Introduction to Computer Graphics
8. Hidden Surface Removal & Culling

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Textbook: E.Angel, D. Shreiner Interactive Computer Graphics, 6th Ed., Pearson
Ref: D.D. Hearn, M. P. Baker, W. Carithers, Computer Graphics with OpenGL, 4th Ed., Pearson

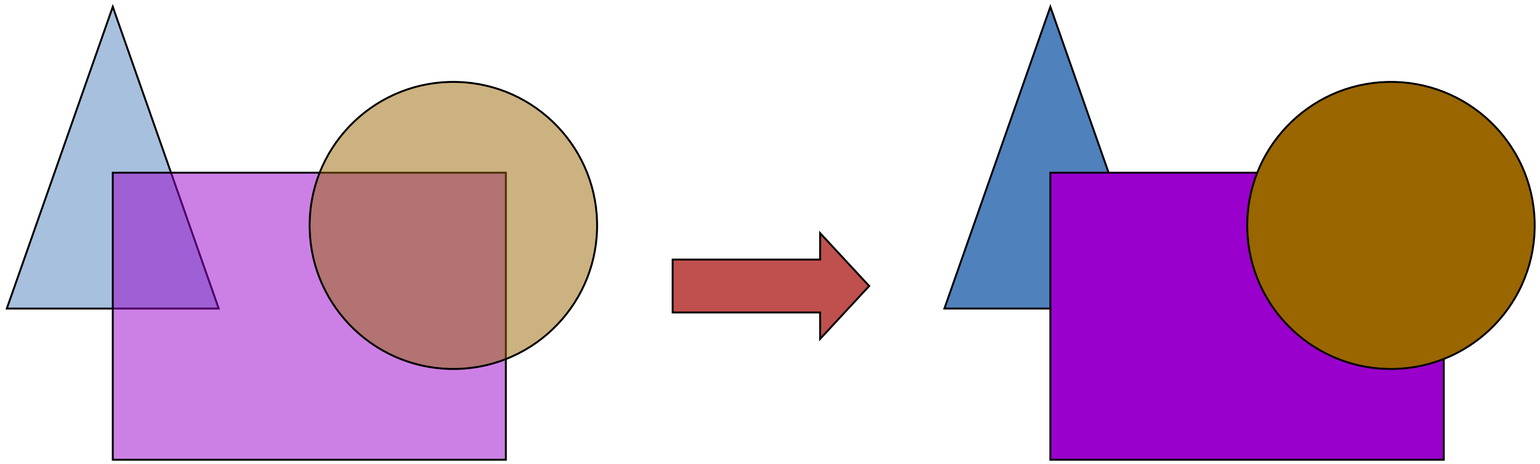
Intended Learning Outcomes

- On completion of this chapter, a student will be able to:
  - **Identify** hidden surfaces and **state** why they are concerned graphics rendering.
  - **Describe** the primary hidden surface removal methods.
  - **Compare** the object-space and image space approaches.
  - **Discuss** where to apply hidden surface removal methods.

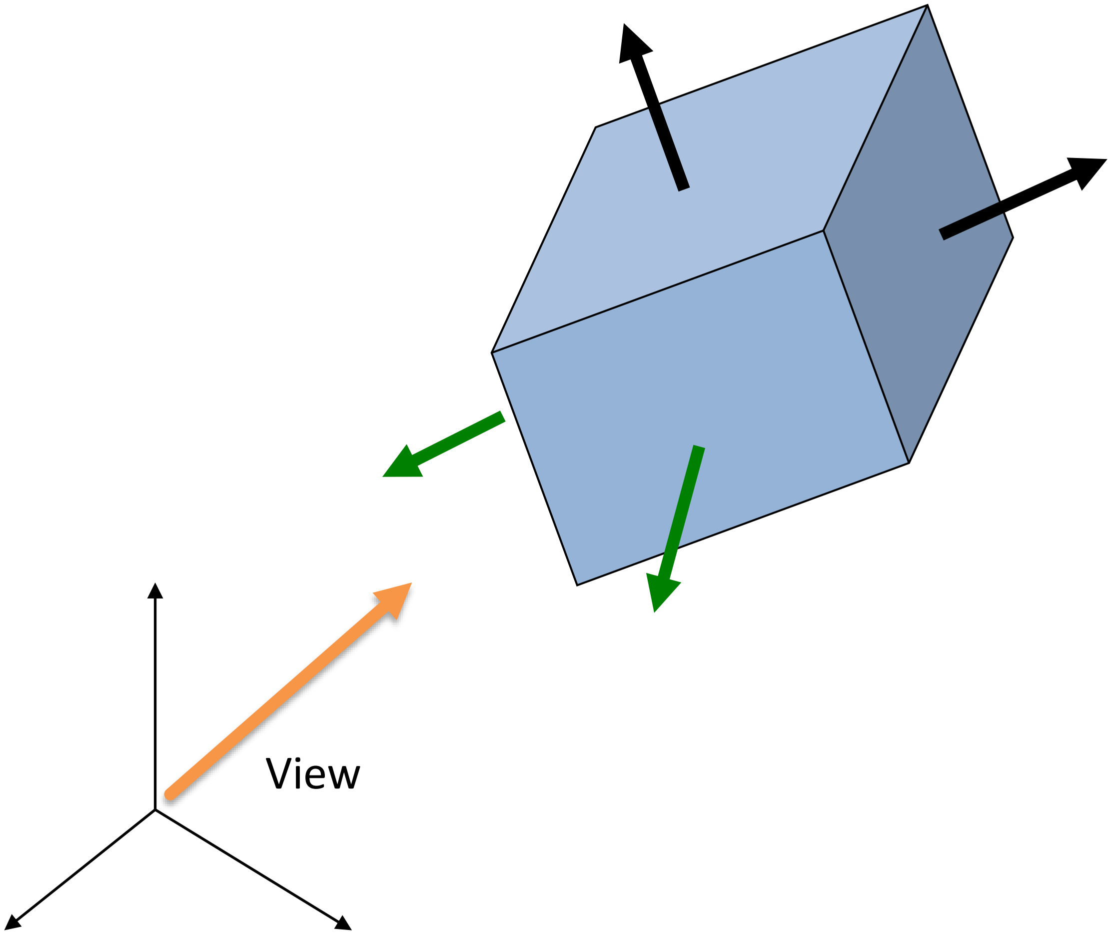
Objectives

- For a 3D wireframe viewer, we can apply viewing transformation and draw the line segments between projected point pairs.

