Computer Graphics

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http://www.cs.pdx.edu/~fliu/courses/cs447/

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Last time

- Rasterization

Today

- Hidden Surface Removal

Where We Stand

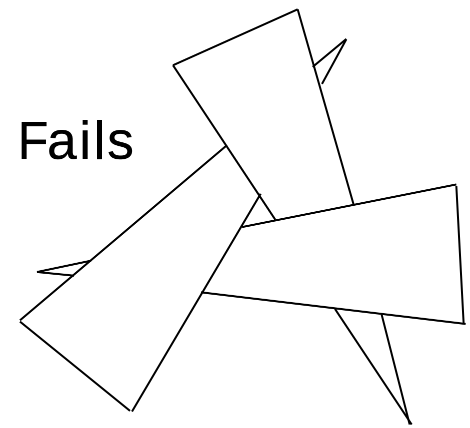
- At this point we know how to:
  - Convert points from local to window coordinates
  - Clip polygons and lines to the view volume
  - Determine which pixels are covered by any given line or polygon
  - Anti-alias
- Next thing:
  - Determine which polygon is in front

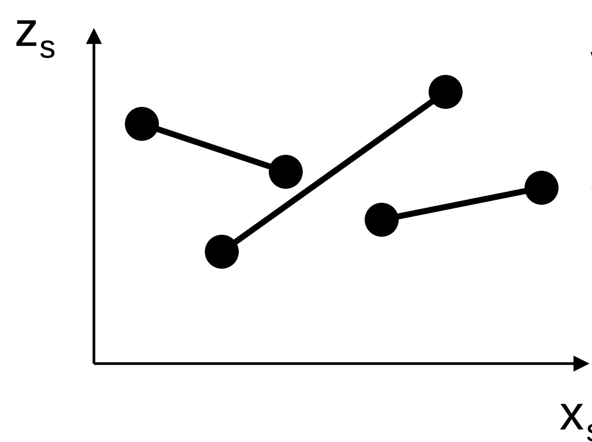
Visibility

- Given a set of polygons, which is visible at each pixel? (in front, etc.). Also called hidden surface removal
- Very large number of different algorithms known. Two main classes:
  - Object precision: computations that operate on primitives
  - Image precision: computations at the pixel level
- All the spaces in the viewing pipeline maintain depth, so we can work in any space
  - World, View and Canonical Screen spaces might be used
  - Depth can be updated on a per-pixel basis as we scan convert polygons or lines
  - Actually, run Bresenham-like algorithm on ***z*** **and** ***w*** **before perspective divide**

Painters Algorithm

- Algorithm:
  - Choose an order for the polygons based on some choice (e.g. depth of a point on the polygon)
  - Render the polygons in that order, deepest one first
- This renders nearer polygons over further
- Difficulty:
  - doesn't work in this form for most geometries - need at least better ways of determining ordering





Which point for choosing ordering?

The Z-buffer (1) (Image Precision)

- For each pixel on screen, have at least two buffers
  - Color buffer stores the current color of each pixel
    - The thing to ultimately display
  - Z-buffer stores at each pixel the depth of the **nearest thing seen so far**
    - Also called the depth buffer
- Initialize this buffer to a value corresponding to the furthest point
- As a polygon is filled in, compute the depth value of each pixel that is to be filled
  - if depth < z-buffer depth, fill in pixel color and new depth
  - else disregard

The Z-buffer (2)

- Advantages:
  - Simple and now ubiquitous in hardware
    - A z-buffer is part of what makes a graphics card "3D"
  - Computing the required depth values is simple
- Disadvantages:
  - Over-renders – rasterizes polygons even if they are not visible
  - Depth quantization errors can be annoying
  - Can't easily do transparency or filter-based anti-aliasing (Requires keeping information about partially covered polygons)

OpenGL Depth Buffer

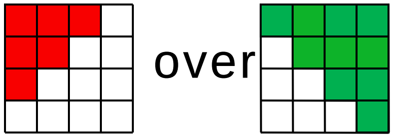
- OpenGL defines a depth buffer as its visibility algorithm
- The enable depth testing: `glEnable(GL_DEPTH_TEST)`
- To clear the depth buffer: `glClear(GL_DEPTH_BUFFER_BIT)`
  - To clear color and depth: `glClear(GL_COLOR_BUFFER_BIT|GL_DEPTH_BUFFER_BIT)`
- The number of bits used for the depth values can be specified (windowing system dependent, and hardware may impose limits based on available memory)
- The comparison function can be specified: `glDepthFunc(…)`
  - Sometimes want to draw furthest thing, or equal to depth in buffer

The A-buffer (Image Precision)

- Handles transparent surfaces and filter anti-aliasing
- At each pixel, maintain a pointer to a **list** of polygons sorted by depth, and a sub-pixel coverage mask for each polygon
  - Coverage mask: Matrix of bits saying which parts of the pixel are covered
- Algorithm: Drawing pass (do not directly display the result)
  - if polygon is opaque and covers pixel, insert into list, removing all polygons farther away
  - if polygon is transparent or only partially covers pixel, insert into list, but don't remove farther polygons

