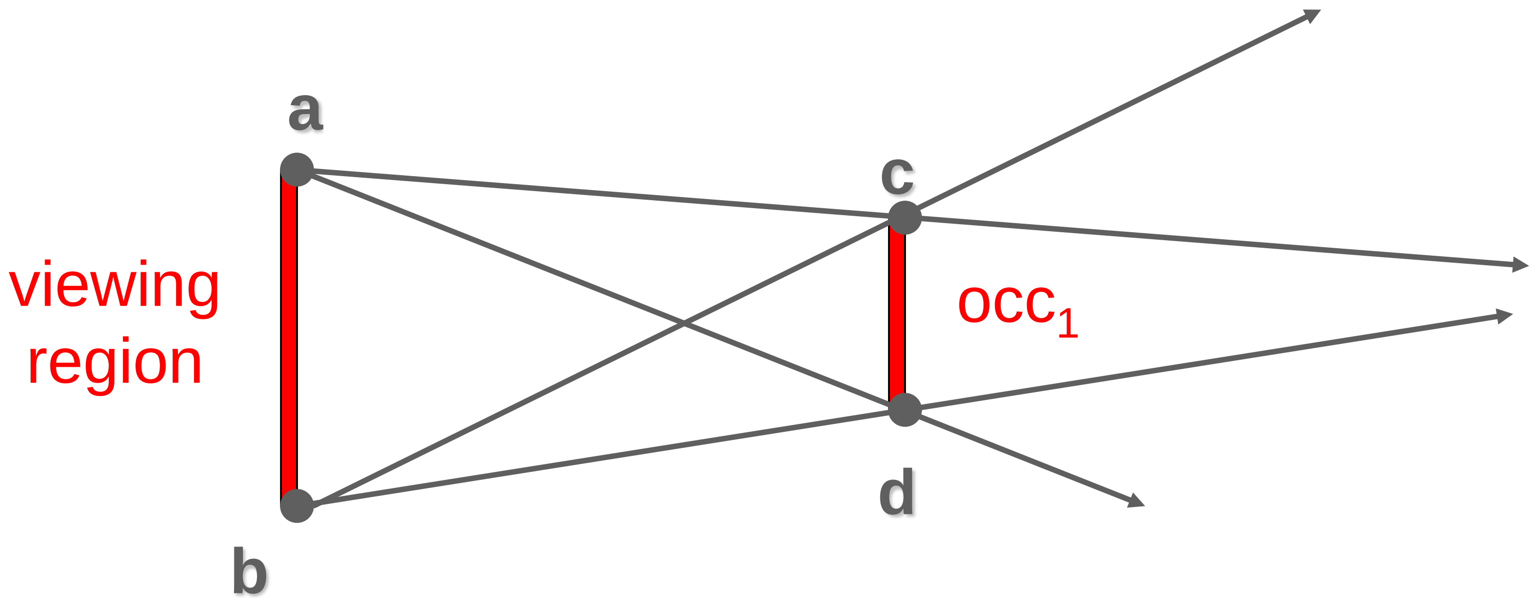
- Idea III: calculate everything (case c)
- Problem: complete region umbra bounded by planes and reguli (ruled, quadric surfaces with negative curvature) (recall visual events!)
- Possible solutions (see later):
  - Sample from viewpoints and shrink occluders
  - Solve problem in line space
  - Extended projections
  - Special case solutions (horizons, cells/portals)

Visibility in Line Space (2D)

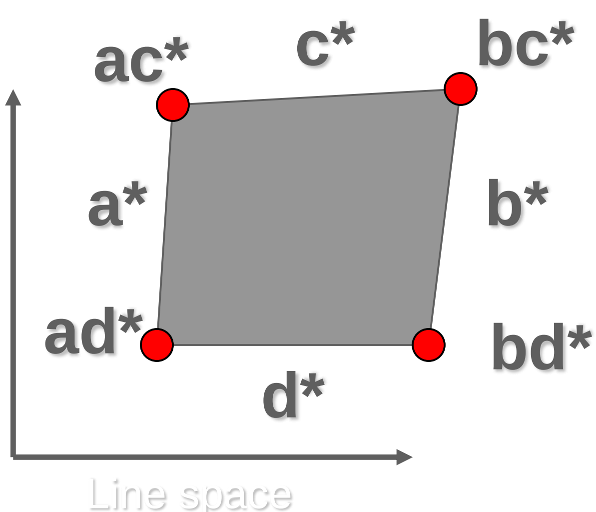
- Oriented 2D line maps to point in 2D oriented projective space (line space)
- Conversely, 2D point maps to line
- Parameter choice:
  - y = **k** x + **d**
  - Plücker coordinates (in practice)



Visibility in Line Space (2D)



- All lines between the view region and an occluder map to a polygon in line space
- “Occluder polygon”, represents all possible sight lines

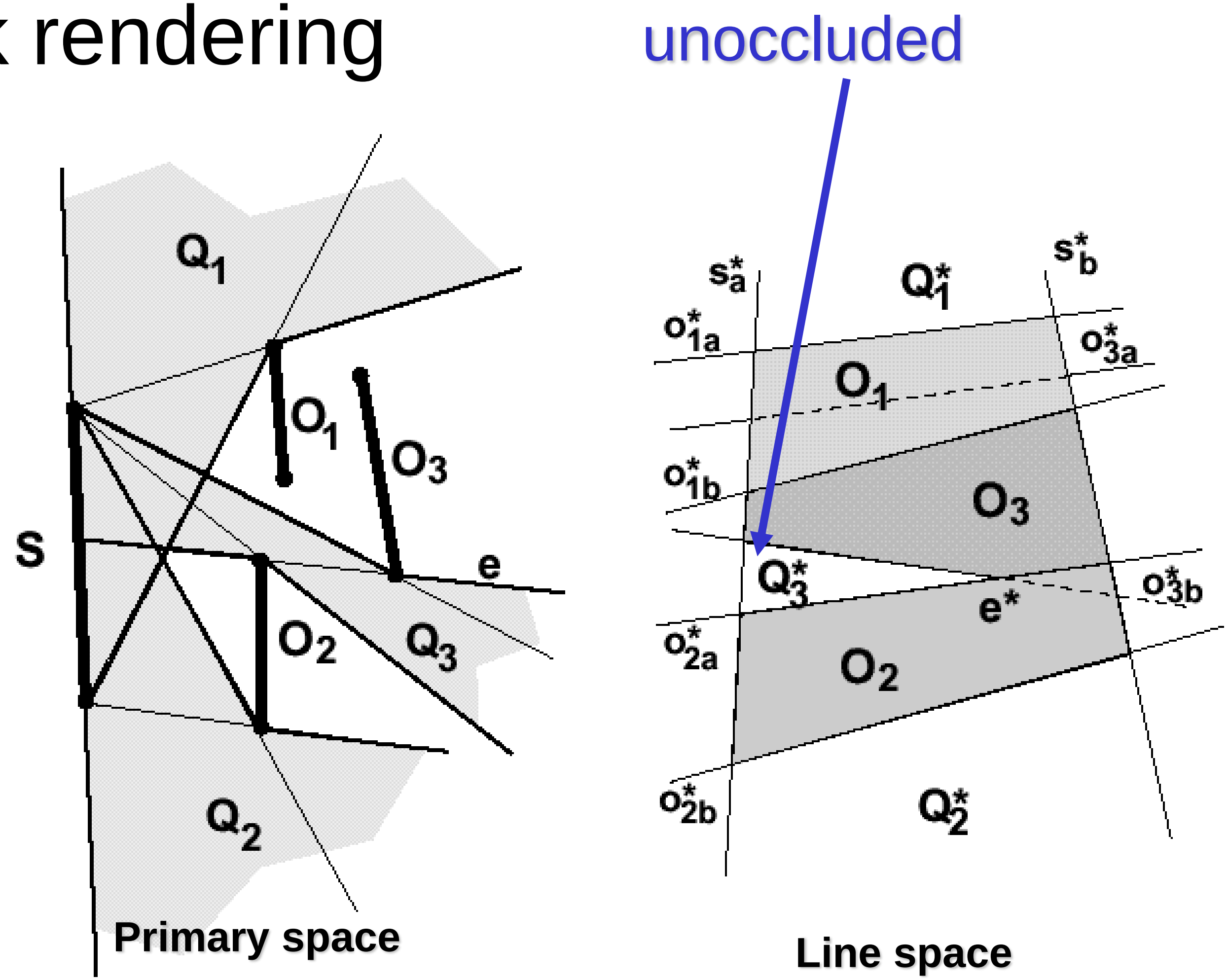


Visibility in Line Space (2D)