- To fill projected polygons, we have to remove "hidden surfaces".



Back-face Removal (Culling)

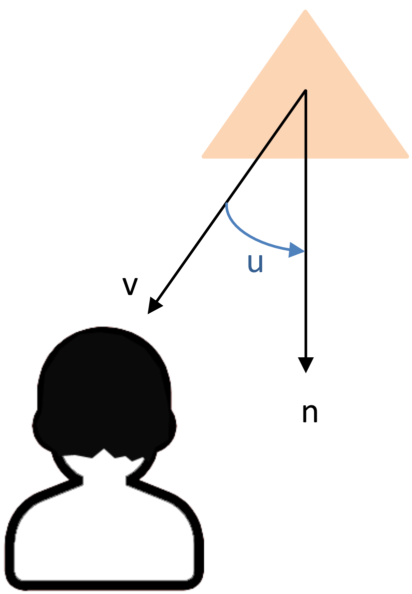


Back-face Removal (Culling)

- A face is visible iff $90 \geq \theta \geq -90$ equivalently $\cos\theta \geq 0$ or $\boldsymbol{v} \bullet \boldsymbol{n} \geq 0$

- When $v = (0\ 0\ 1\ 0)^T$, $n = (a, b, c, 0)^T$, we only need to test the sign of c.

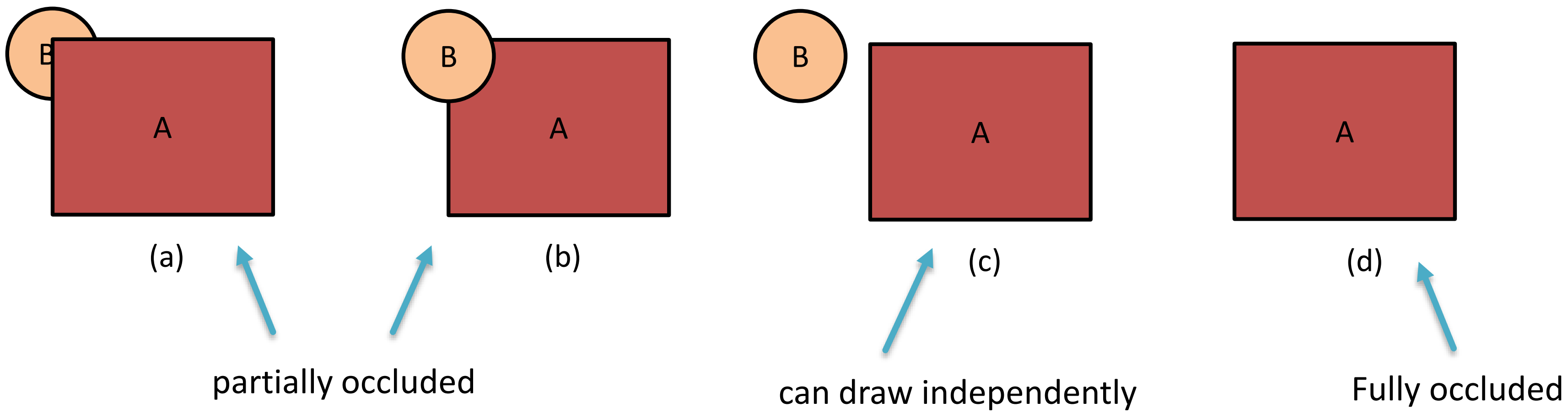
- We can enable Back-face culling in OpenGL, but it may not work correctly if we have nonconvex objects



Hidden Surface Removal

- Object-space approach: use pairwise testing between polygons (objects)

- Worst case complexity O(n^2) for n polygons

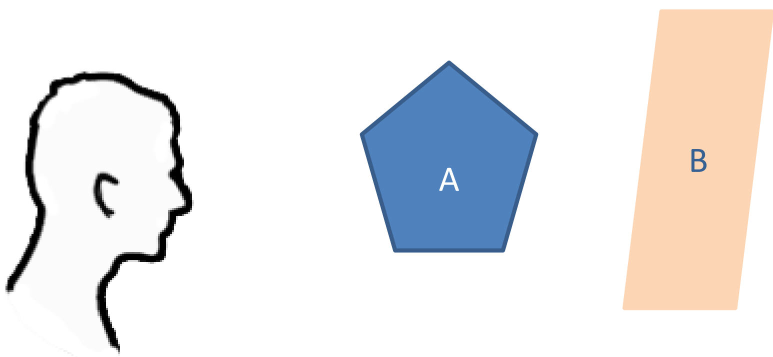


Take a look at “2D” cases

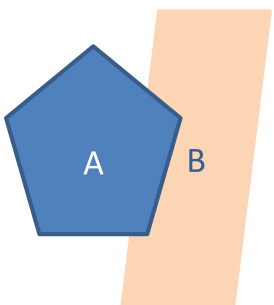
- How to hide regions behind the foreground characters?

