Introduction to Computer Graphics

7. Hidden Surface Removal & Culling

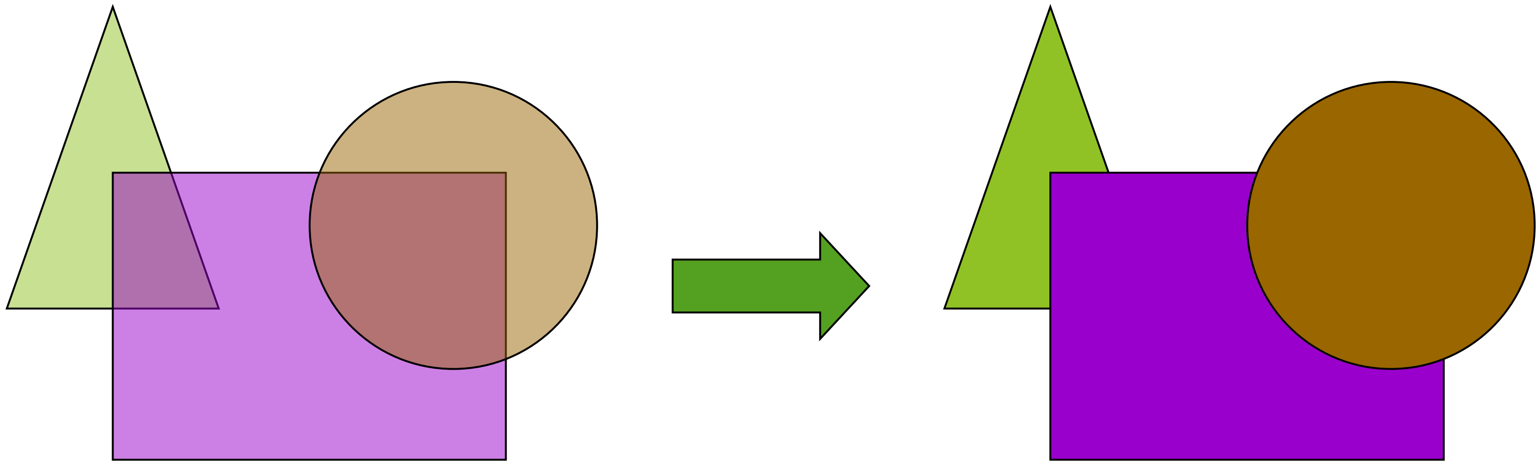
I-Chen Lin

National Chiao Tung Univ., Taiwan

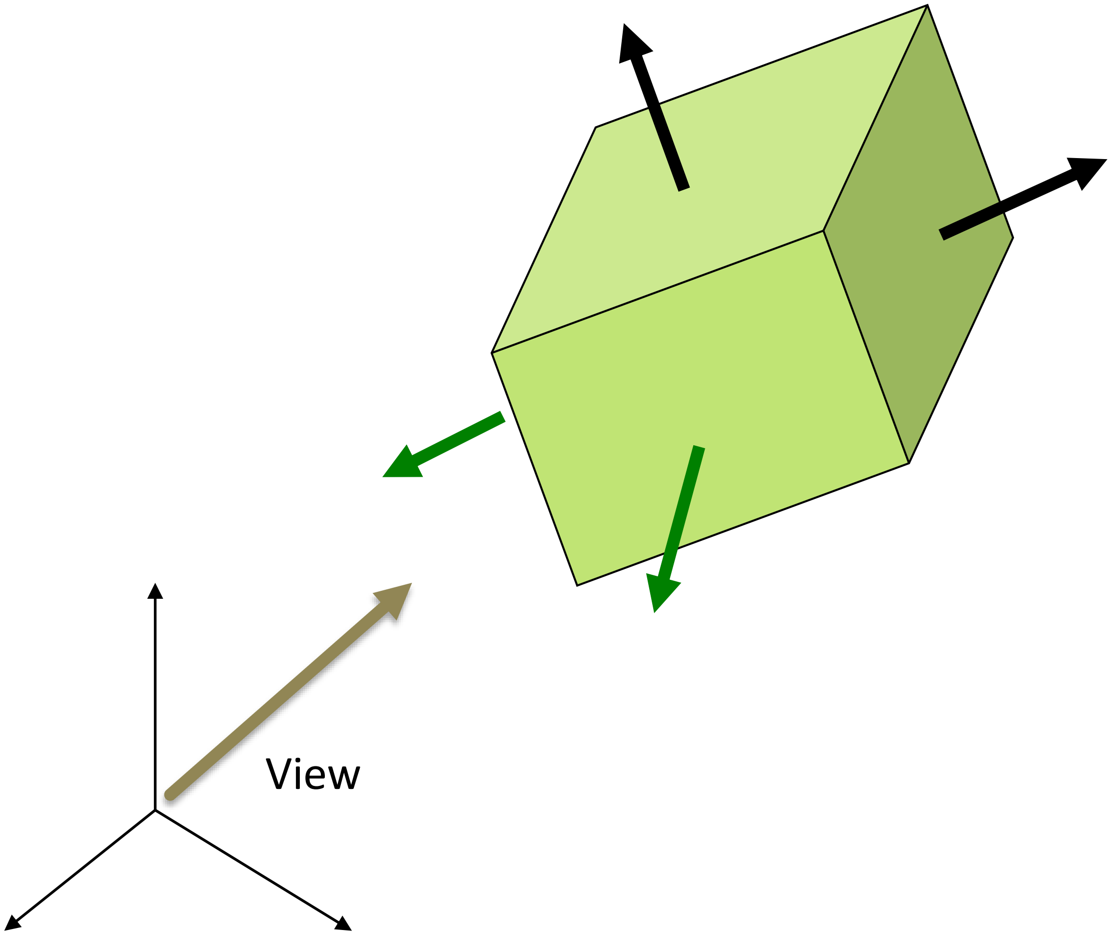
Textbook: E.Angel, D. Shreiner Interactive Computer Graphics, 6th Ed., Pearson
Ref: D.D. Hearn, M. P. Baker, W. Carithers, Computer Graphics with OpenGL, 4th Ed., Pearson

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".