- Use a data structure that classifies line space as in / out to store the umbra
- Front-to-back rendering

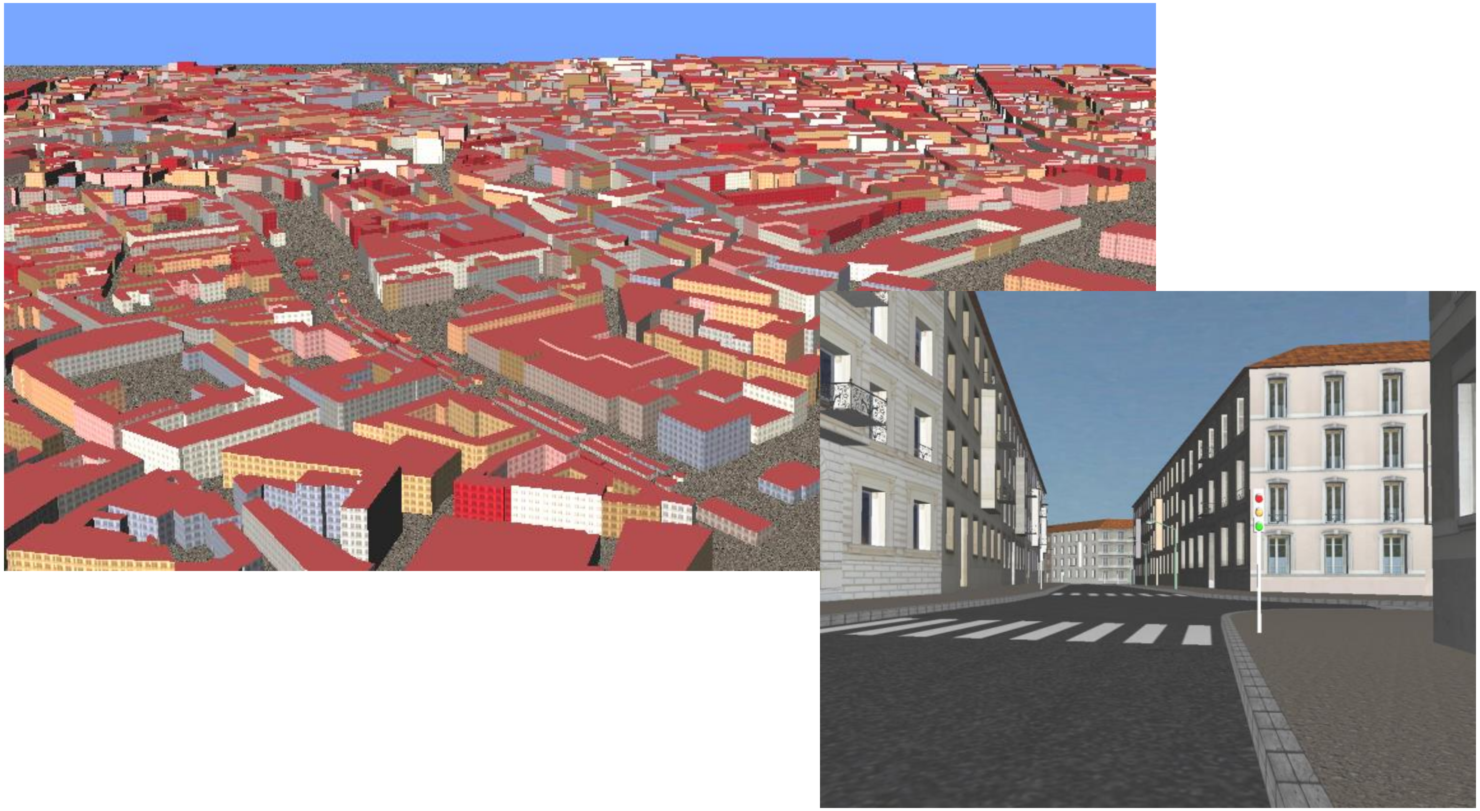
S = view area

O_x = occluder



Overview of Occlusion Culling Algorithms

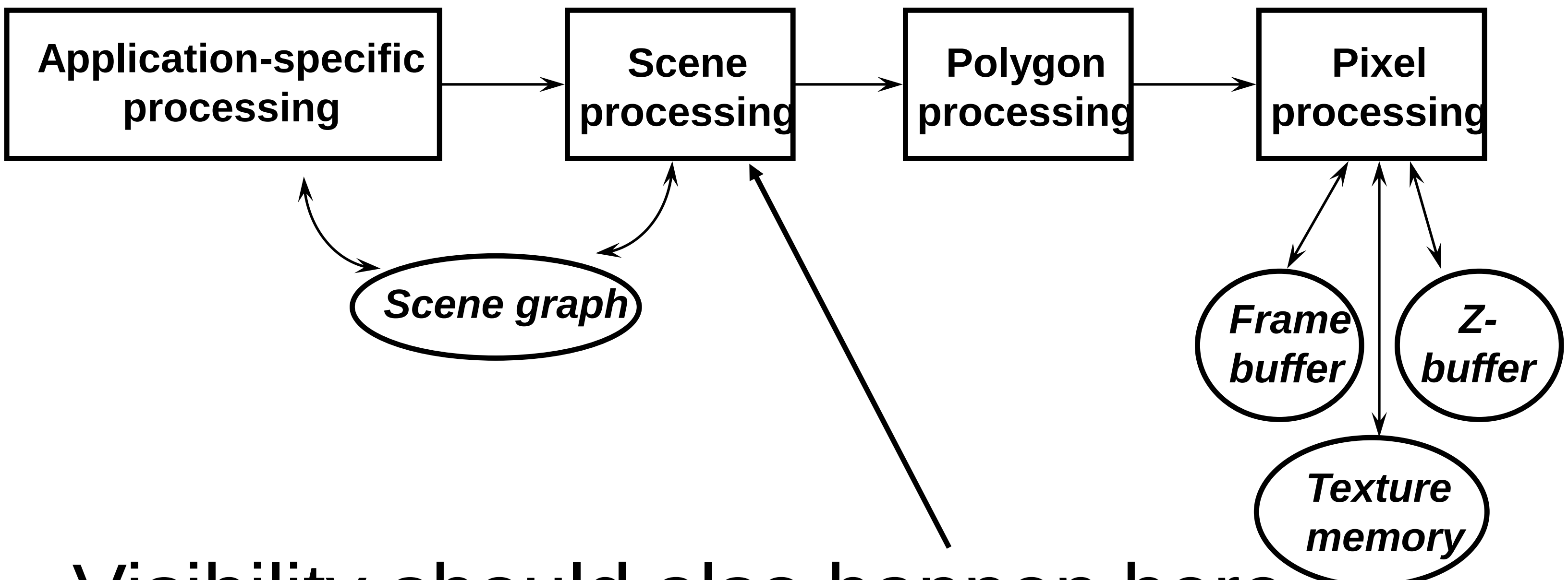
Visibility in Real-Time Rendering



- Interactively walk through a large model
- Large model → millions of polygons → acceleration necessary (e.g. visibility)

Why is the Z-Buffer Not Enough?