Painter's Algorithm

- Render polygons in a back to front order so that polygons behind others are simply painted over



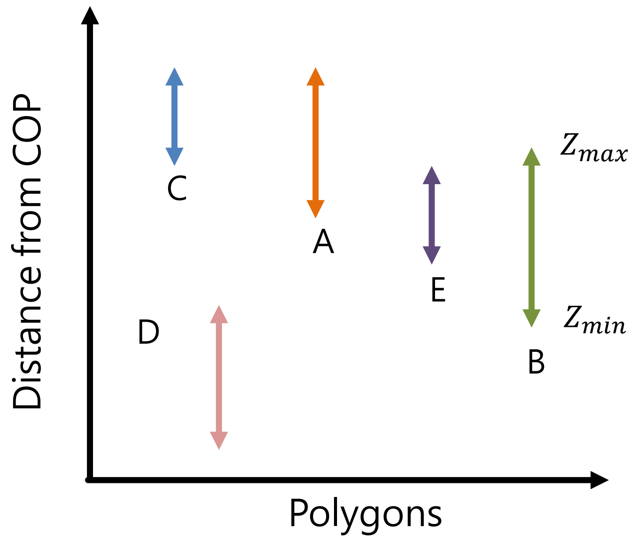
B behind A as seen by the viewer



Fill B then A

Depth Sort

- Requires ordering polygons first
  - O(n log n) calculation for ordering
  - Not every polygon is either in front or behind all other polygons
- Order polygons and deal with easy cases first, harder later

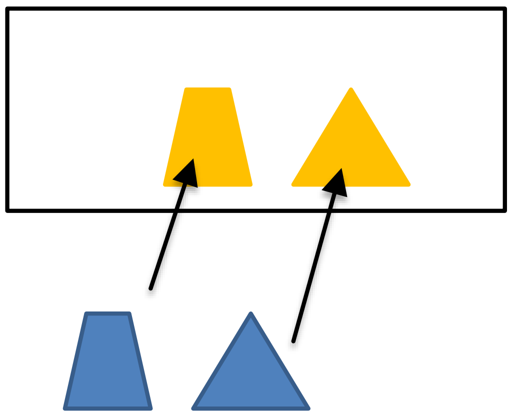


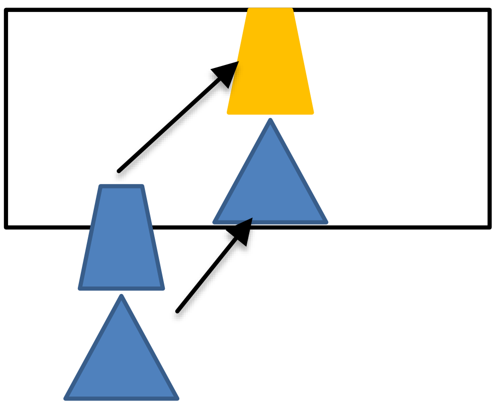
How about "3D" cases

- Is the painter's algorithm applicable to general 3D cases?

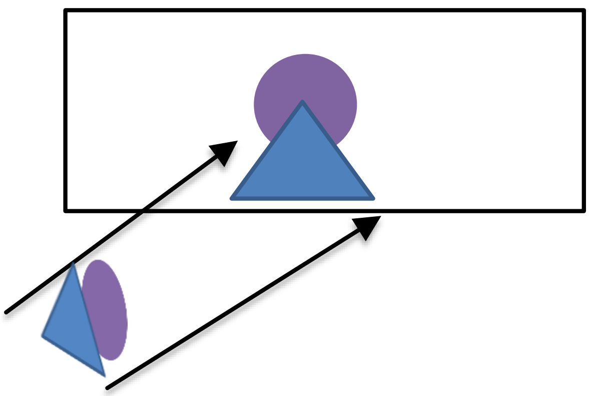
Easy Cases

- A polygon lies behind all other polygons
  - Can render
- Polygons overlap in z but not in either x or y
  - Can render independently