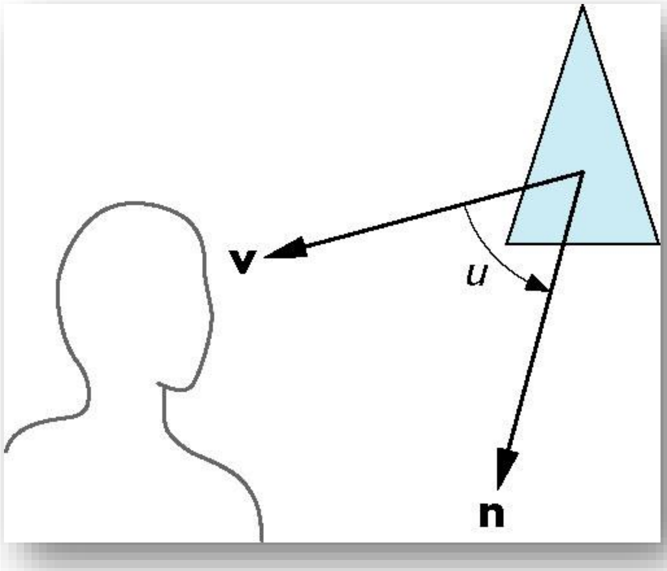


Back-face Removal (Culling)



Back-face Removal (Culling)

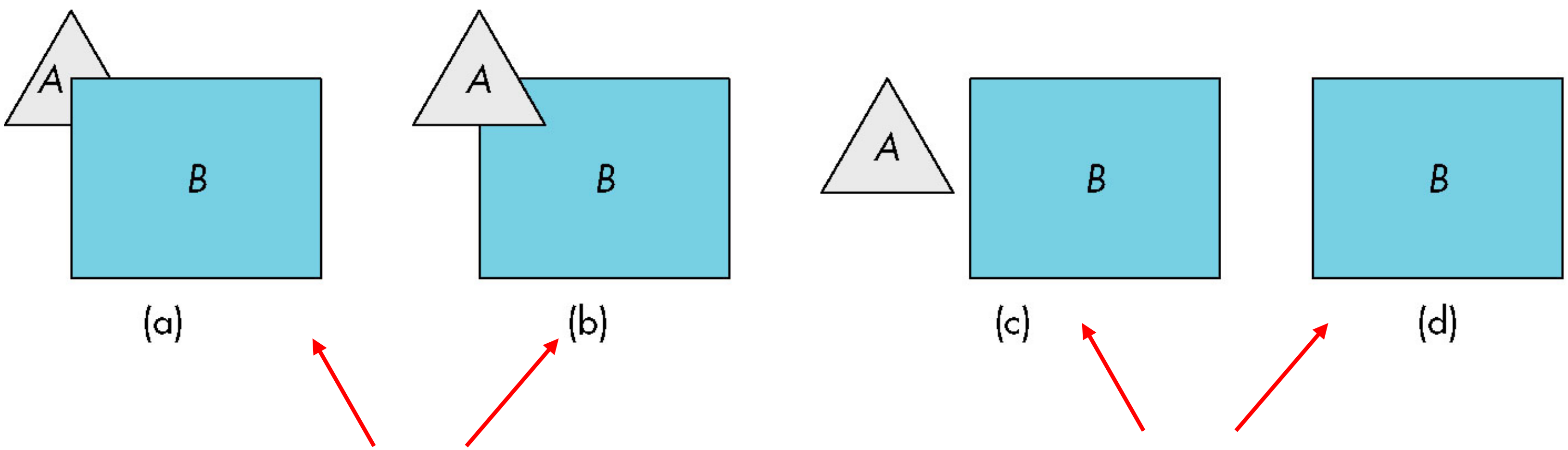
- A face is visible iff $90 \geq \theta \geq -90$ equivalently $\cos\theta \geq 0$ or $\boldsymbol{v} \bullet \boldsymbol{n} \geq 0$
- When $v = (0\ 0\ 1\ 0)^T$, $n = (a, b, c, 0)^T$, we only need to test the sign of c.
- We can enable Back-face culling in OpenGL, but it may not work correctly if we have nonconvex objects