The A-buffer (2)

- Algorithm: Rendering pass
  - At each pixel, traverse buffer using polygon colors and coverage masks to composite:

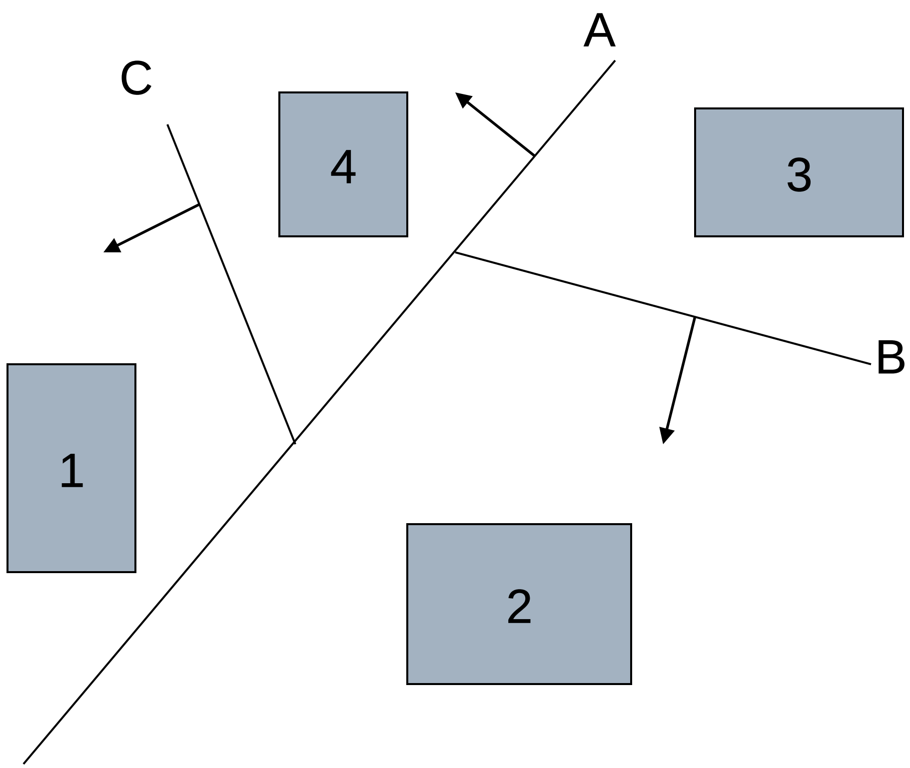


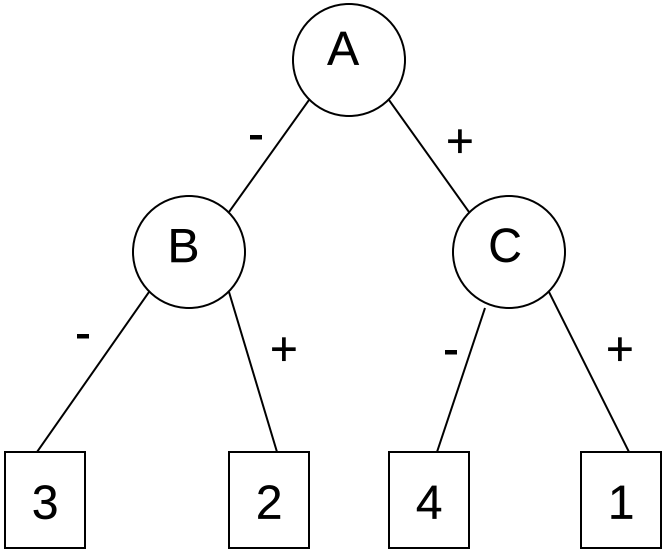
- Advantage:
  - Can do more than Z-buffer
  - Coverage mask idea can be used in other visibility algorithms
- Disadvantages:
  - Not in hardware, and slow in software
  - Still at heart a z-buffer: Over-rendering and depth quantization problems
- But, used in high quality rendering tools

BSP-Trees (Object Precision)

- Construct a binary space partition tree
  - Tree gives a rendering order
  - A list-priority algorithm
- Tree splits 3D world with planes
  - The world is broken into convex cells
  - Each cell is the intersection of all the half-spaces of splitting planes on tree path to the cell
- Also used to model the shape of objects, and in other visibility algorithms