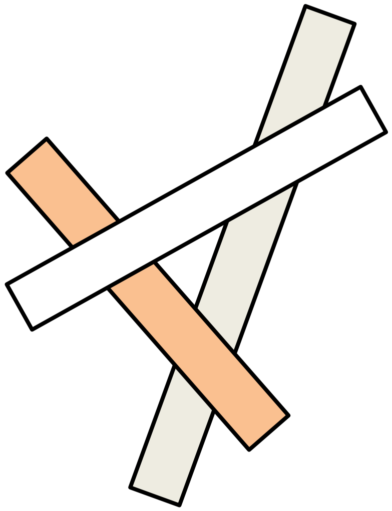




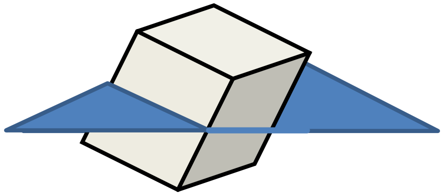
Difficult Cases



Overlap in all x, y, z directions but one is fully on one side of the other



cyclic overlap

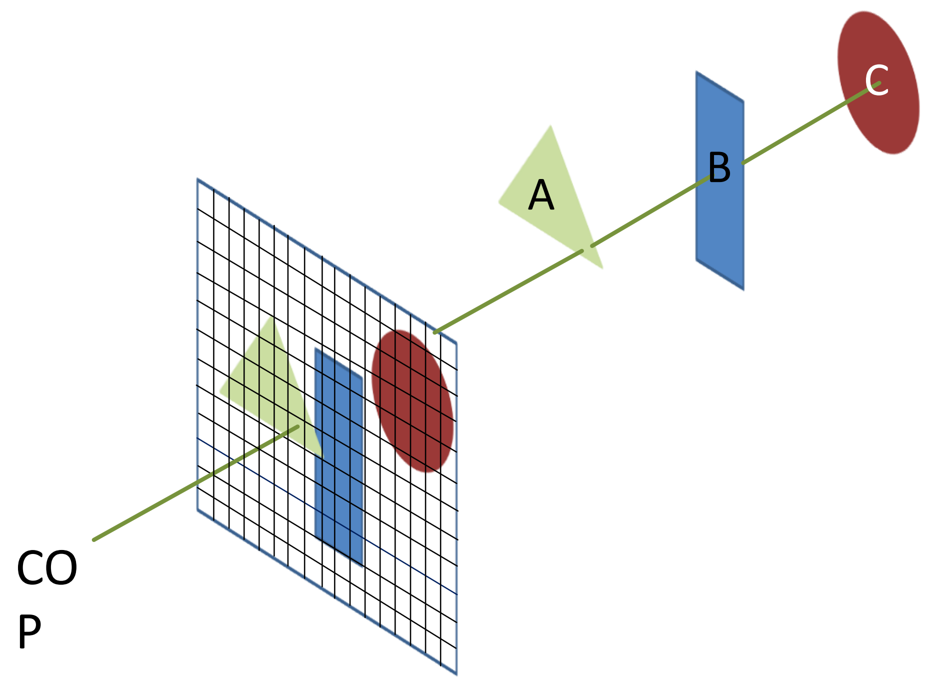


penetration

Image Space Approach

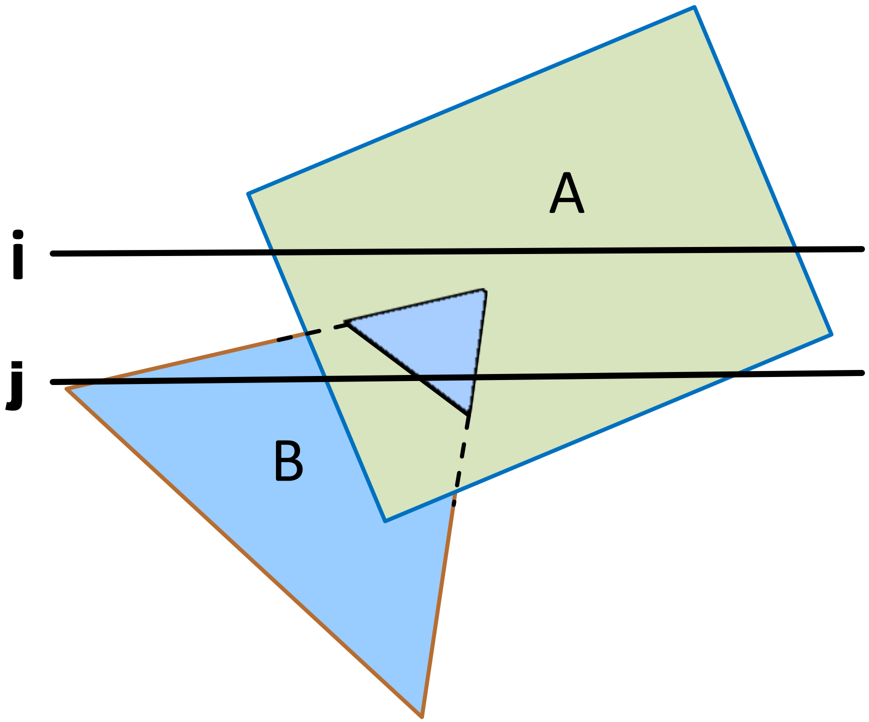
- Look at each projector (nm for an $n \times m$ frame buffer) and find closest of k polygons
- Complexity O(nmk)

- Ray casting
- z-buffer



Scan-Line Algorithm

- Can combine shading and HSR through scan-line algorithms.



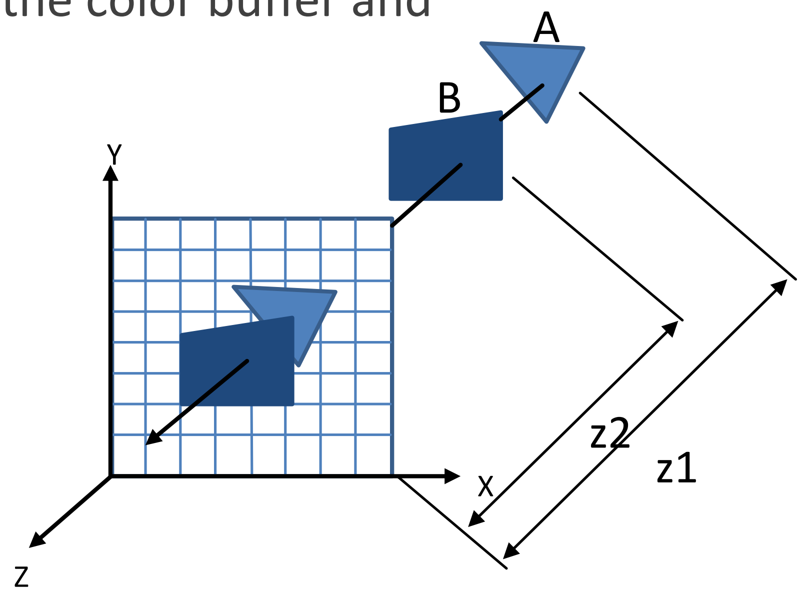
scan line **i**:
no need for depth information