Hidden Surface Removal

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

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

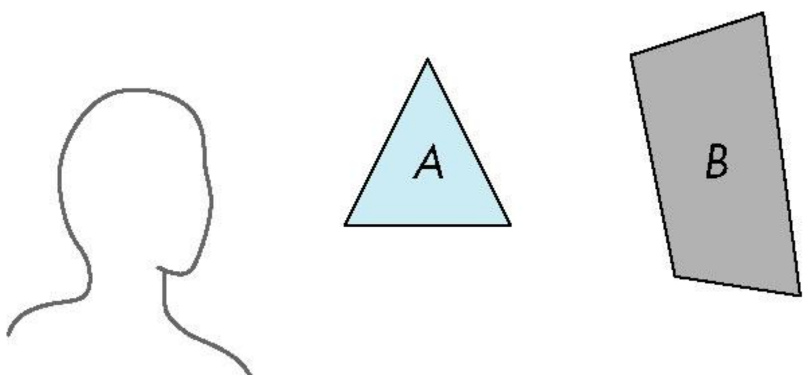


partially obscuring

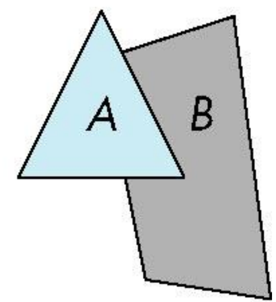
can draw independently

Painter’s Algorithm

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



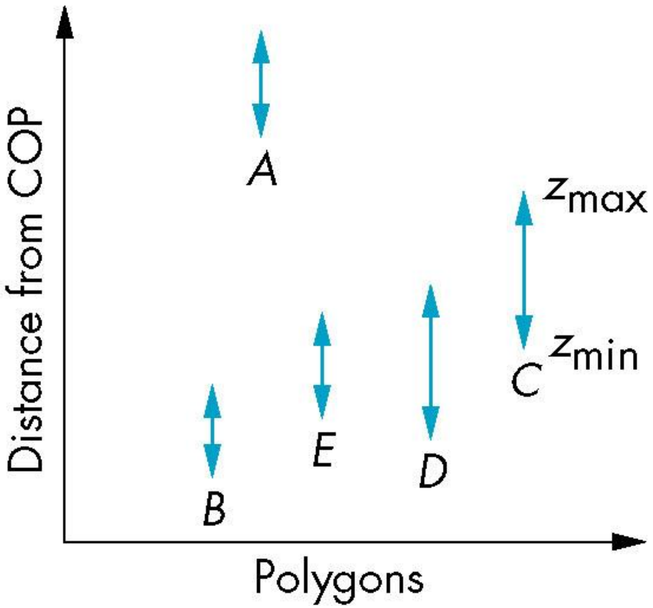
B behind A as seen by the viewer



Fill B then A

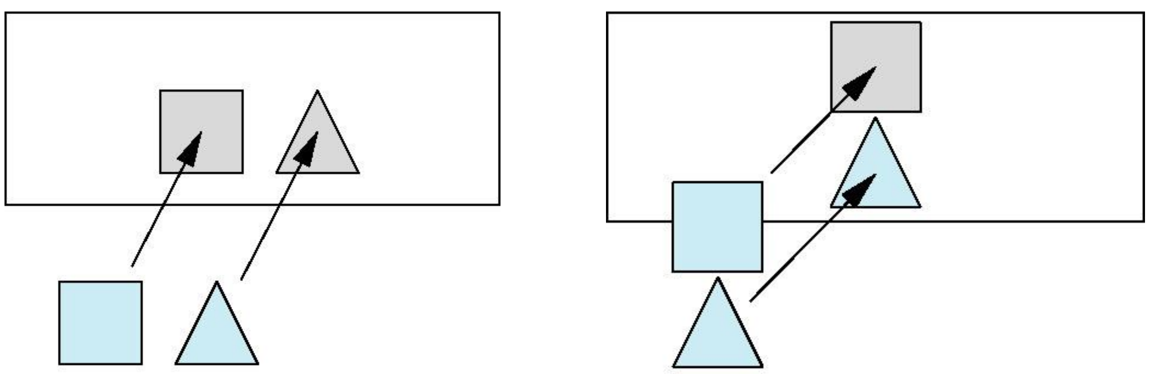
Depth Sort

- 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

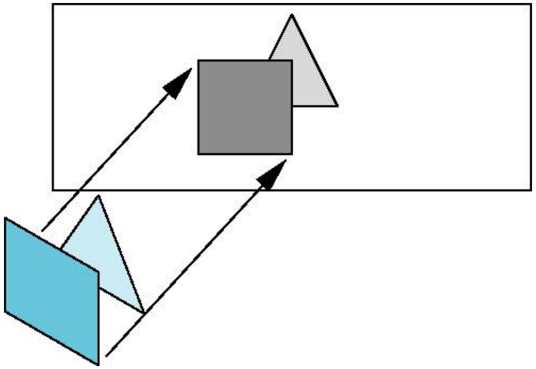


Easy Cases

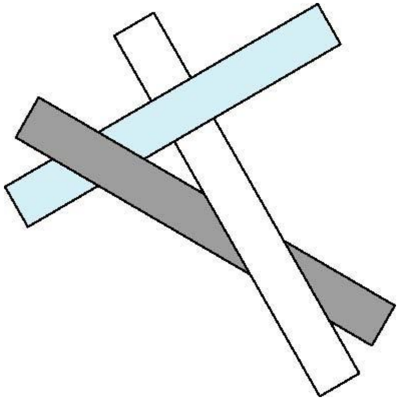
- A polygon lies behind all other polygons
  - Can render
- Polygons overlap in z but not in either x or y
  - Can render independently



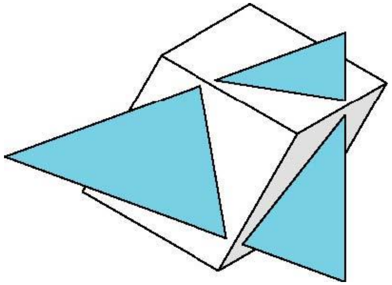
Difficult Cases



Overlap in all directions but can one is fully on one side of the other



cyclic overlap

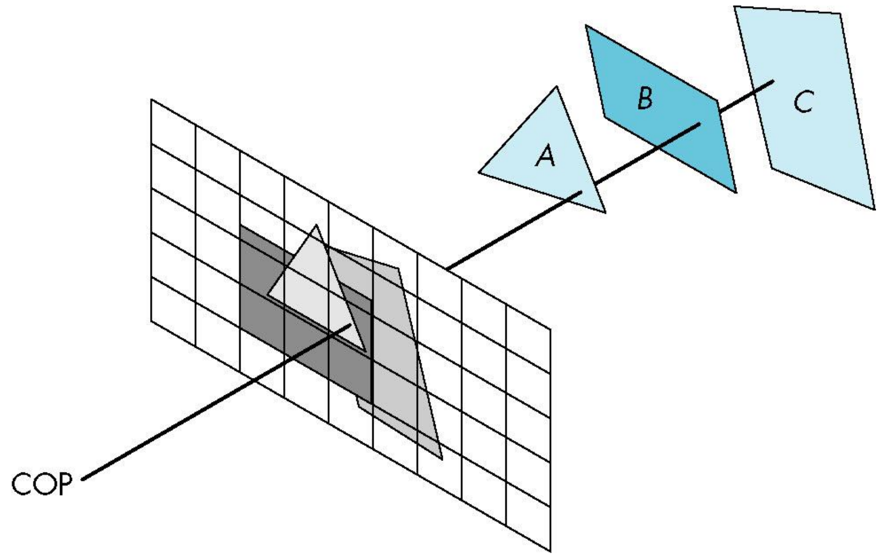


penetration

Image Space Approach

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

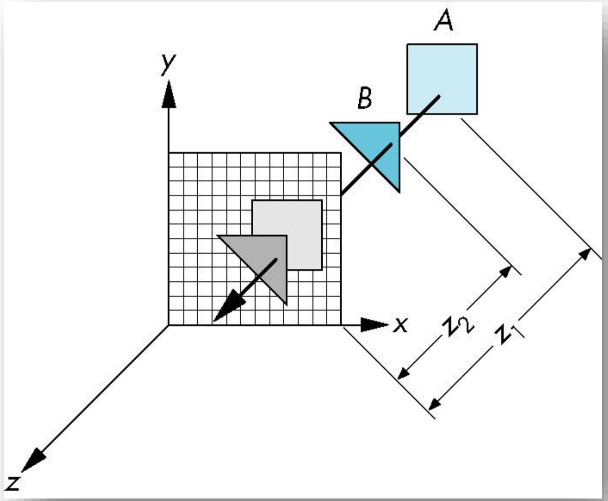
- Ray casting
- z-buffer



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



Efficiency (z-Buffer)