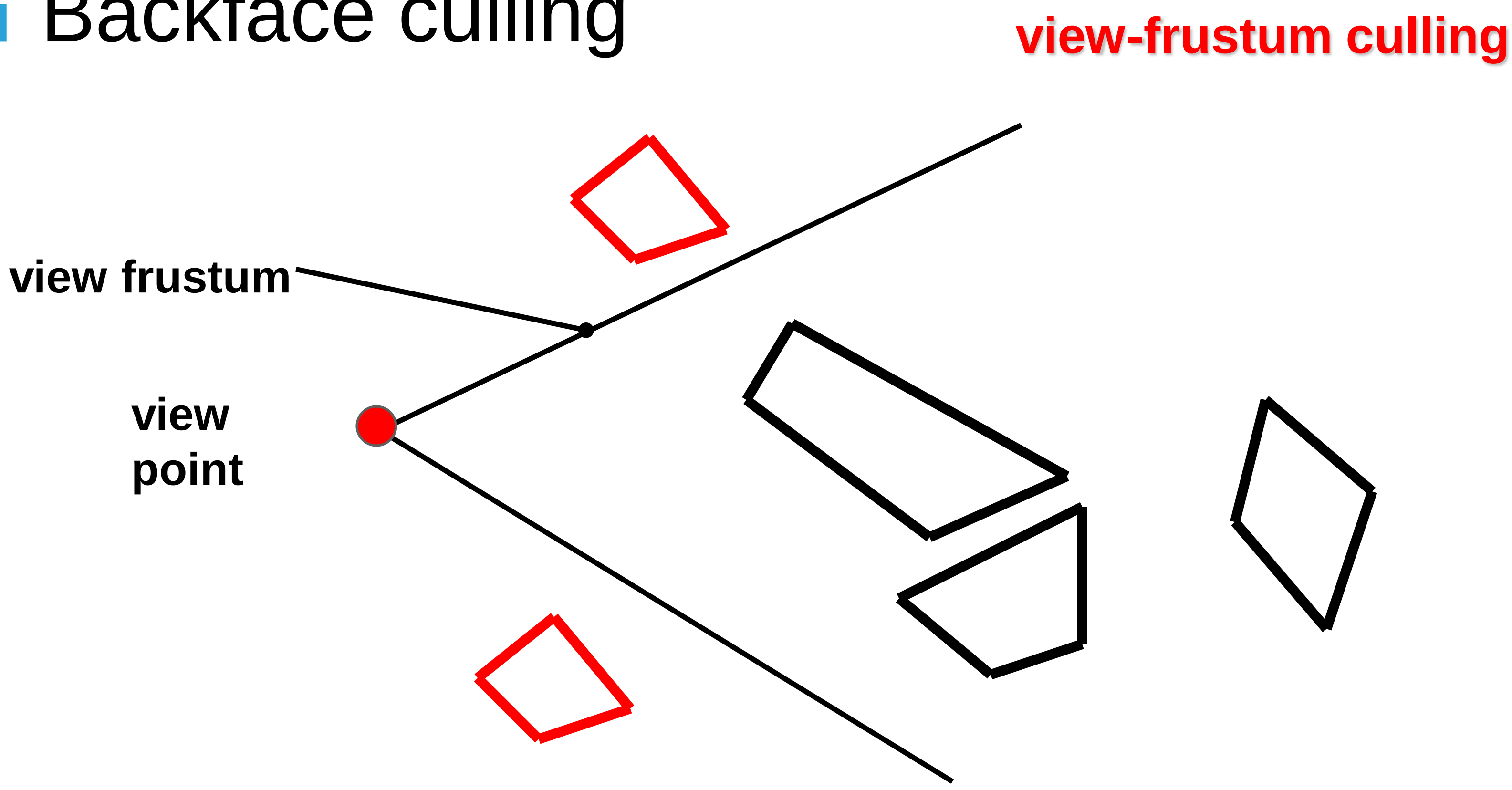
- Does not eliminate depth-complexity (overdraw) (but: early-z in newer cards)
- Does not eliminate application/vertex processing of occluded objects