scan line **j**:
need depth information when A and B overlap

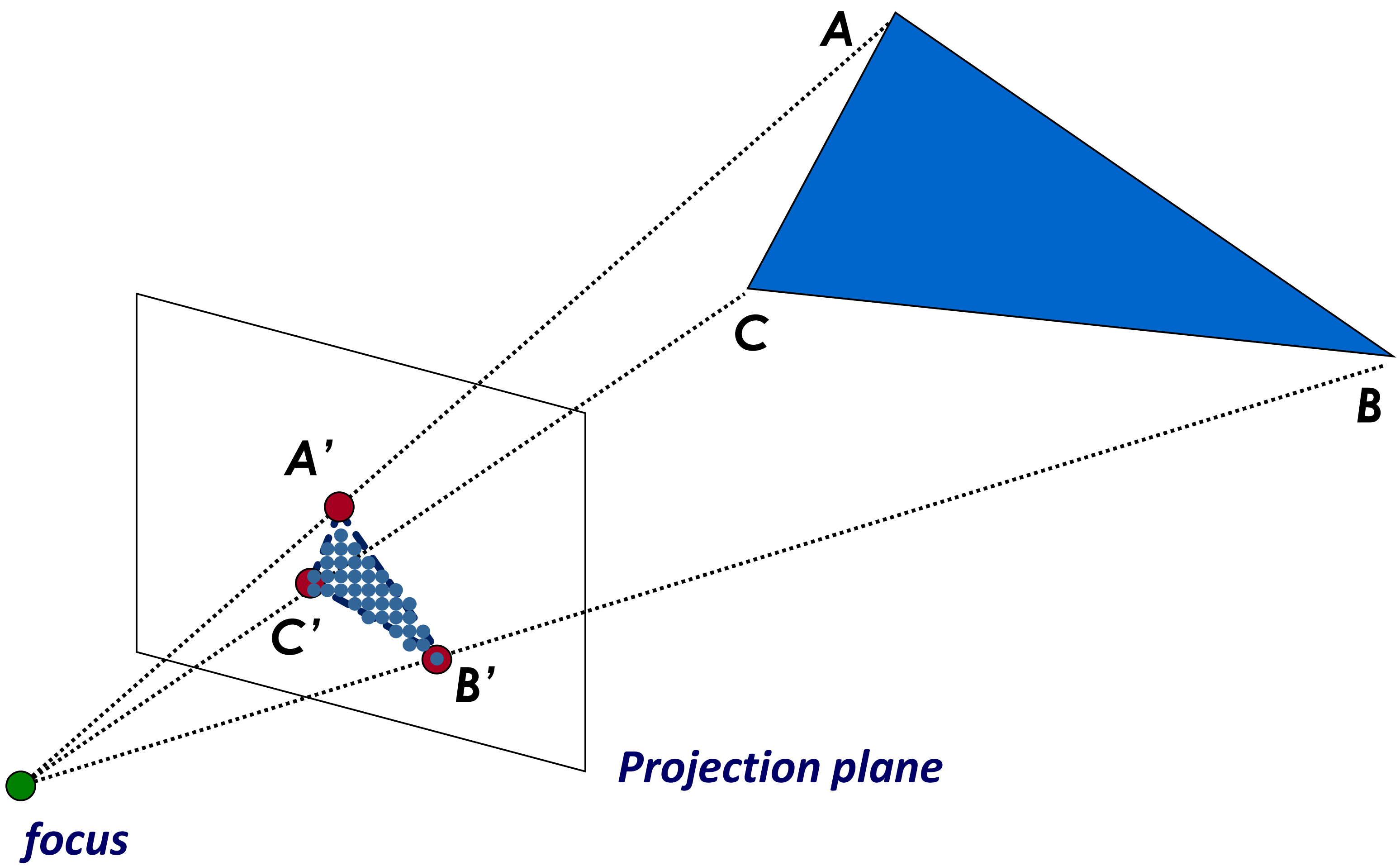
z-Buffer Algorithm

- The z or depth buffer
  - stores the depth of the closest object at each pixel found so far

- As we render each polygon, compare the depth of each pixel to depth in z buffer
  - If less, place the shade of pixel in the color buffer and update z buffer

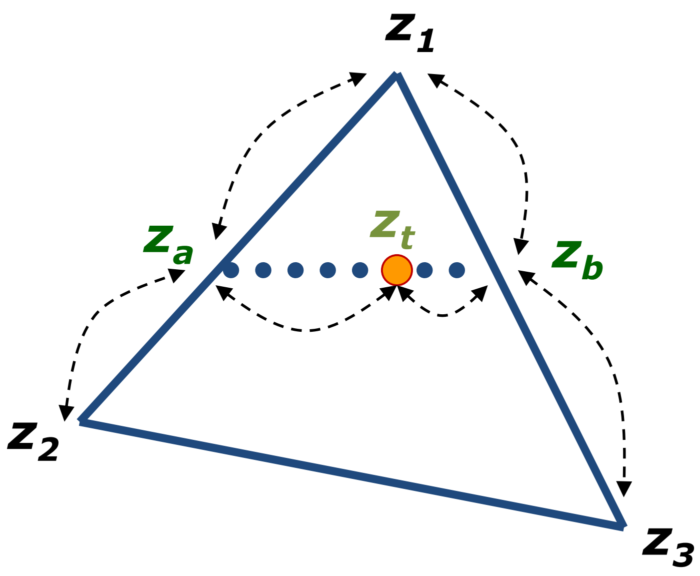


Interpolation of Z values



Interpolation of Z values

- How to estimate z of in-between pixels ?



Efficiency (z-Buffer)

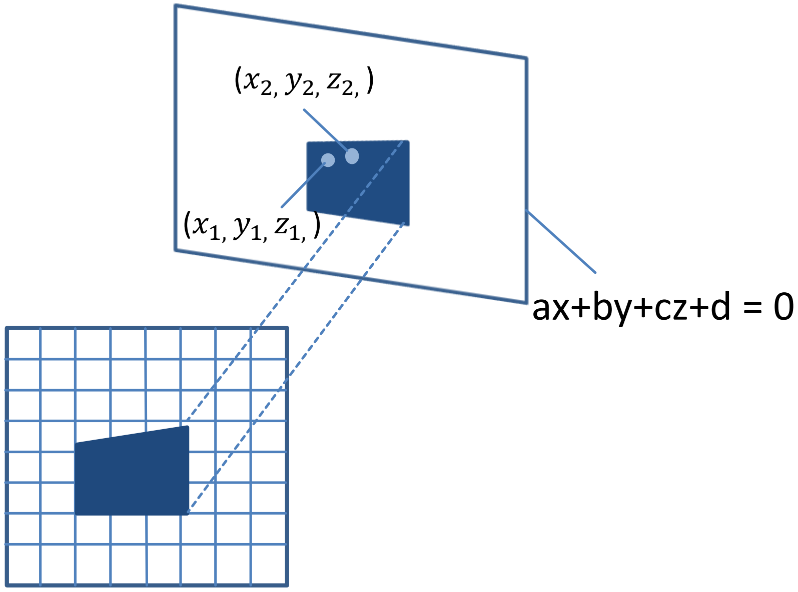
- If we work scan line by scan line as we move across a scan line, the depth changes satisfy $a\Delta x+b\Delta y+c\Delta z=0$