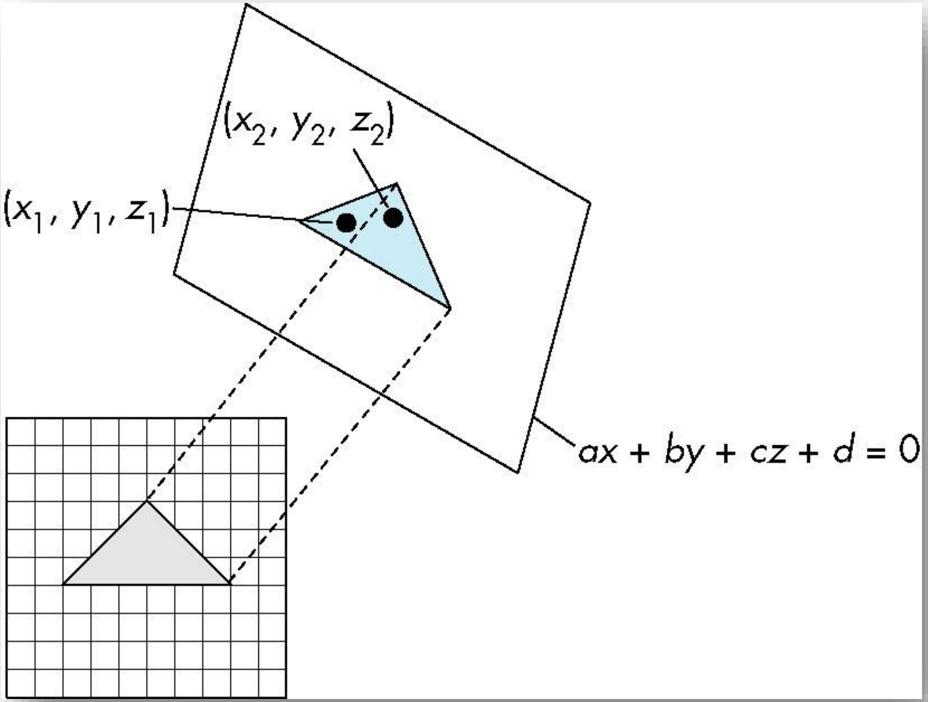
- If we work scan line by scan line as we move across a scan line, the depth changes satisfy $a\Delta x+b\Delta y+c\Delta z=0$

Along scan line

$$\Delta y = 0$$

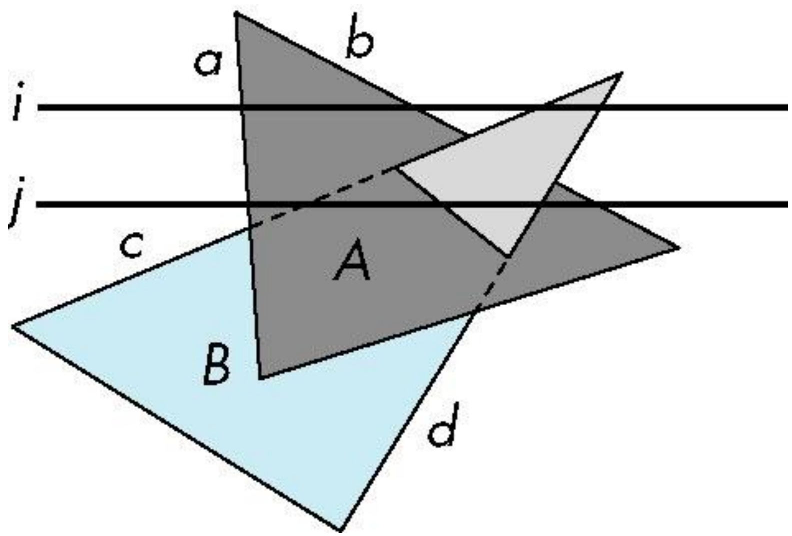
$$\Delta z = -\frac{a}{c}\Delta x$$

In screen space $\Delta x = 1$



Scan-Line Algorithm

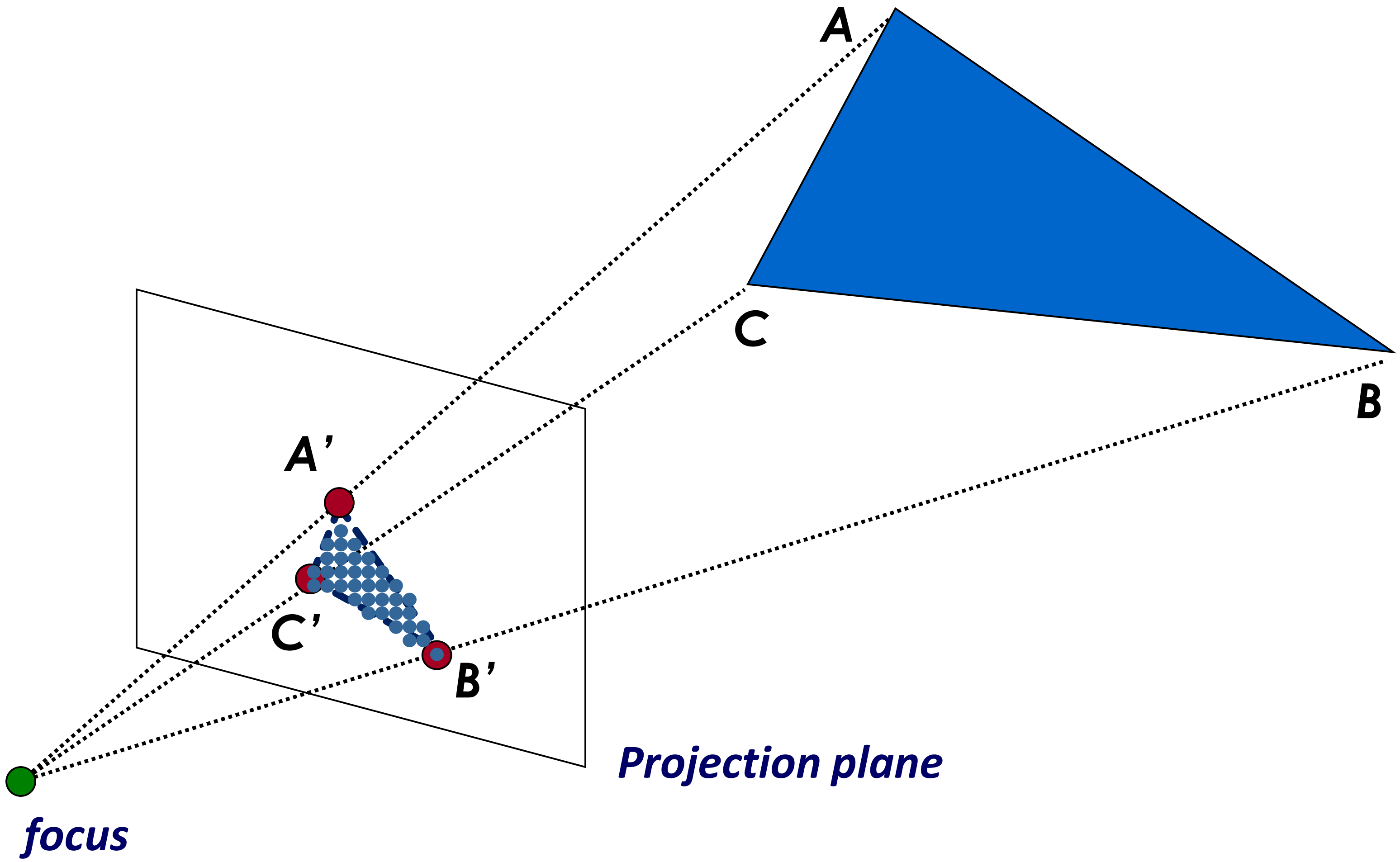
- Can combine shading and HSR through scan line algorithm.