BSP-Tree Example



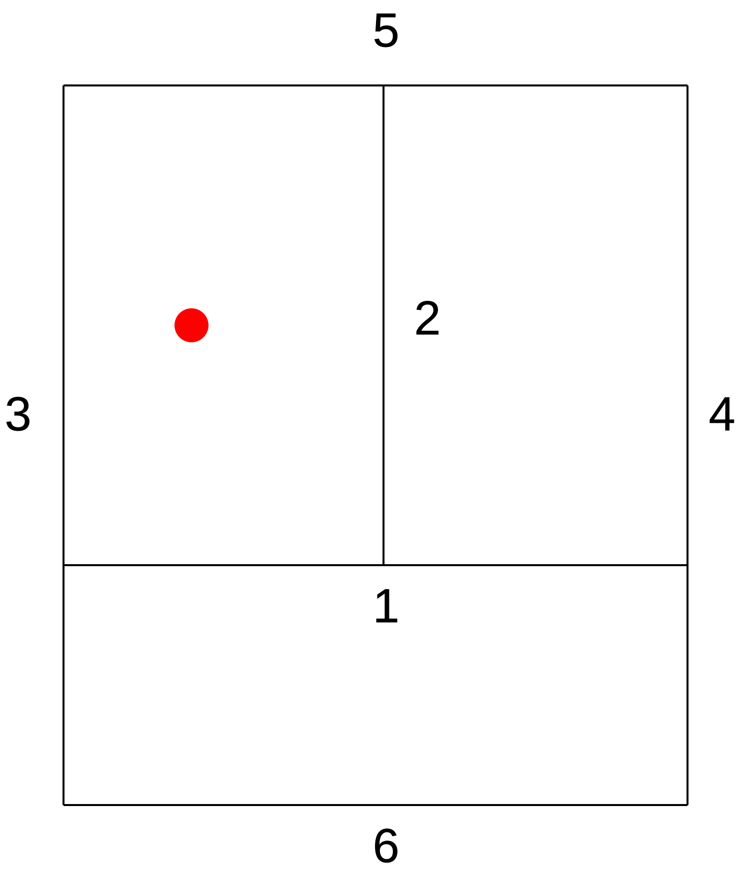


Building BSP-Trees

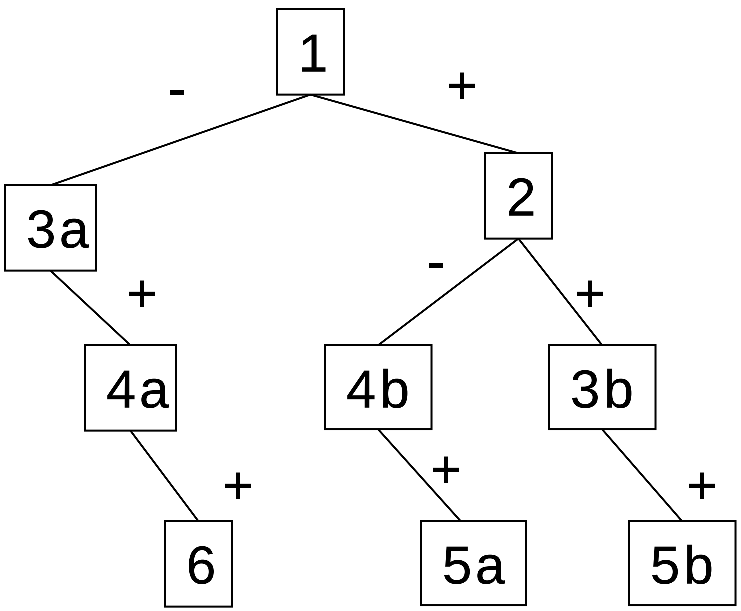
- Choose polygon (arbitrary)
- Split its cell using plane on which polygon lies
  - May have to chop polygons in two (Clipping!)
- Continue until each cell contains only one polygon fragment
- Splitting planes could be chosen in other ways, but there is no efficient optimal algorithm for building BSP trees
  - Optimal means minimum number of polygon fragments in a balanced tree

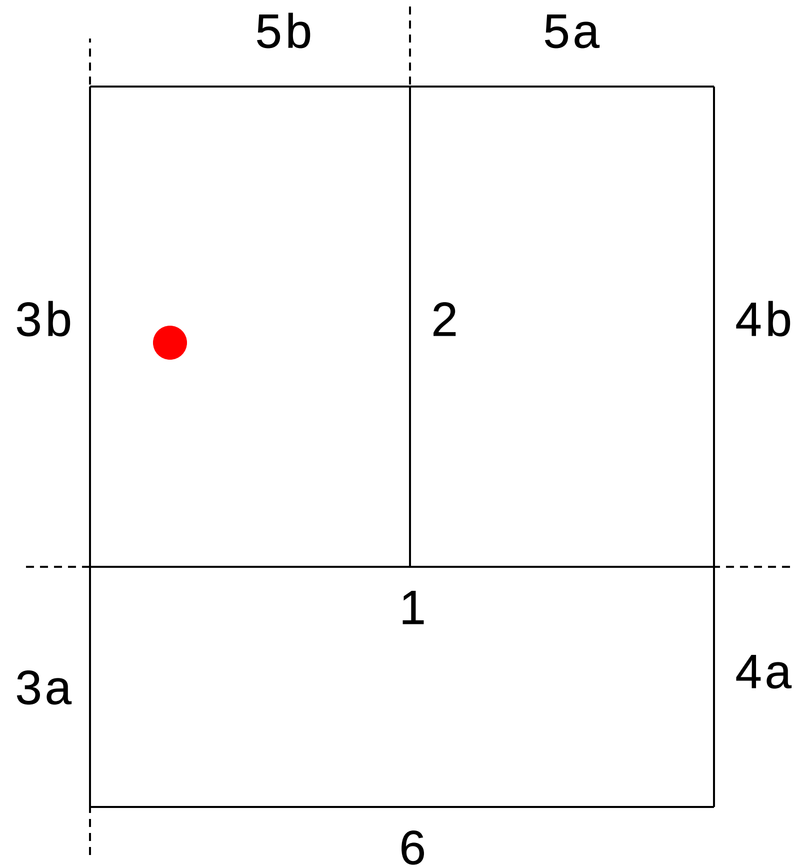
Building Example

- We will build a BSP tree, in 2D, for a 3 room building
  - Ignoring doors
- Splitting edge order is shown
  - "Back" side of edge is side with the number