Along scan line

$$\Delta y = 0$$

$$\Delta z = -\frac{a}{c}\Delta x$$

In screen space $\Delta x = 1$



Space Partitioning

- Avoid rendering an object when it's unnecessary.
  - In many real-time applications, we want to eliminate as many objects as possible within the application.
  - Reduce burden on pipeline
  - Reduce traffic on bus

- Octree

- BSP tree

Octree

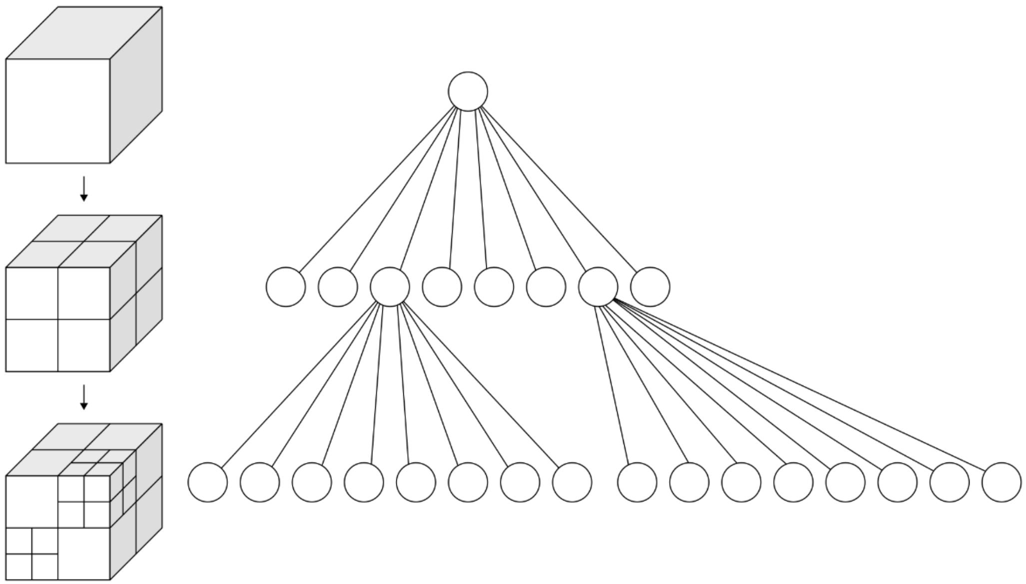
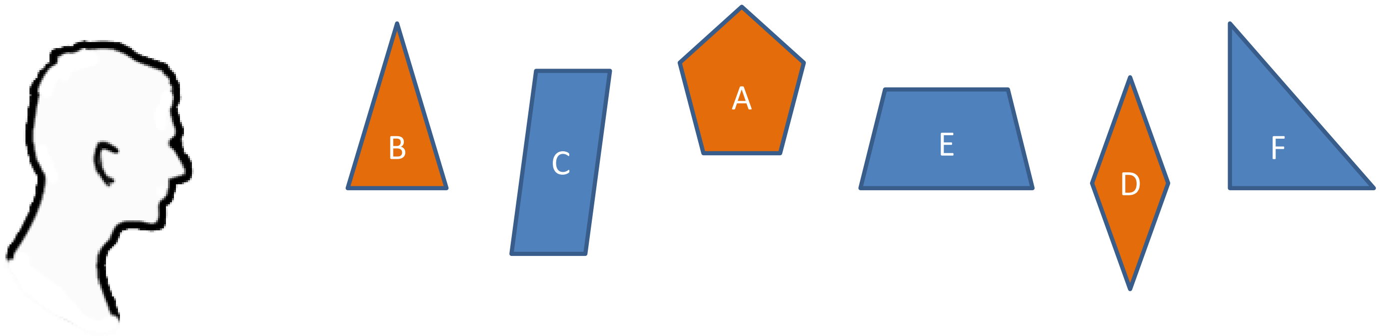


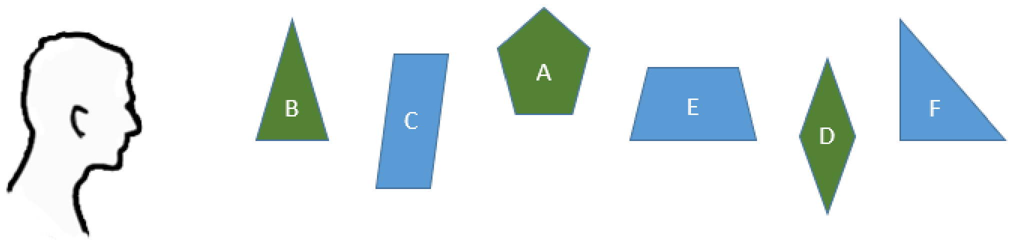
Fig. from en.wikipedia.org/wiki/Octree

Why do we use BSP trees?