- Visibility should also happen here

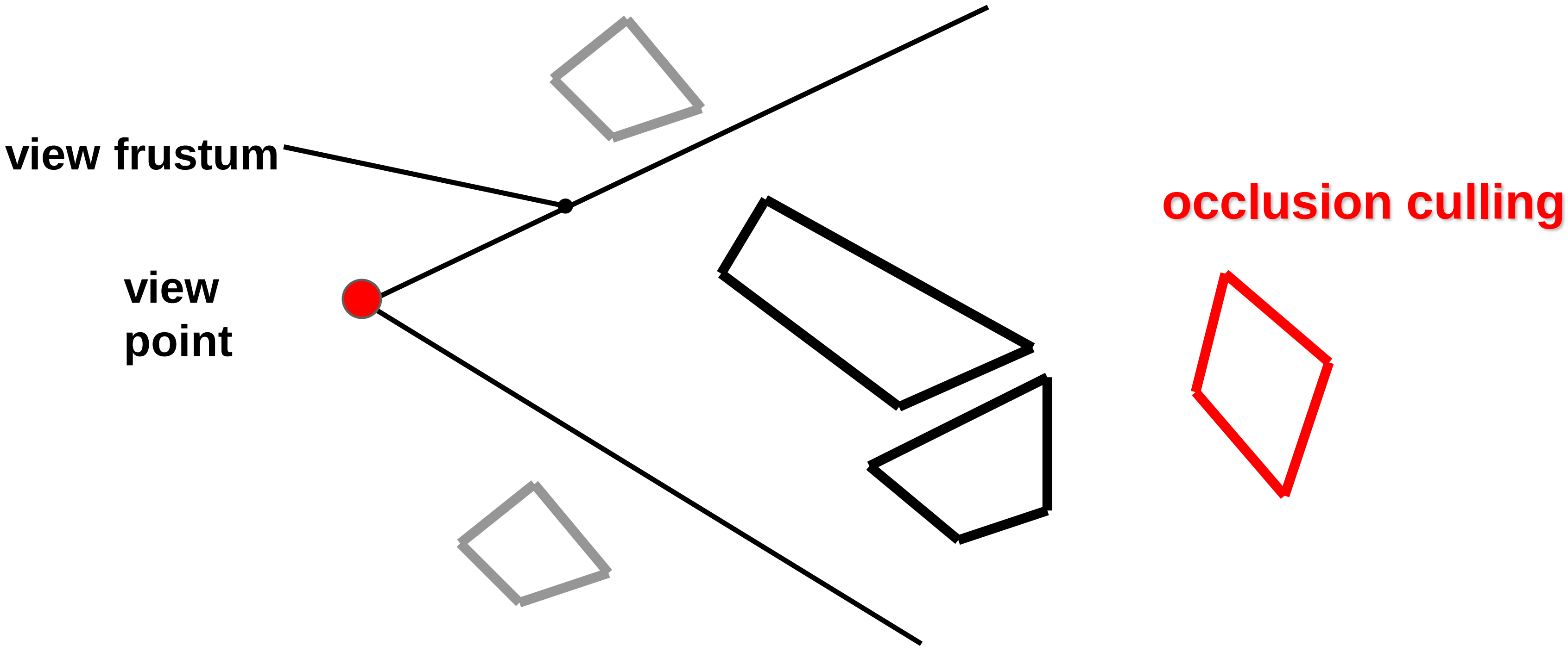
Visibility Culling

- View-frustum culling
- Occlusion culling
- Backface culling



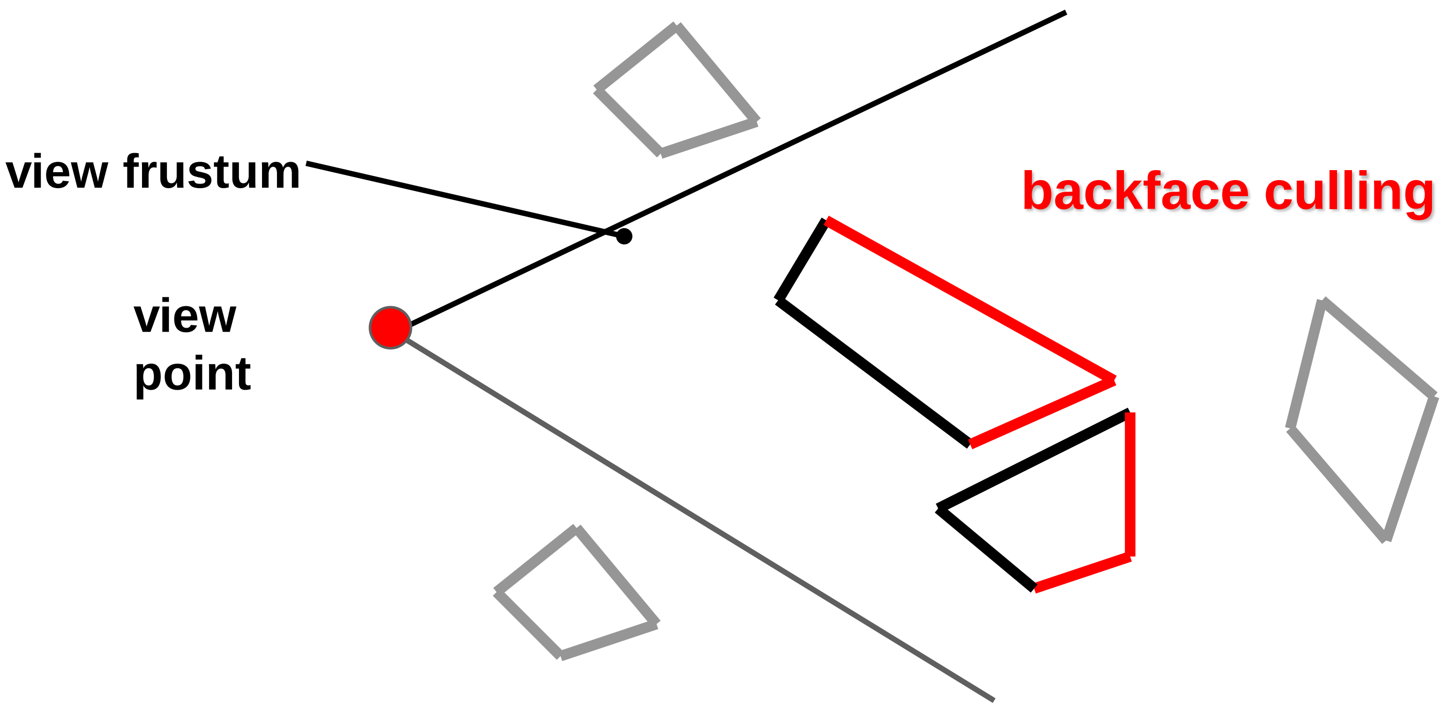
Visibility Culling

- View-frustum culling
- Occlusion culling
- Backface culling



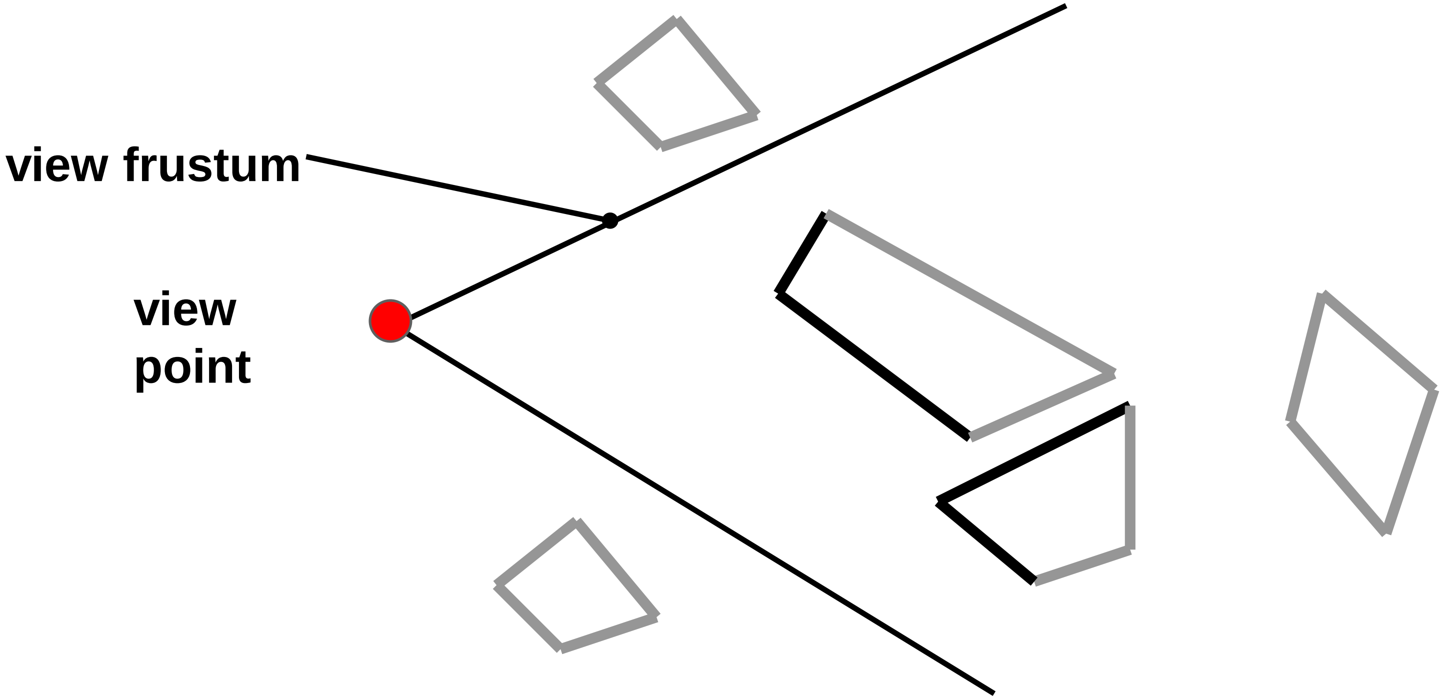
Visibility Culling

- View-frustum culling
- Occlusion culling
- Backface culling



Visibility culling

- Result

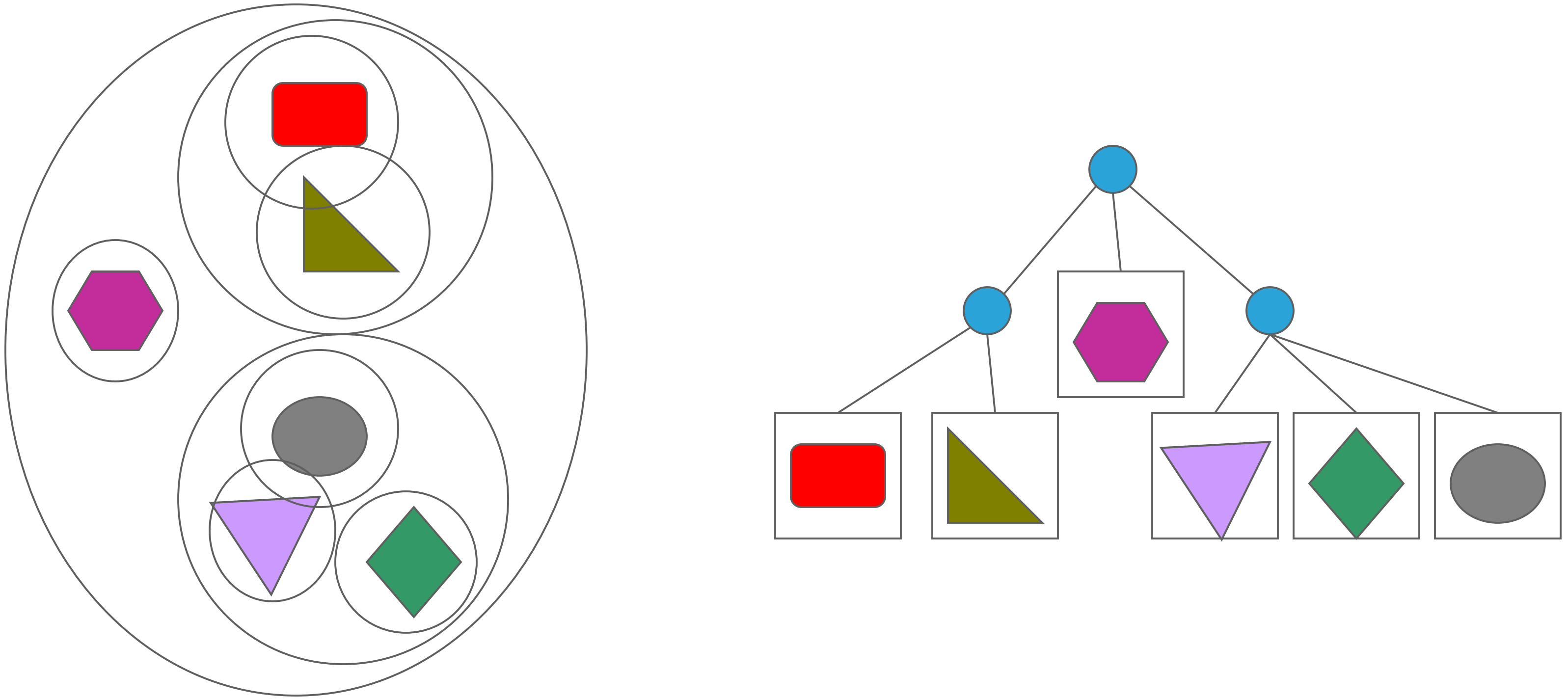


View-Frustum Culling

- Eliminate polygons outside of the view frustum
- Hierarchical data structure
  - Bounding-volume hierarchy
  - or any spatial data structure