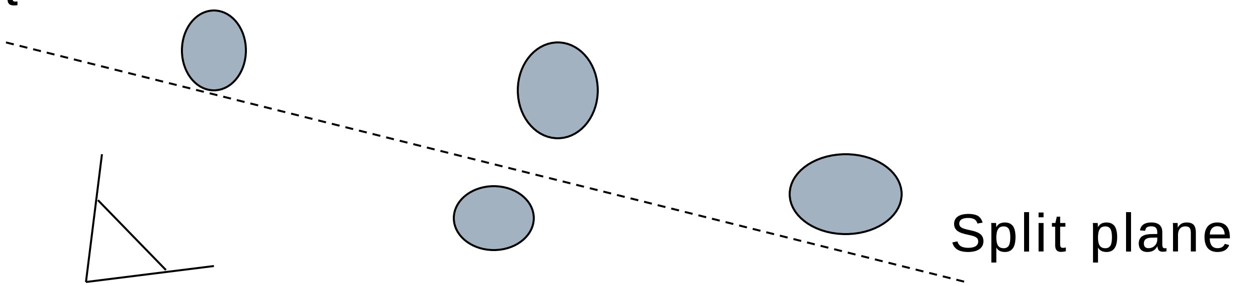
Building Example (Done)





Using a BSP-Tree

- Observation: Things on the opposite side of a splitting plane from the viewpoint cannot obscure things on the same side as the viewpoint

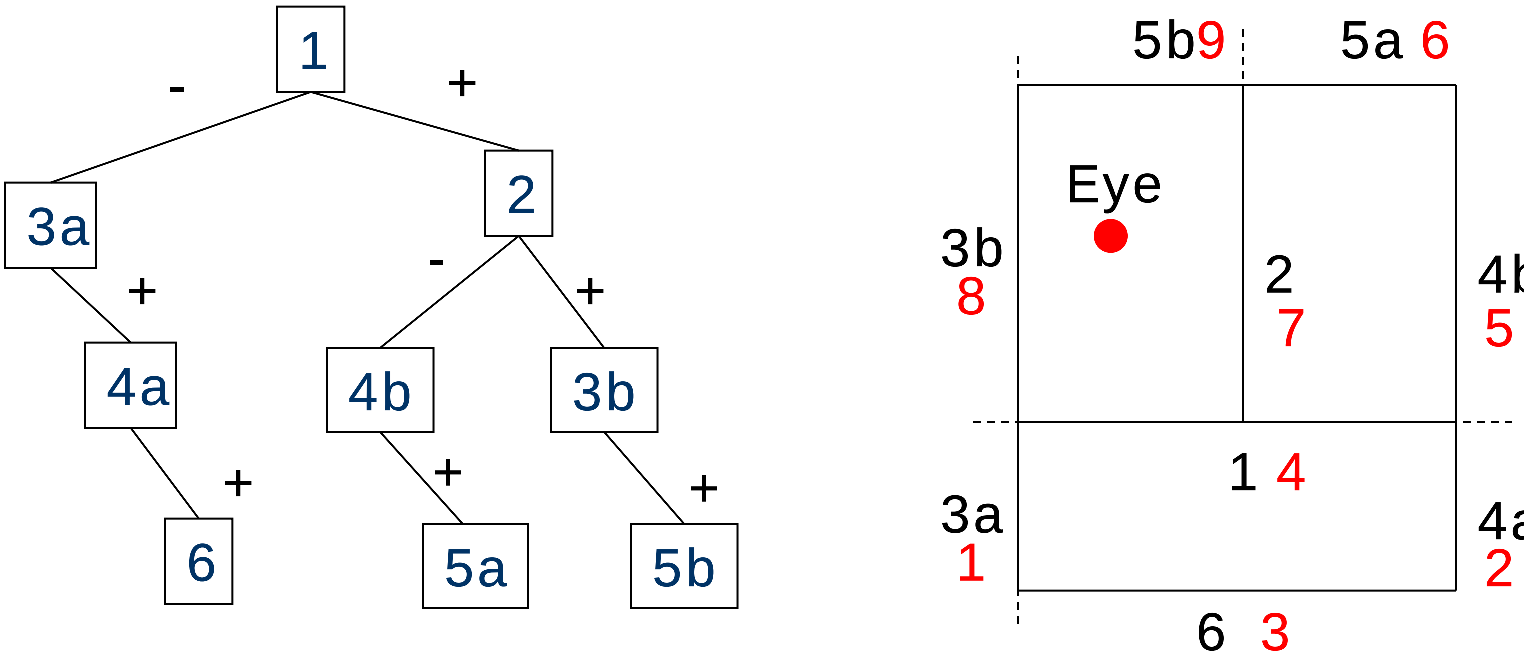


- A statement about rays – a ray must hit something on this side of the split plane before it hits the split plane and before it hits anything on the back side
- NOT a statement about distance – things on the far side of the plane can be closer than things on the near side
  - Gives a *relative* ordering of the polygons, not absolute in terms of depth or any other quantity