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

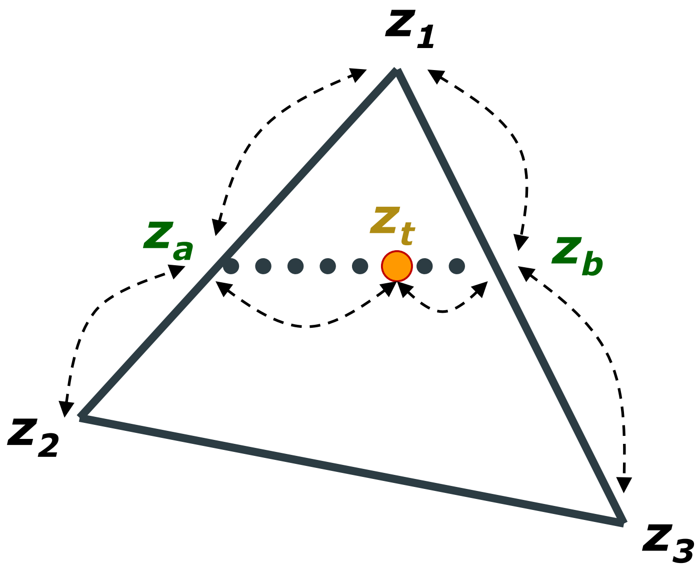
scan line **j**:
need depth information when A and B overlap

Interpolation of Z values



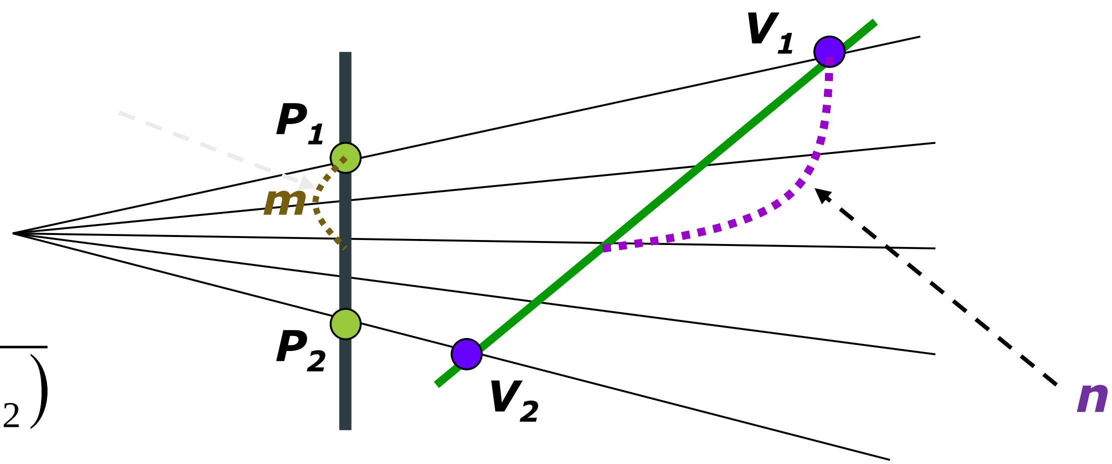
Interpolation of Z values

- How to estimate z of in-between pixels ?