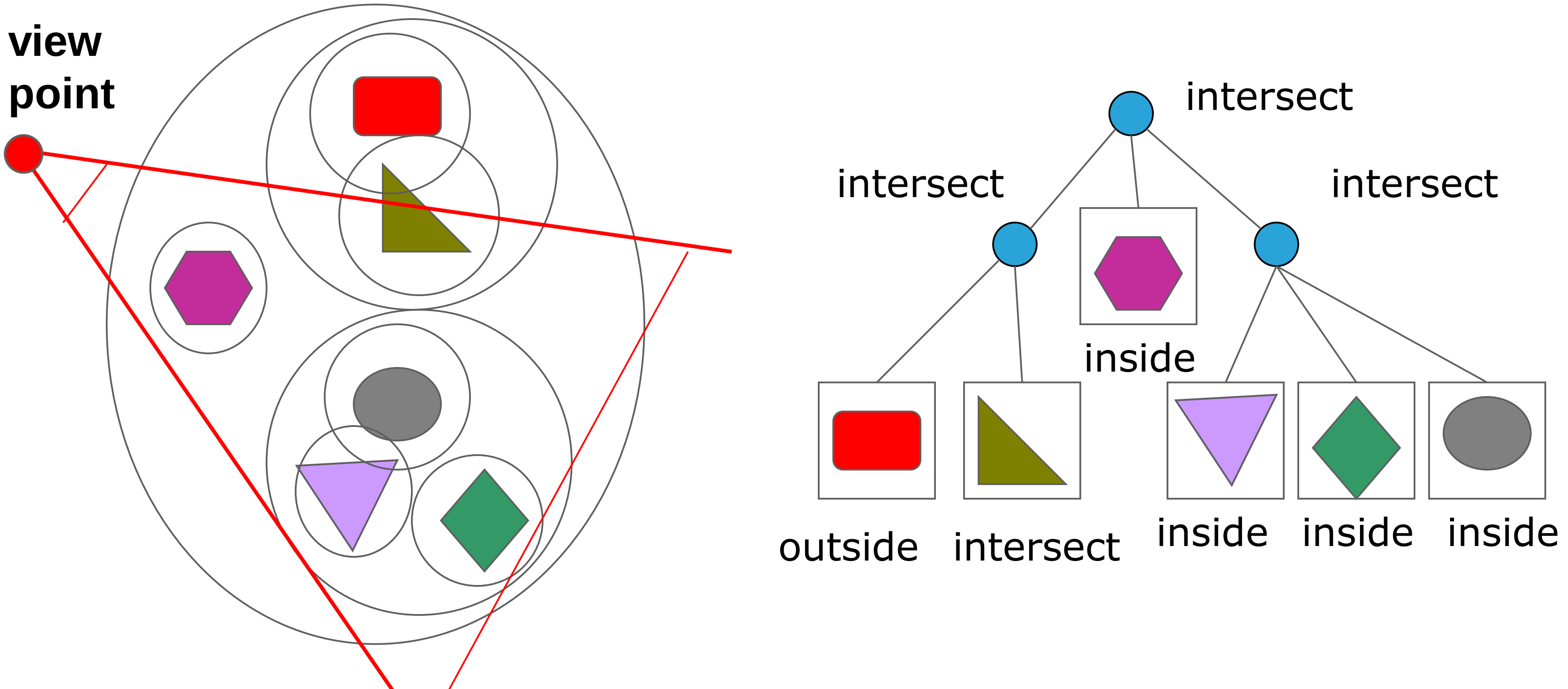
View-frustum culling

- Hierarchy based on bounding volume



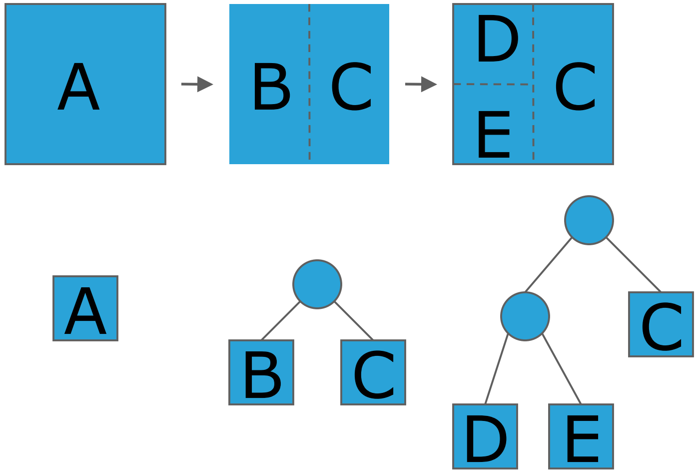
View-Frustum Culling

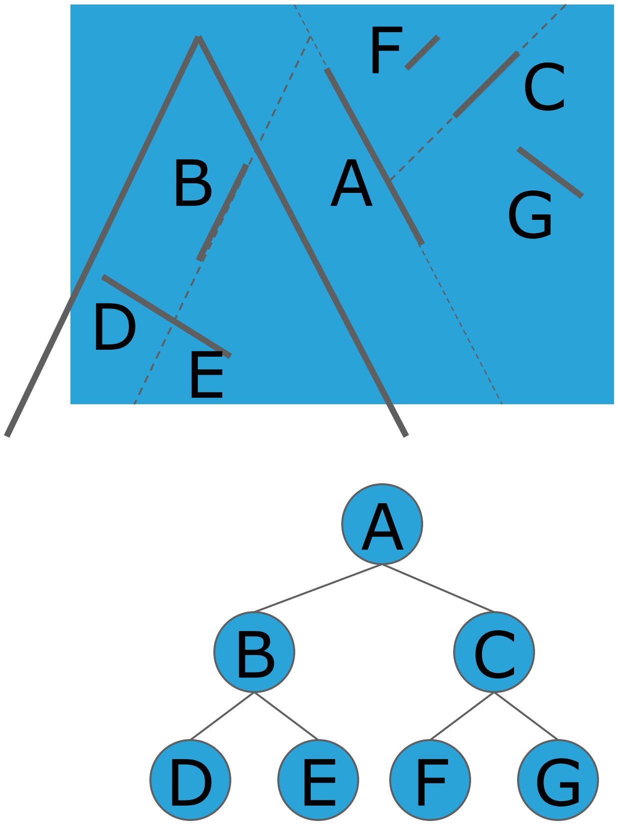
- Hierarchical view-frustum culling based on bounding volume



View-Frustum Culling

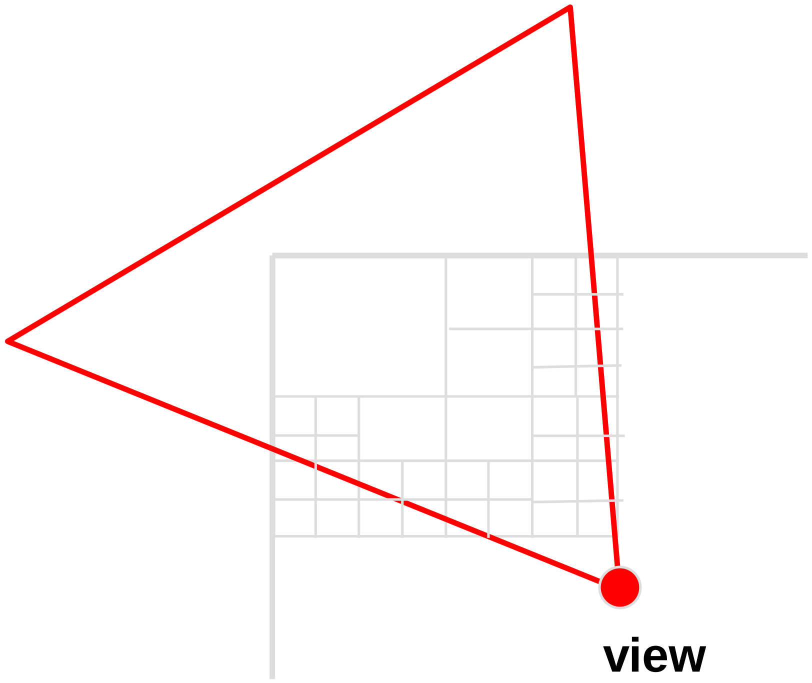
- Hierarchical view-frustum culling using BSP (Binary Space Partitioning) trees





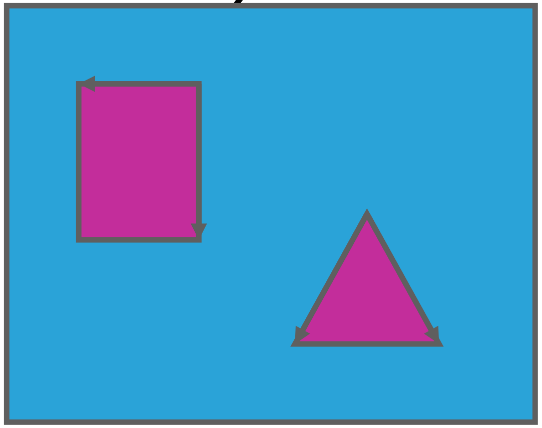
View-Frustum Culling

- Hierarchical view-frustum culling using quadtree (octree)

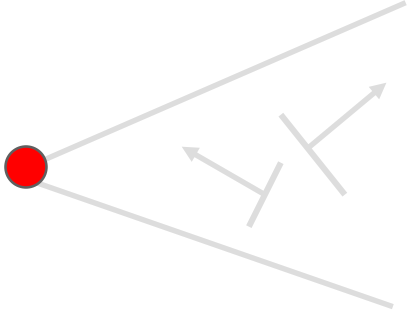


Backface Culling

- Screen space
  - Cross product (only z is needed!)
  - Orientation of a polygon is determined by the vertex order
  - Calculated by hardware