BSP-Tree Rendering

- Observation: Things on the opposite side of a splitting plane from the viewpoint cannot obscure things on the same side as the viewpoint
- Rendering algorithm is recursive descent of the BSP Tree
- At each node (for back to front rendering):
  - Recurse down the side of the sub-tree that does not contain the viewpoint
    - Test viewpoint against the split plane to decide which tree
  - Draw the polygon in the splitting plane
    - Paint over whatever has already been drawn
  - Recurse down the side of the tree containing the viewpoint

Rendering Example



Back-to-front rendering order is
3a,4a,6,1,4b,5a,2,3b,5b

BSP-Tree Rendering (2)

- Advantages:
  - One tree works for any viewing point
  - Filter anti-aliasing and transparency work
    - Have back to front ordering for compositing
- Disadvantages:
  - Can be many small pieces of polygon
  - Over-rendering

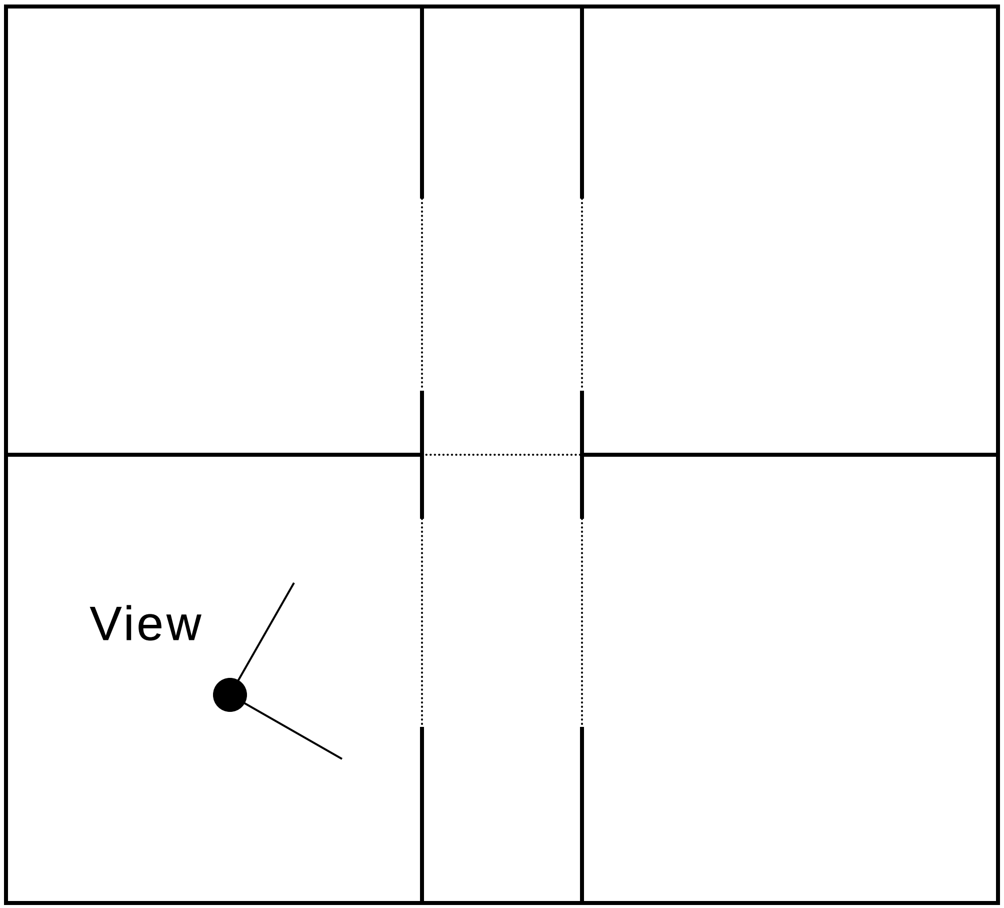
Exact Visibility

- An *exact visibility* algorithm tells you what is visible and only what is visible
  - No over-rendering
- Difficult to achieve efficiently in practice
  - Small detail objects in an environment make it particularly difficult
- But, in mazes and other simple environments, exact visibility is extremely efficient

Cells and Portals

- Assume the world can be broken into *cells*
  - Simple shapes
  - Rooms in a building, for instance
- Define *portals* to be the transparent boundaries between cells
  - Doorways between rooms, windows, etc
- In a world like this, can determine exactly which parts of which rooms are visible
  - Then render visible rooms plus contents