Screen Space vs. 3D Space

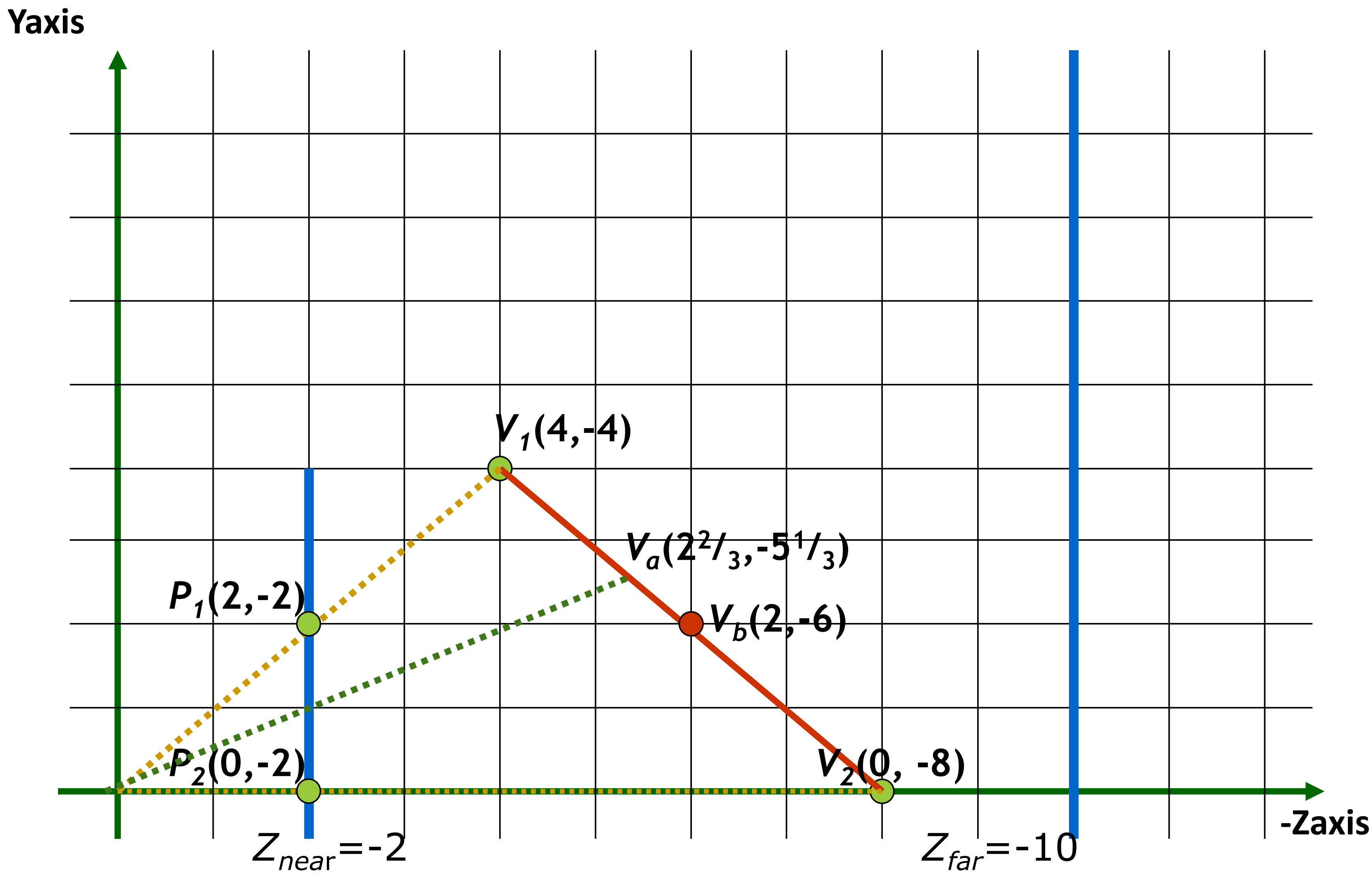
- Interpolation in screen space
  - $P(m) = P_1 + m(P_2 - P_1)$
- Interpolation in 3D space
  - $V(n) = V_1 + n(V_2 - V_1)$
  - $P_y(n) = V_y(n) / V_z(n)$