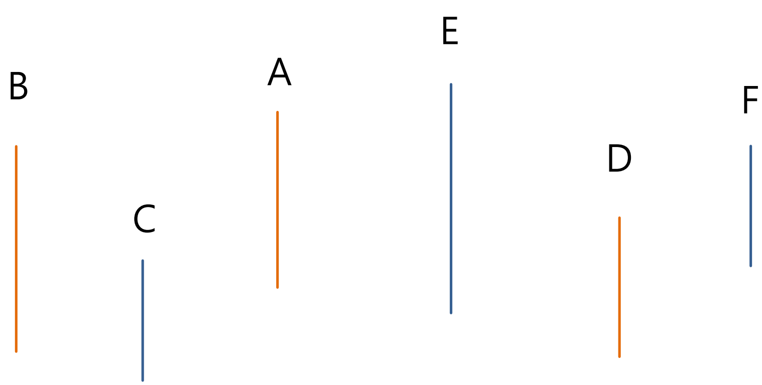
- Hidden surface removal
  - A back-to-front painter's algorithm
- Partition space with Binary Spatial Partition (BSP) Tree



A Simple Example



consider 6 parallel polygons



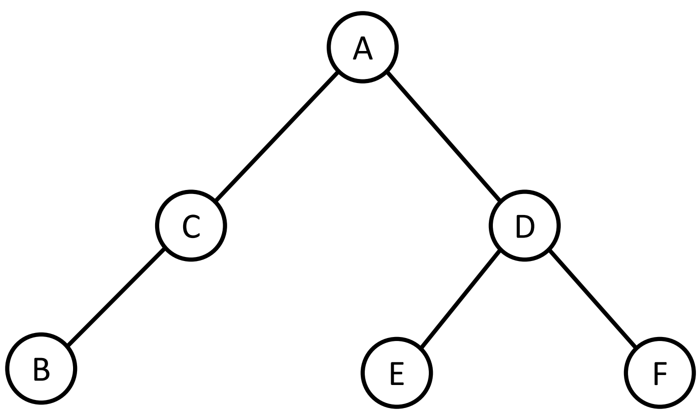
top view

The plane of A separates B and C from D, E and F

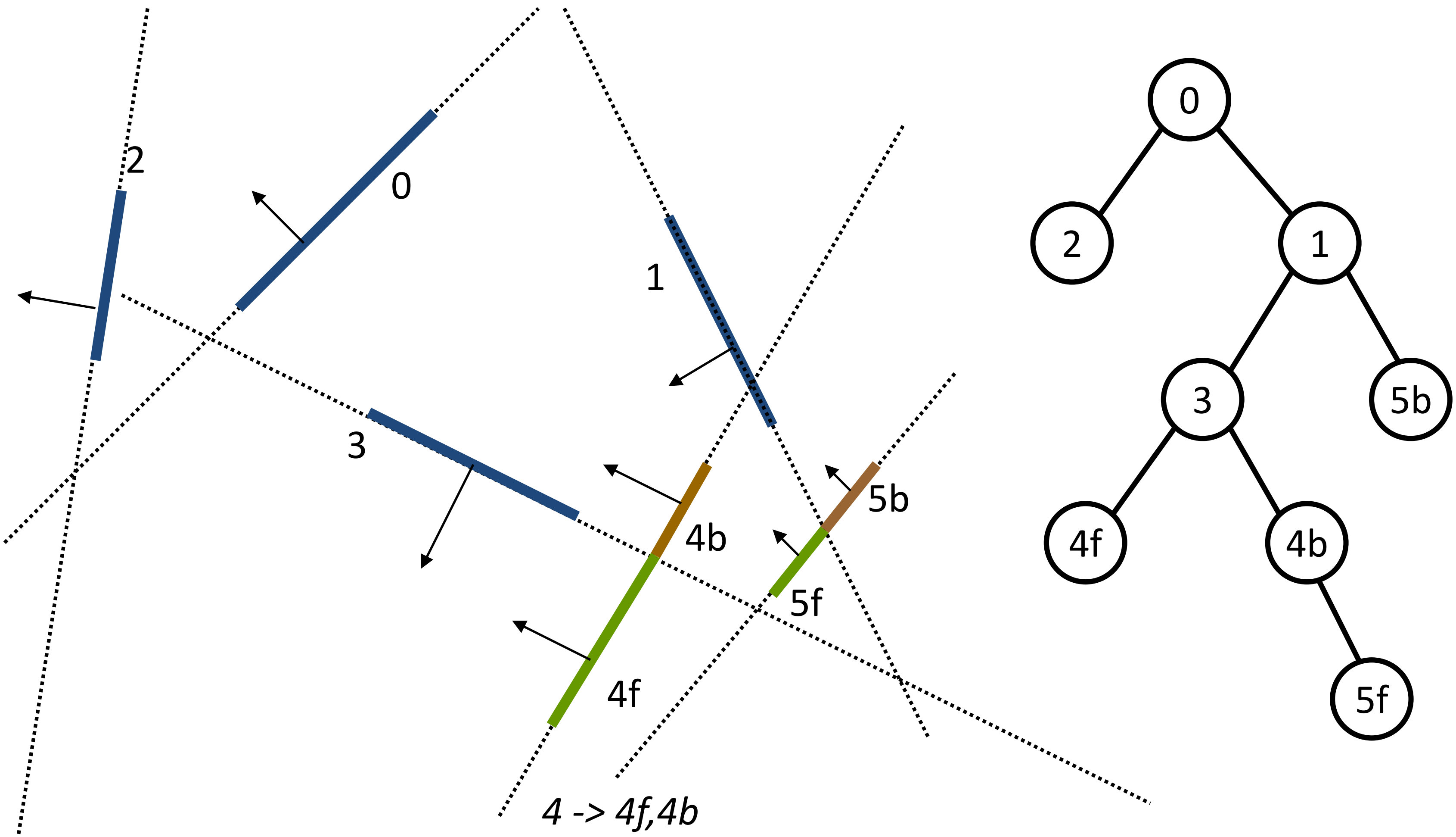
Binary Space Partitioning Tree

- Can continue recursively
  - Plane of C separates B from A
  - Plane of D separates E and F

- Can put this information in a BSP tree
  - Use for visibility and occlusion testing