- Eye space
  - Dot product

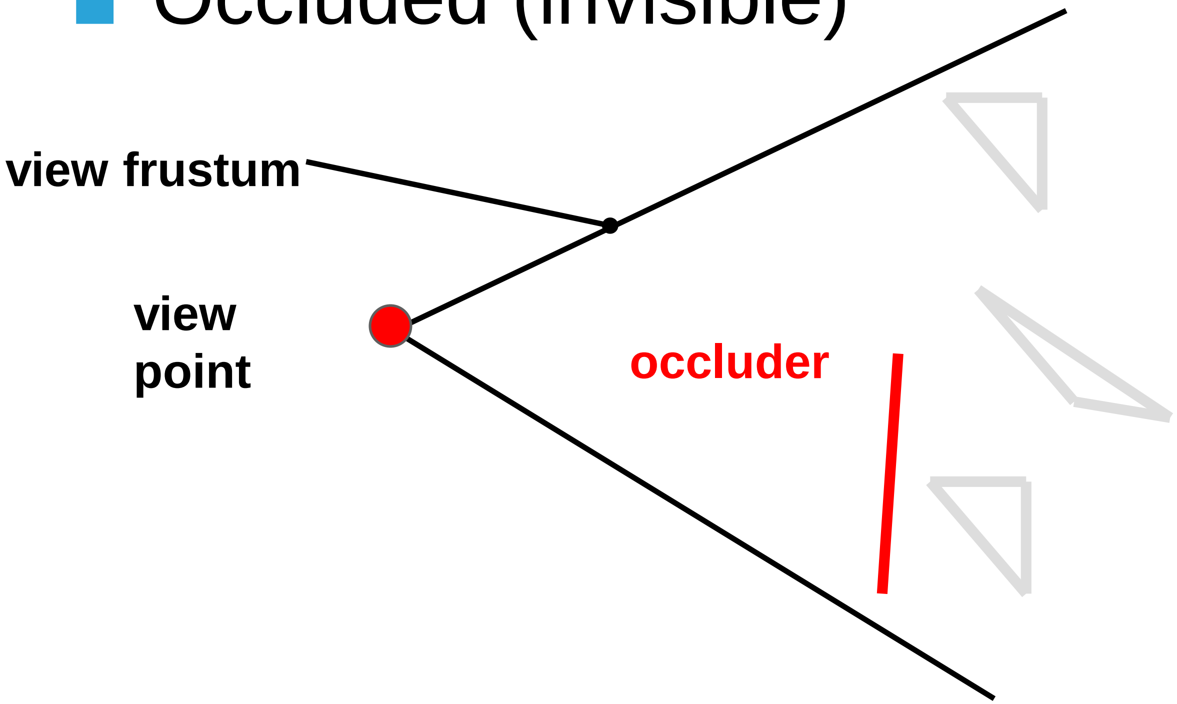


Occlusion Culling / Overview

- General Information
- Occlusion Culling from a point
  - Object Space
  - Image Space
- Occlusion Culling from a region
  - Cells Portals
  - Extended Projection
  - Point Sampling
  - Line Space Visibility

Occlusion Culling

- Possible results:
  - Visible
  - Partially visible
  - Occluded (invisible)



Occlusion Culling

- Calculate PVS = potentially visible set
- Exact hidden surface removal is done by the z-buffer
- PVS can be
  - Aggressive, PVS $\subseteq$ EVS
  - Conservative, PVS $\supseteq$ EVS (preferred)
  - Approximate, PVS ~ EVS
- EVS = exact solution (on a per-object basis)

Occlusion Culling

- Objects (not individual triangles) are organized in a hierarchical data structure (scene data structure SDS)
  - bounding box tree
  - octree, quadtree
  - kd tree
  - bsp tree
  - …

Occlusion Culling (We need:)

- The scene organized in a hierarchical data structure (= SDS).
- A (hierarchical) data structure for the umbra (= UDS)
- A (selected) set of occluders (also stored in the SDS)
  - Sometimes all triangles in the scene can be occluders
  - If not, large polygons close to the viewpoint or viewing region are selected

Occlusion Culling (General Idea)

- Traverse the SDS top-down / front-to-back
- Test each node of the SDS against the UDS for visibility
  - If node invisible → skip node
  - If node visible →
    - Traverse down or
    - mark objects in node visible and insert occluders into UDS (see earlier)

- Note: interleave creating UDS and checking SDS

Occlusion Culling Acceleration

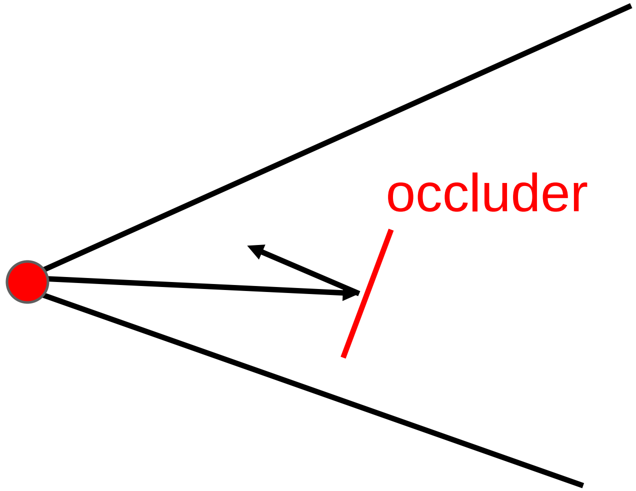
- Ideas to accelerate occlusion culling / overcome implementation problems
  - 2.5D occlusion culling
  - Occluder selection
  - Lazy update of the UDS
  - Approximate front-to-back sorting

Idea: 2.5D Occlusion Culling

- Buildings are occluders, connected to the ground
- → 2.5D visibility algorithms
  - General 3D SDS, occluder is a function f(x,y) = z
    → UDS only 2.5D

Idea: Occluder Selection

- Costly to use all scene polygons as occluders
  - Each occluder requires update to UDS
- Idea: Select only subset of polygons that
  - Are close to the view point (view region)
  - Have a large area
  - Are facing the view point (view region)



Idea: Lazy Update of UDS

- Normally interleave:
  - adding occluders to UDS
  - testing objects of SDS against UDS
- But: UDS can be costly to update or access
  - E.g., z-buffer
- Idea: Lazy update
  - Insert many occluders into UDS at once
  - Or: insert all occluders, then test (as in first part of lecture)

Idea: Approximate front-to-back sorting

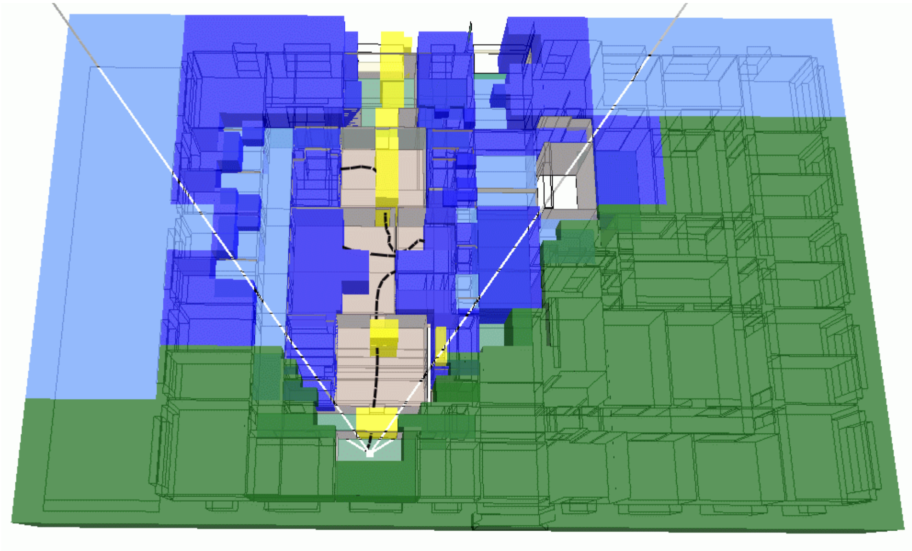
- Exact front-to-back sorting is expensive
- Use approximate front-to-back sorting
  - Usually based on hierarchy
  - Need to be careful not to calculate incorrect occlusion, especially for visibility from a region

Occlusion Culling Algorithms: From Point

- Object space: Occlusion trees
- Image Space: Hierarchical z-Buffer
- Image Space, hardware: Occlusion Queries