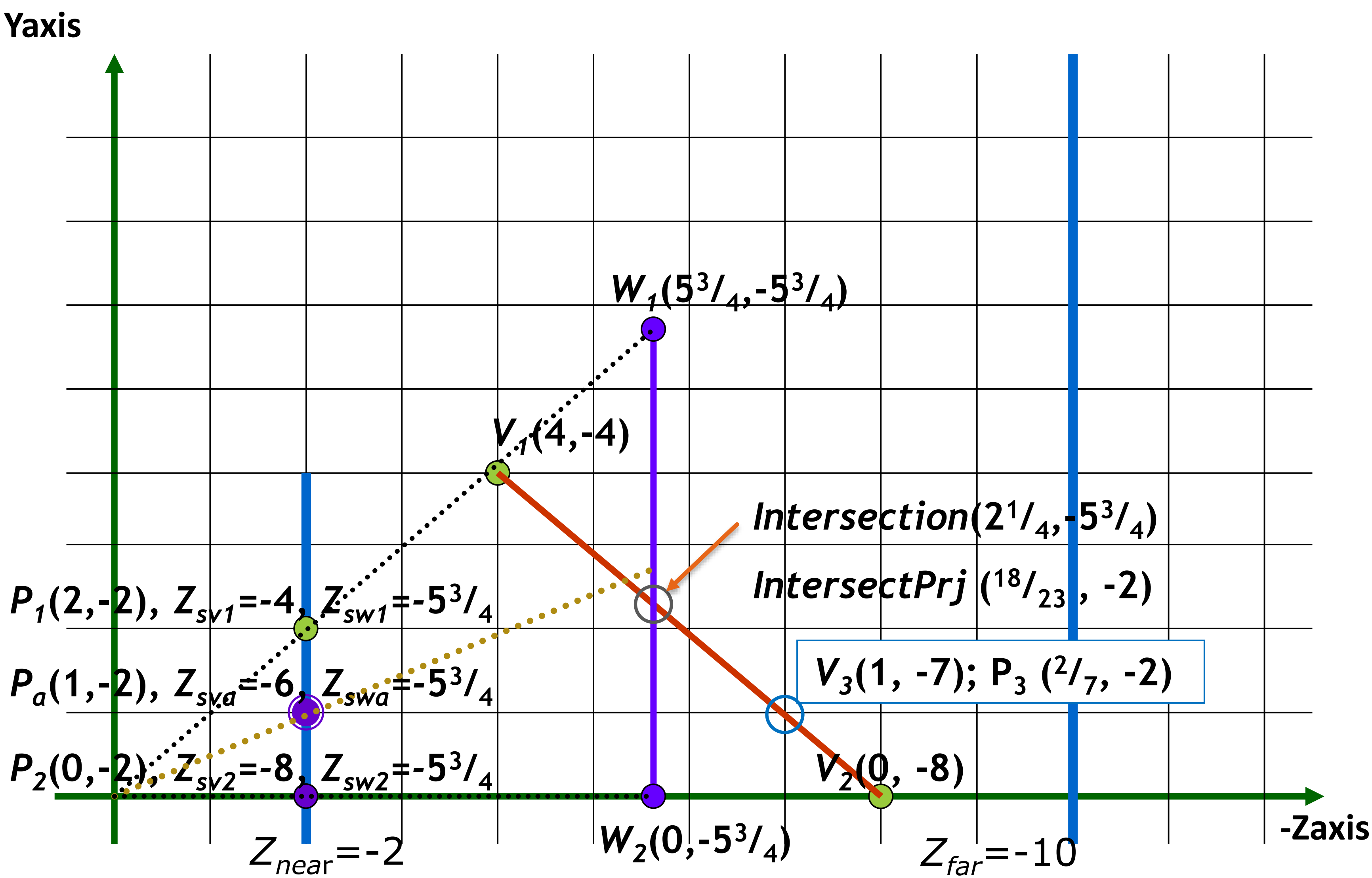
$$n \neq m$$

$$n = \frac{m z_1}{z_2 + m(z_1 - z_2)}$$

Screen Space vs. 3D Space



Simple Screen Interpolation



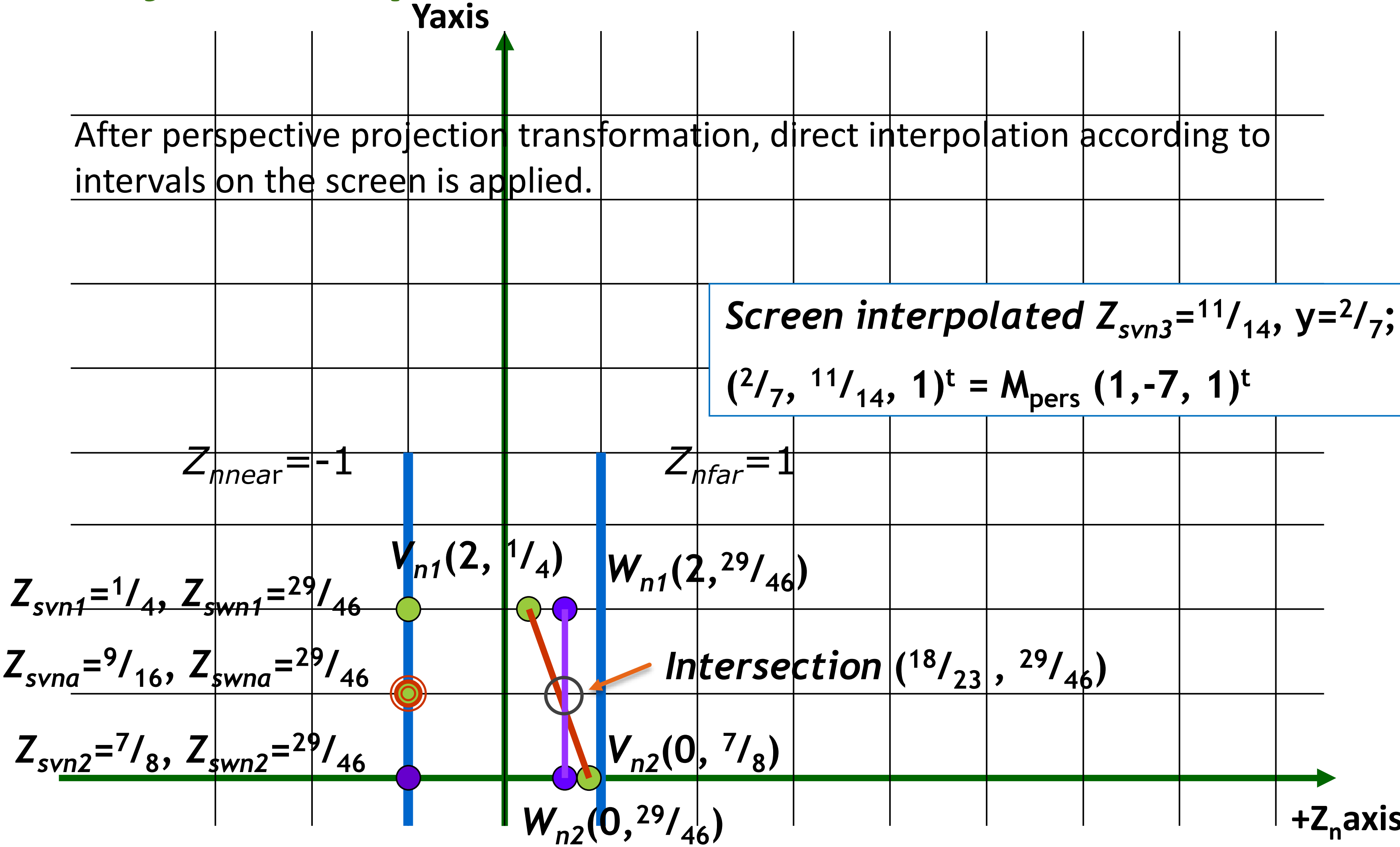
Perspective Projection Space

$$M_{pers} = \begin{bmatrix} -z_{near} & 0 & 0 & 0 \\ 0 & -z_{near} & 0 & 0 \\ 0 & 0 & \dfrac{z_{near}+z_{far}}{z_{near}-z_{far}} & \dfrac{-2z_{near}z_{far}}{z_{near}-z_{far}} \\ 0 & 0 & -1 & 0 \end{bmatrix}$$

After perspective projection transformation, direct interpolation according to intervals on the screen is applied.

Screen interpolated $Z_{svn3}={}^{11}/_{14}$, $y={}^{2}/_{7}$;