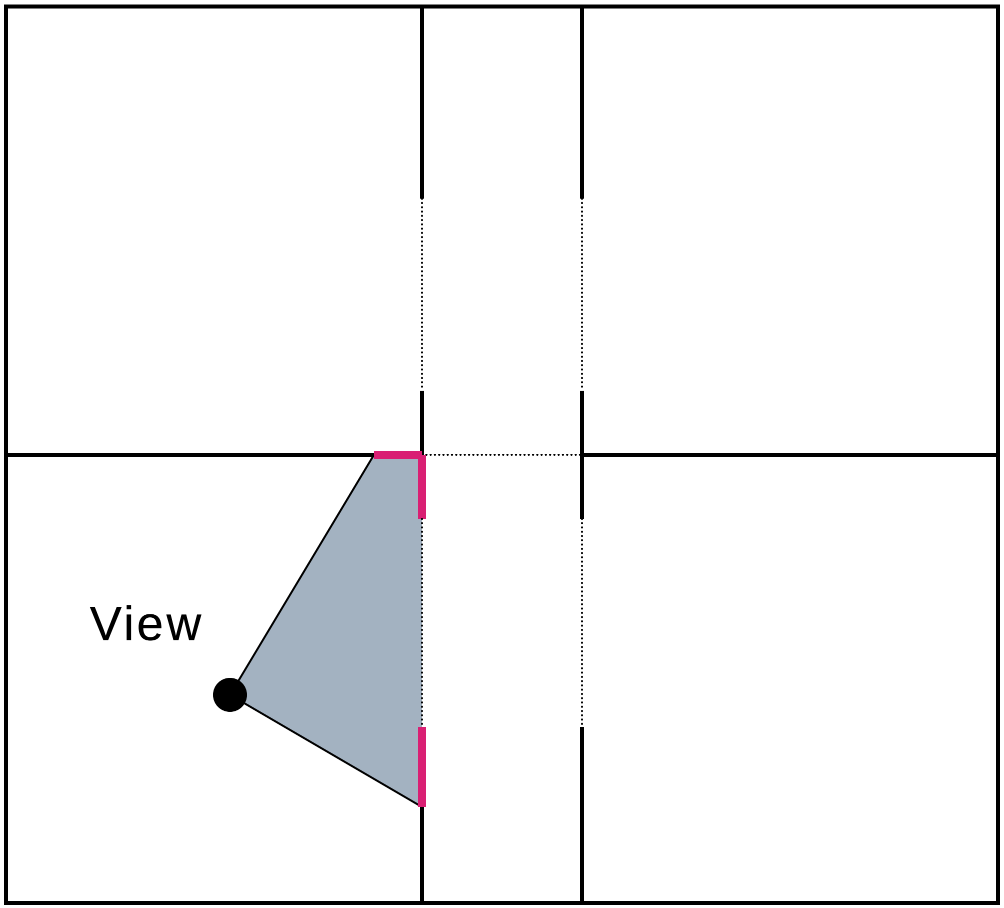
Cell-Portal Example (1)