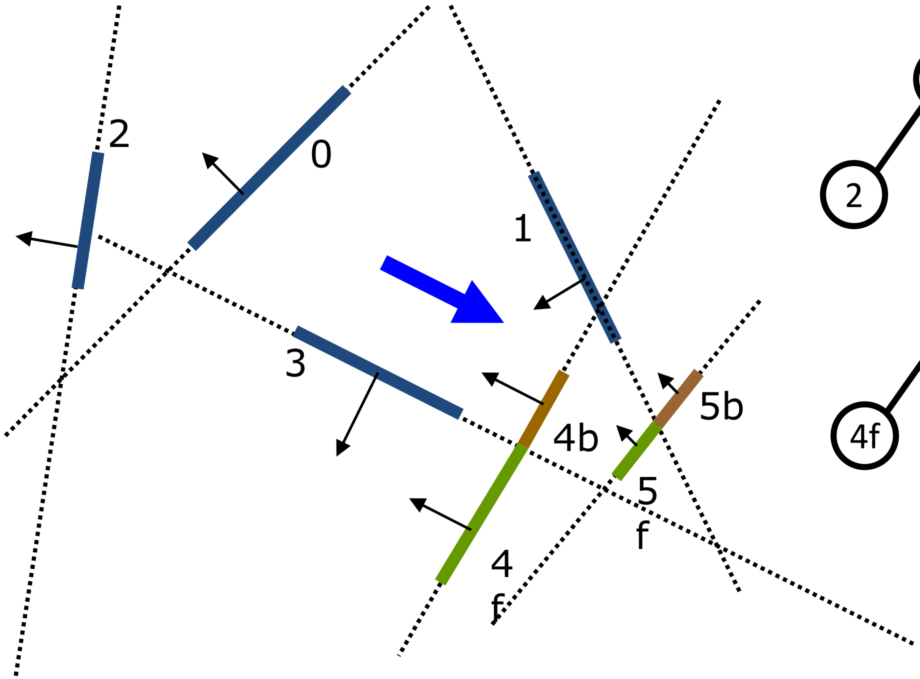
Creating a BSP tree

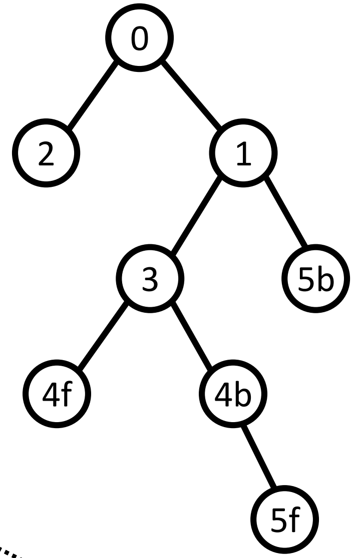


Back-to-Front Render

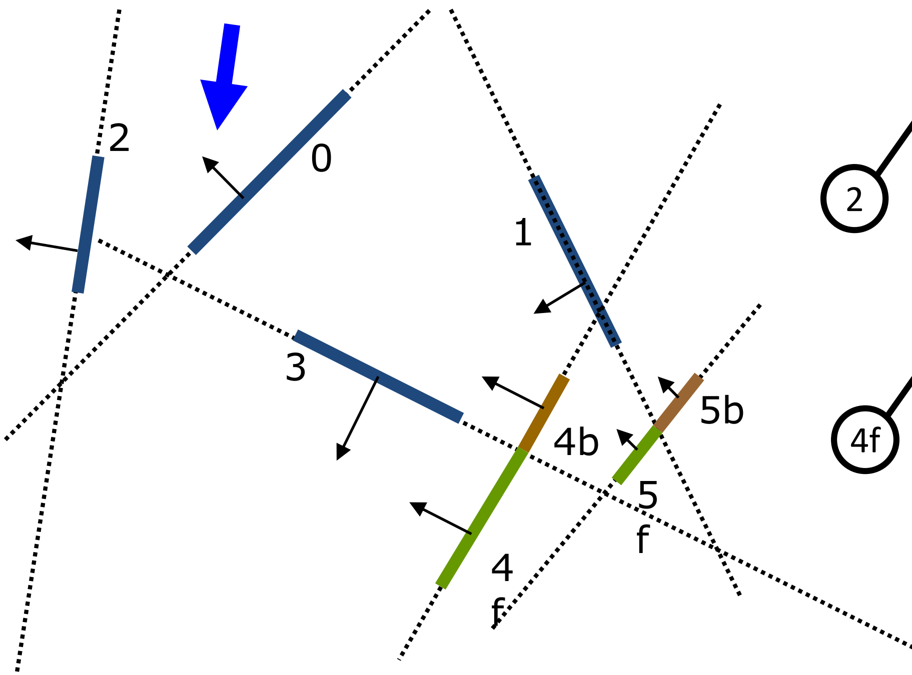
```
Render(node, view){
    if node is a leaf
      { draw this node to the screen }
    else
      if the viewpoint is in back of the dividing line
      {
      render(front subnode)
            draw node to screen
            render(back subnode)
      }
        else the viewpoint is in front of the dividing line
          {
          render (back subnode)
            draw node to screen
            render (front subnode)
      }
```

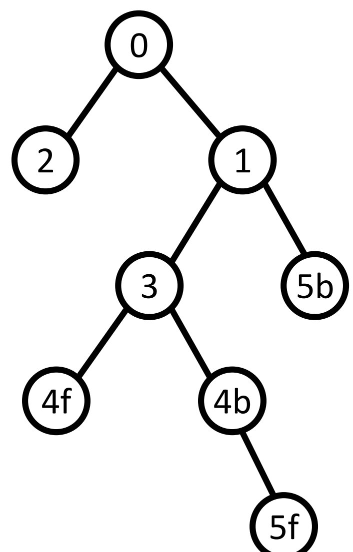
Back-to-Front Render





Back-to-Front Render





BSP-based Culling

- Pervasively used in first person shooting games.
  - Doom, quake….etc.

- Visibility test
- Skip objects that are “occluded”.

Other Culling Methods

- Portal Culling
  - Walking through architectures
  - Dividing space into cells
  - Cells only see other cells through portals

The End of Chapter 8