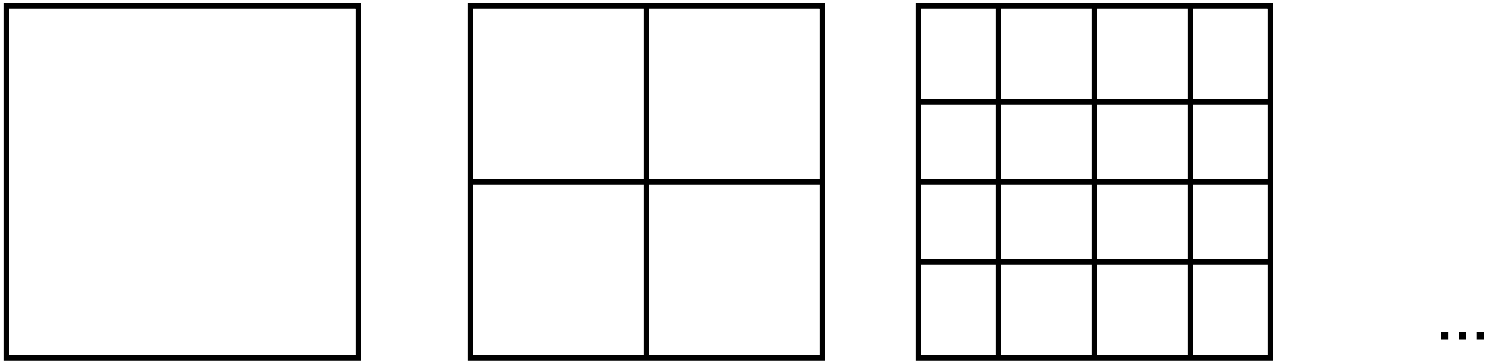
Occlusion Trees

- [Bittner98]
  - SDS = kd tree
  - UDS = BSP tree
- Works fine, all sorts of occluder fusion
- Adding thousands of occluders to the UDS is slow



Hierarchical z-Buffer

- [Greene93]
  - SDS = octree
  - UDS = z-pyramid



Z-Pyramid

- Lowest level: full-resolution Z-buffer
- Higher levels: each pixel represents the maximum depth of the four pixels “underneath” it

Hardware Implementation

- Only 2-3 levels on current hardware
- Only per-fragment culling
  - Works automatically
  - Saves rasterization time
- Per-object culling: occlusion queries
  - Ask whether an object would have been rendered
  - Uses hardware pyramid
  - Problem: latency of query

Hardware Occlusion Queries

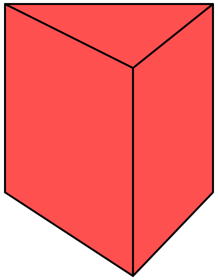
- Extension name: ARB_occlusion_query
- Returns no. of pixels that pass
  - For aggressive occlusion culling
- Provides an interface to issue multiple queries at once before asking for the result of any one
  - Allows hiding latency
  - Do other work in parallel
- Coherent Hierarchical Culling [Bittner04]
  - Exploit temporal coherence to eliminate latency and reduce queries

Occlusion Culling Algorithms: From Region

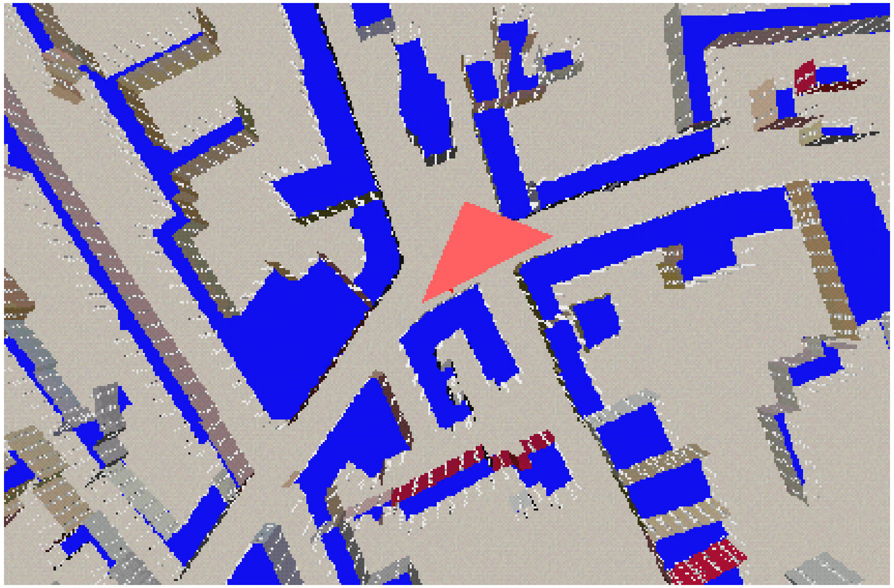
- Special case: Cells and portals
- Image space: Extended Projections
- Point Sampling
- Line Space

Visibility Preprocessing

- Subdivide view space into view cells
- Calculate PVS for each view cell
- Store all PVS on disk

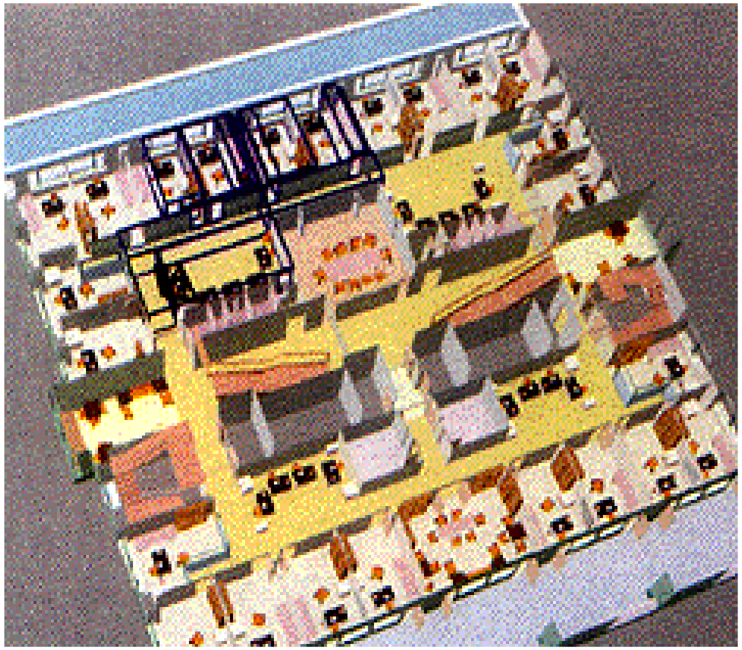


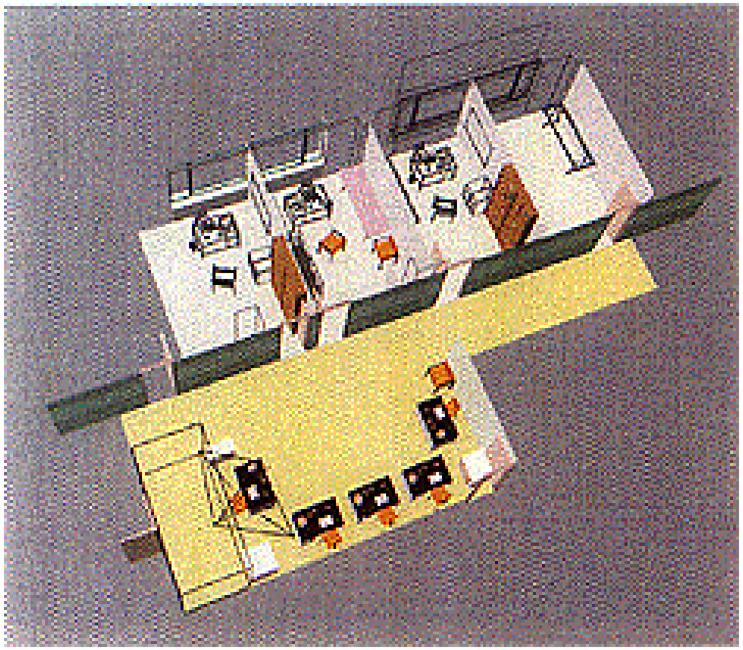
view cell



Cells and Portals

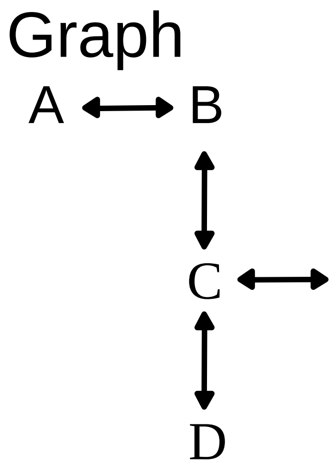
- Architectural walkthroughs
- Structure scene into
  - Cells (mainly rooms)
  - Portals (mainly doors)