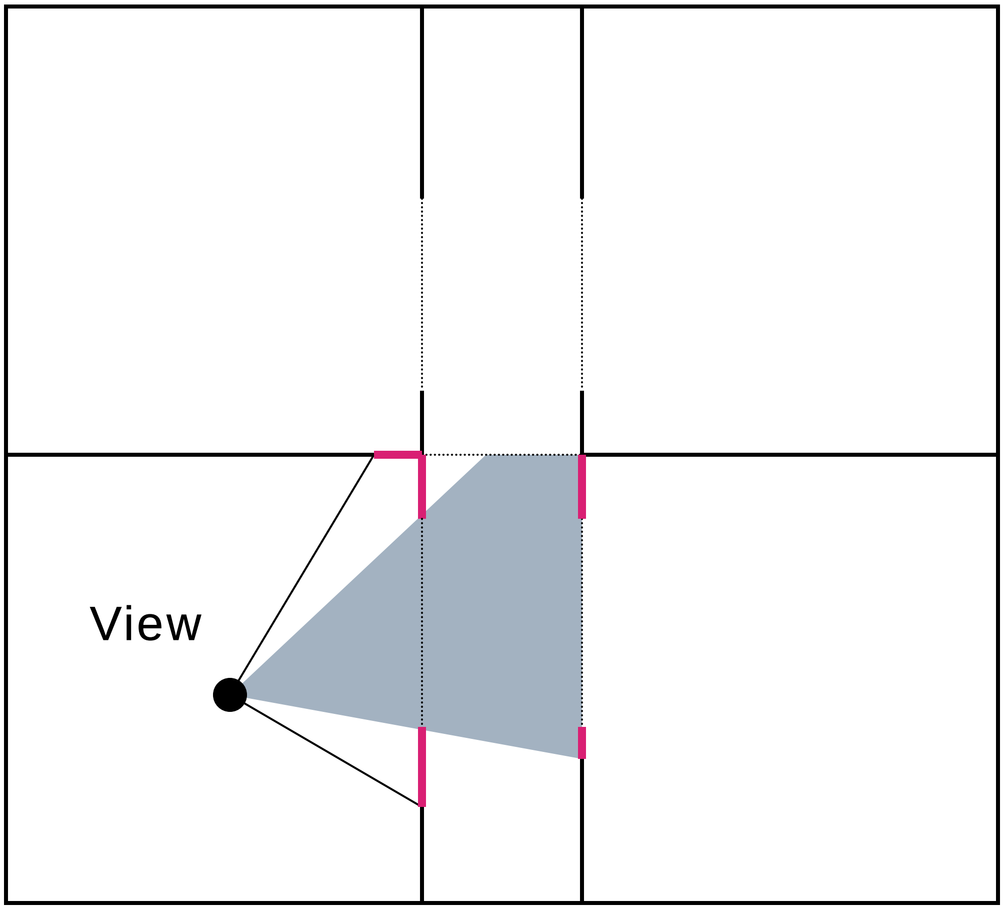
Cell and Portal Visibility

- Start in the cell containing the viewer, with the full viewing frustum
- Render the walls of that room and its contents
- Recursively clip the viewing frustum to each portal out of the cell, and call the algorithm on the cell beyond the portal

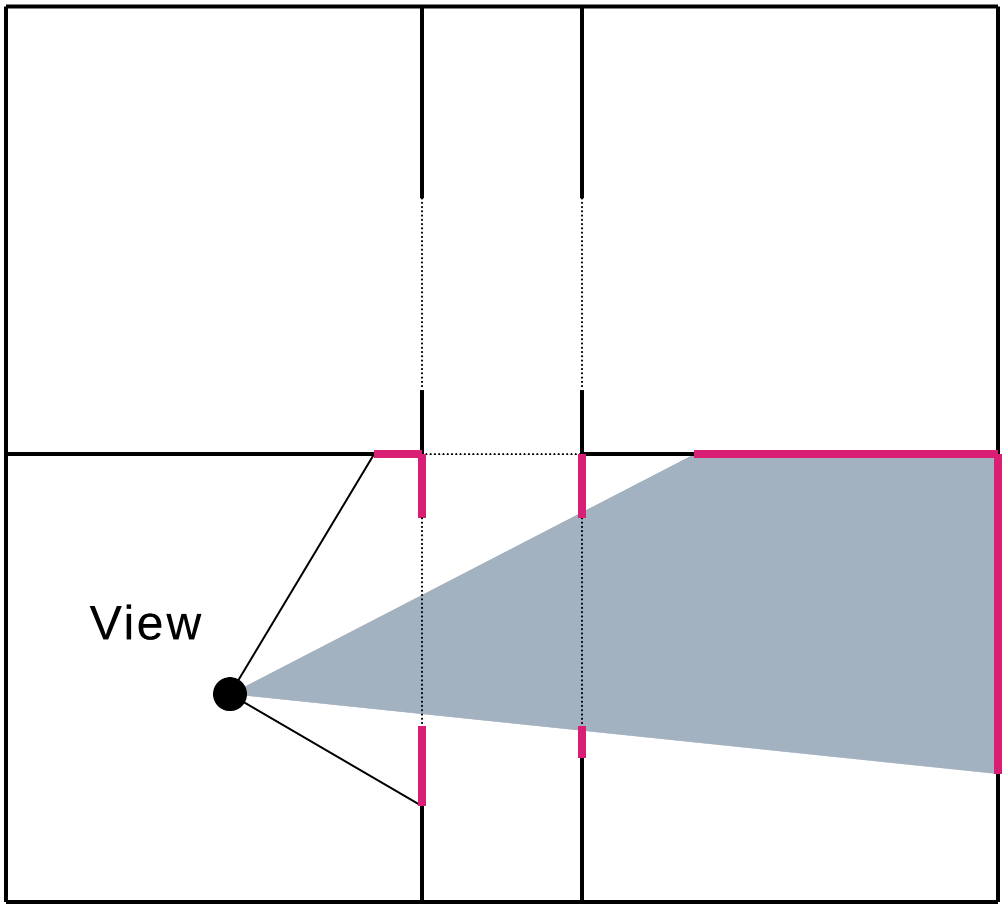
Cell-Portal Example (2)



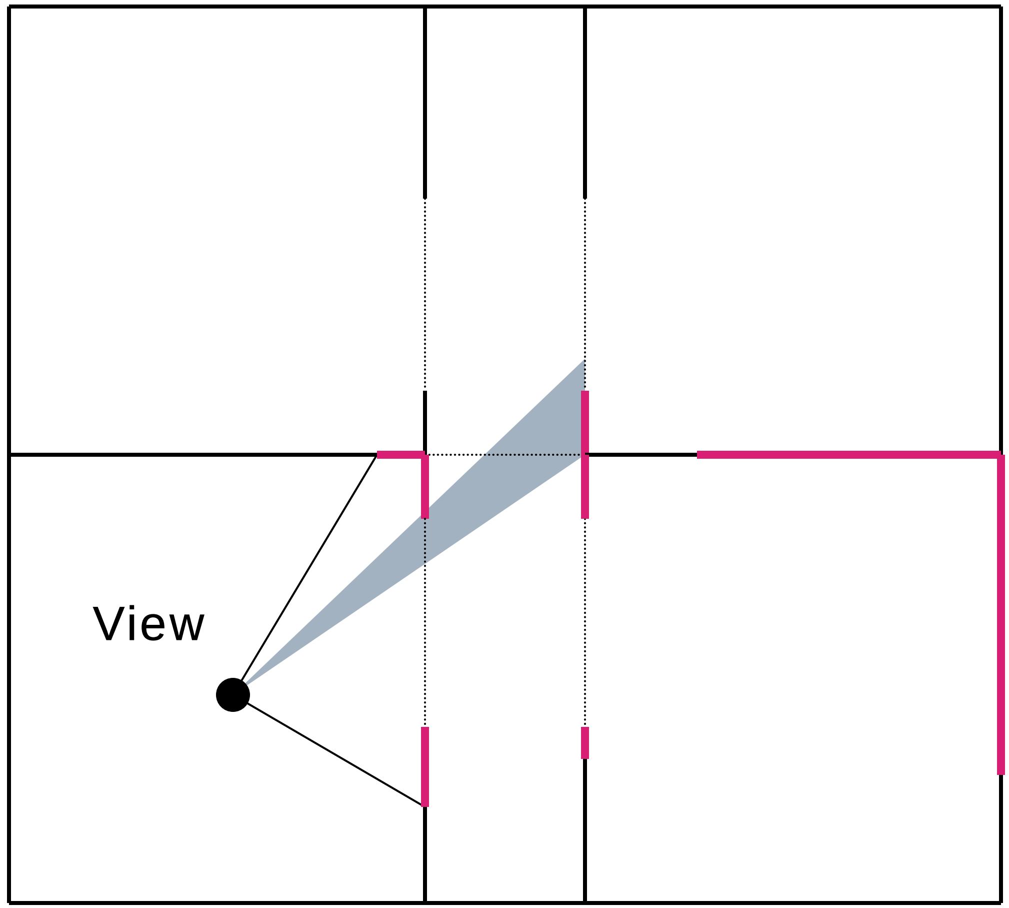
Cell-Portal Example (3)



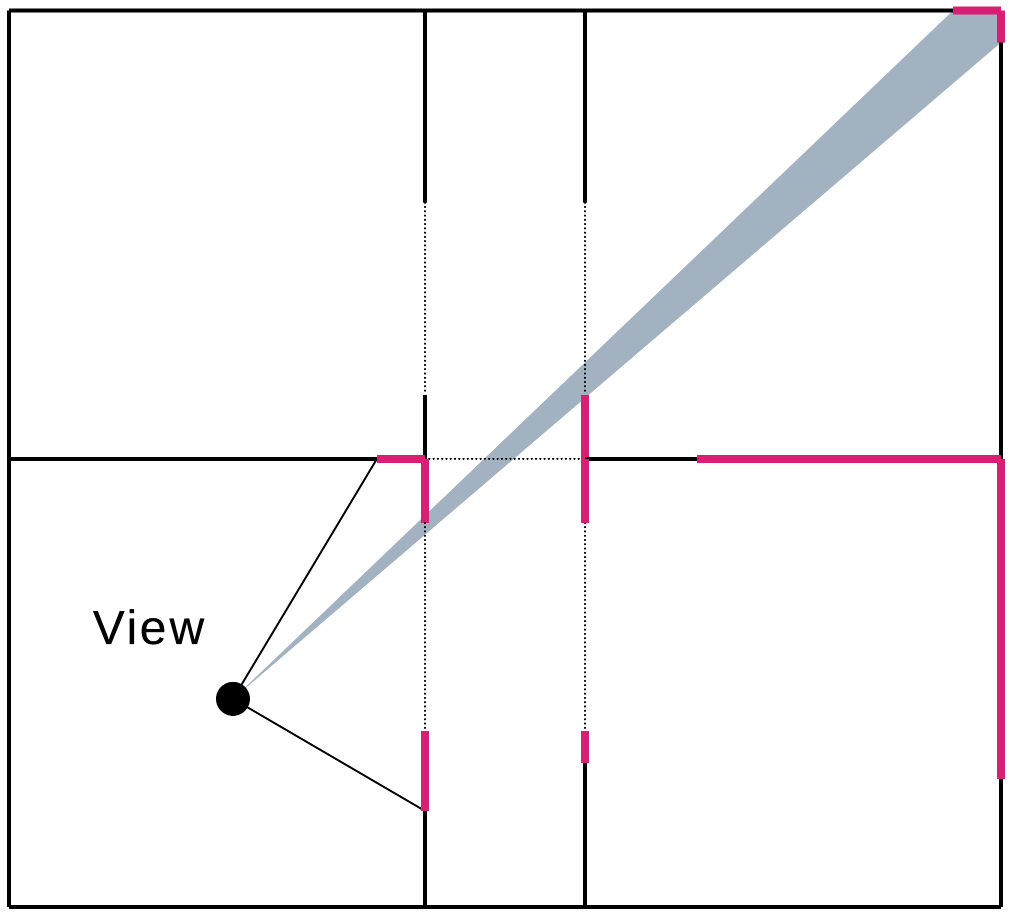
Cell-Portal Example (4)



Cell-Portal Example (5)



Cell-Portal Example (6)



Next Time

- Mid-term
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