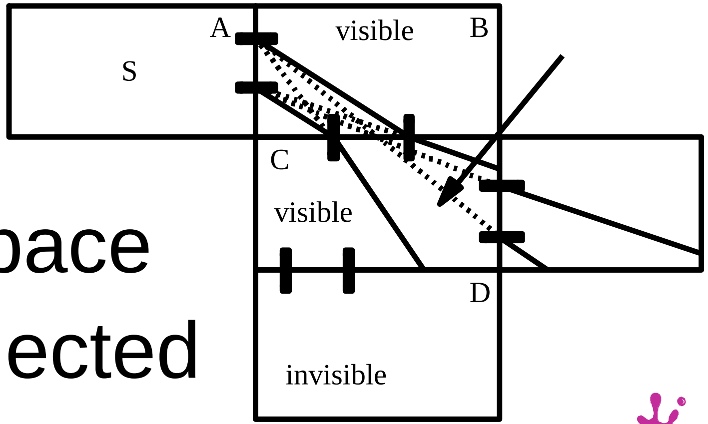




Cells and Portals

- Build adjacency graph
  - Cells = nodes, portals = edges
- Portal sequences
- Preprocess algorithm:
  - Test sightlines through an oriented portal sequence
  - Use depth search in adjacency graph (e.g. linear-programming)
- Online algorithm:
  - Project portals to screen space
  - Intersect with previous projected portals





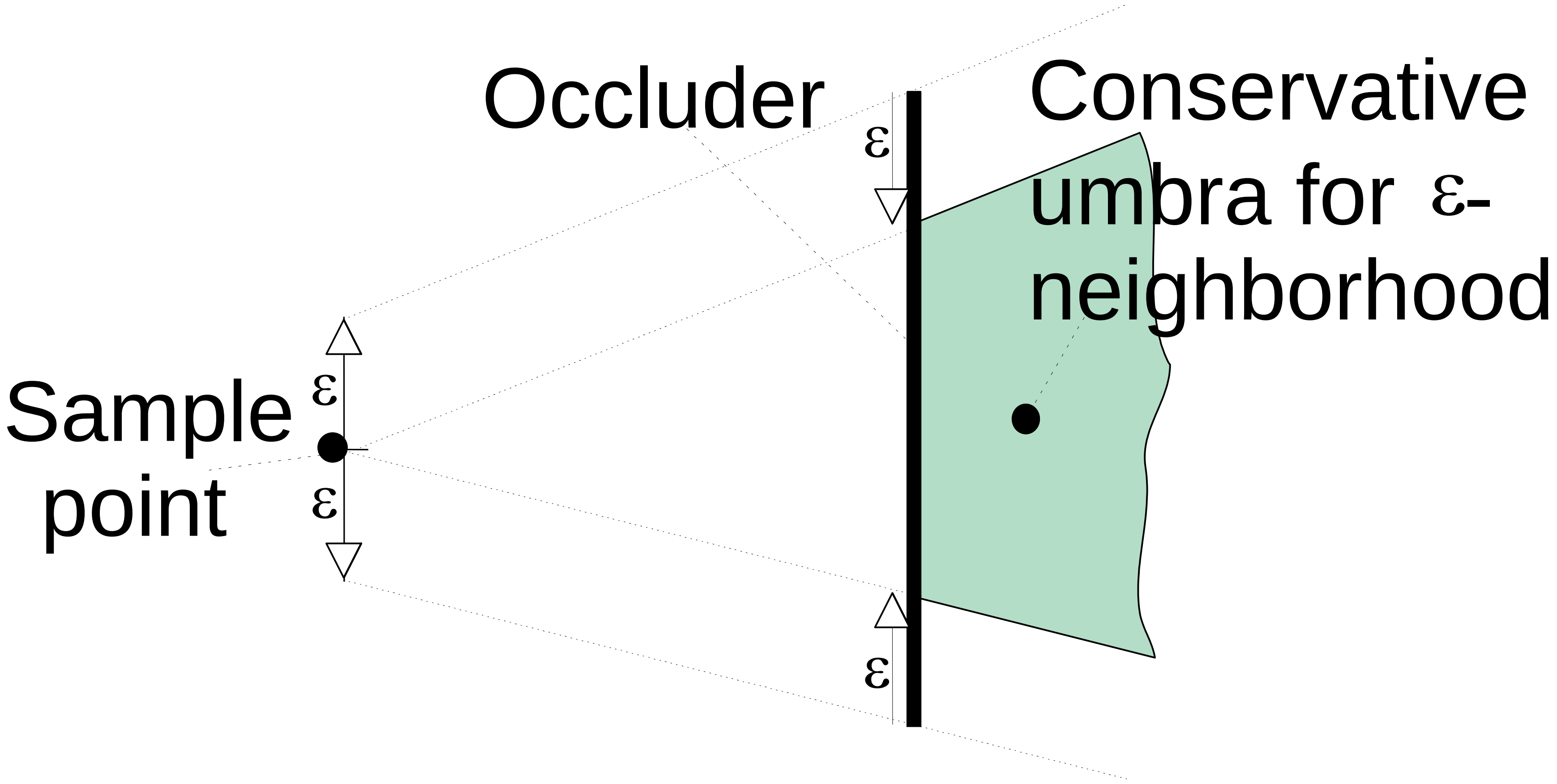
Extended Projections

- [Durand2000]
  - SDS = anything
  - UDS = z-pyramid / z-buffer
- Image space algorithm
- Modifies projection of
  - Occluder (smaller)
  - Occludee (larger)
  - Depending on viewing region

Point Sampling

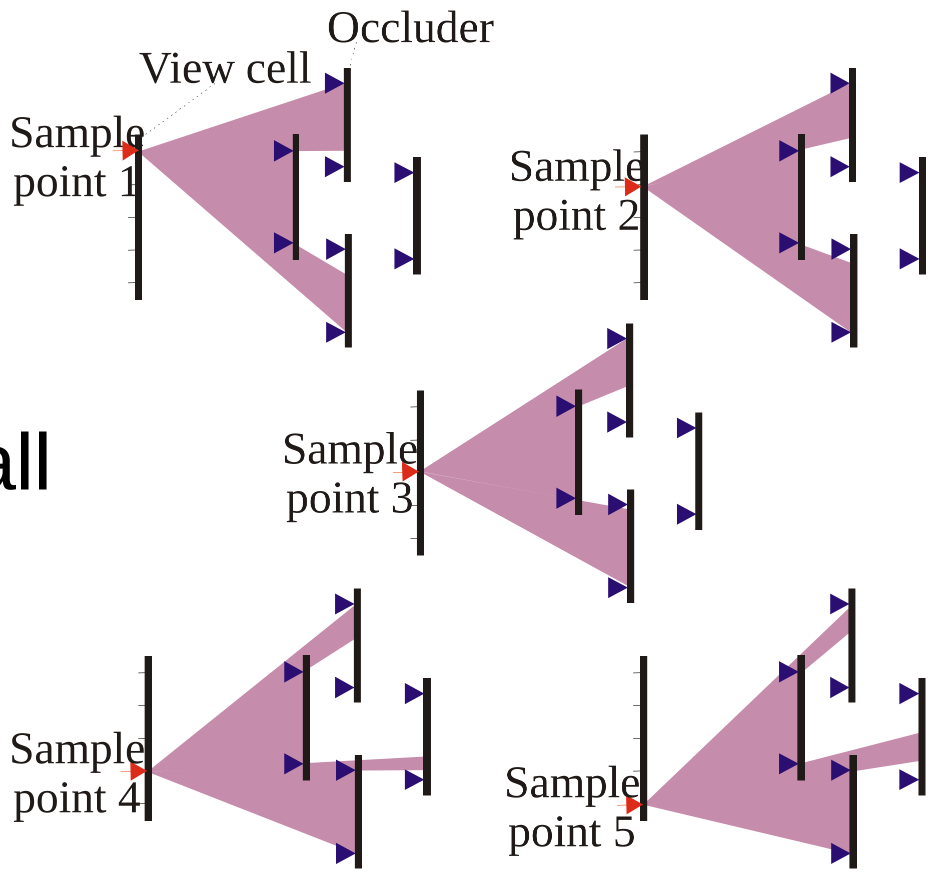
- [Wonka2000]
- Make point sampling possible for conservative occlusion culling for a region

Idea: Shrink Occluders



Algorithm Overview

- Shrink all occluders
- For each view cell
  - For each sample point calculate PVS
  - Calculate union of all PVS



Line Space

- [Bittner02]
  - SDS = kd tree
  - UDS = Line Space BSP tree
  - 3D primary space → 5D line space

Literature

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