$({}^{2}/_{7},\ {}^{11}/_{14},\ 1)^t = M_{pers}\ (1,-7,\ 1)^t$



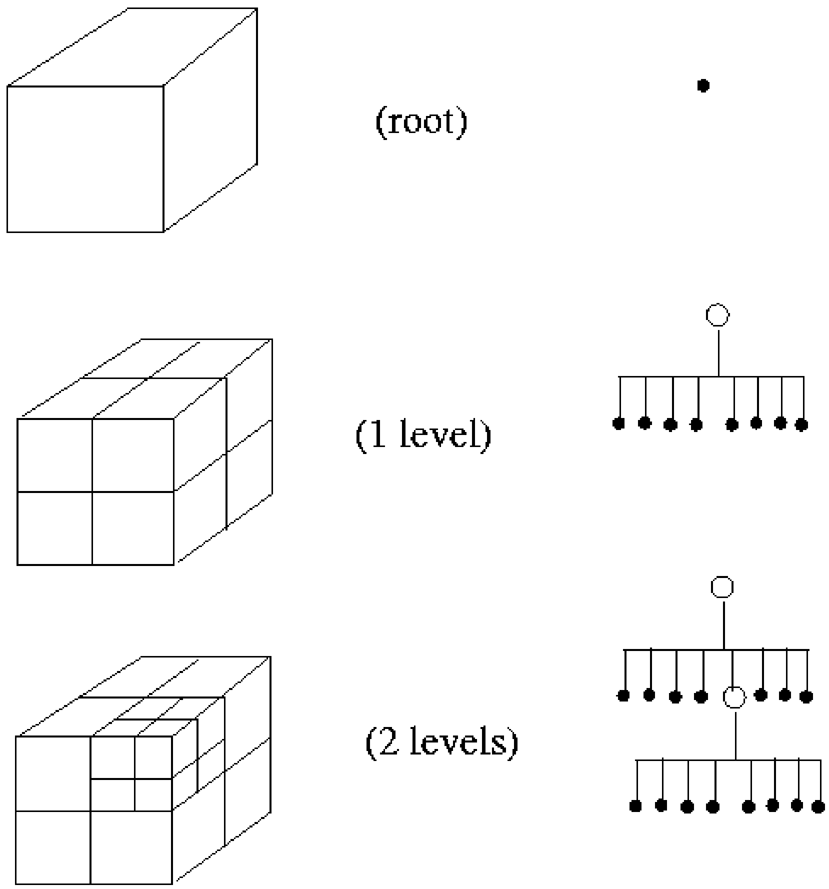
Space Partitioning

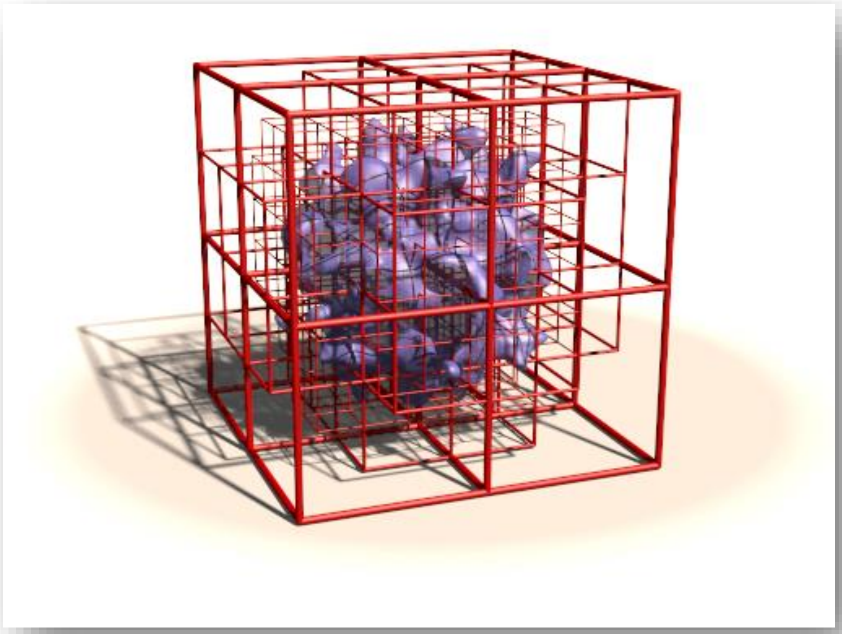
- Avoid rendering an object when it’s unnecessary.
  - In many real-time applications, we want to eliminate as many objects as possible within the application.
  - Reduce burden on pipeline
  - Reduce traffic on bus

- Octree

- BSP tree

Octree



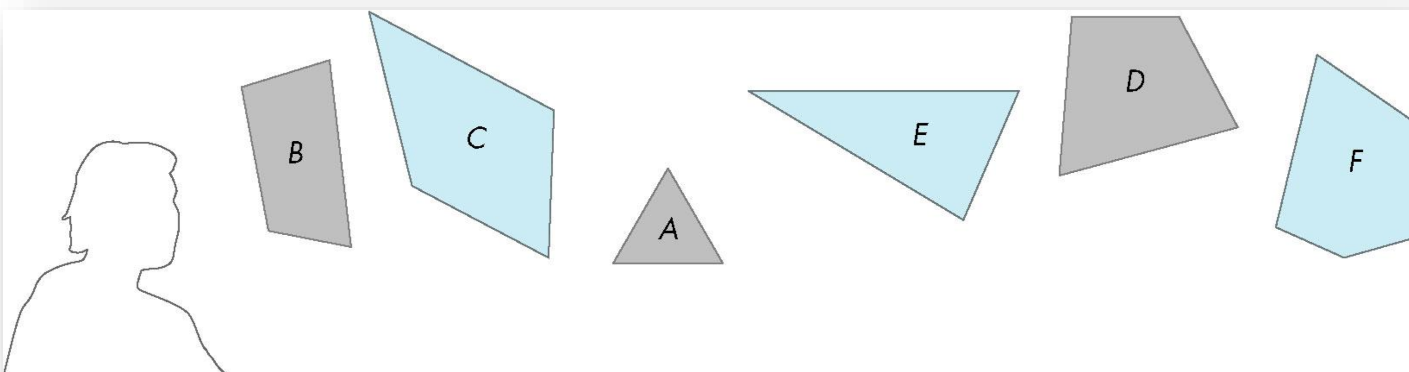


http://www.imagico.de/fast_iso/patch.html

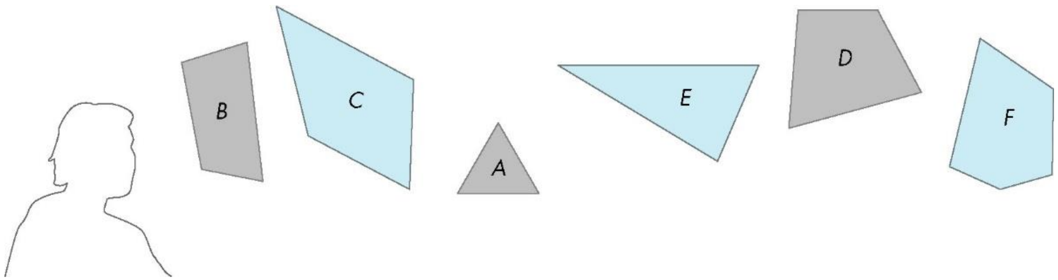
Why do we use BSP trees?

- Hidden surface removal
  - A back-to-front painter's algorithm

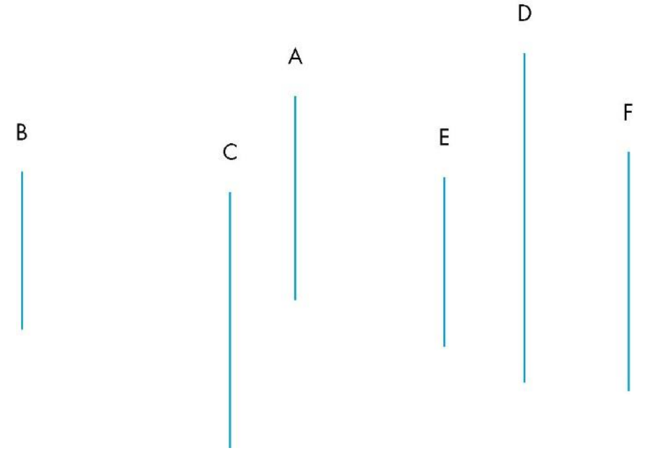
- Partition space with Binary Spatial Partition (BSP) Tree



A Simple Example



consider 6 parallel polygons



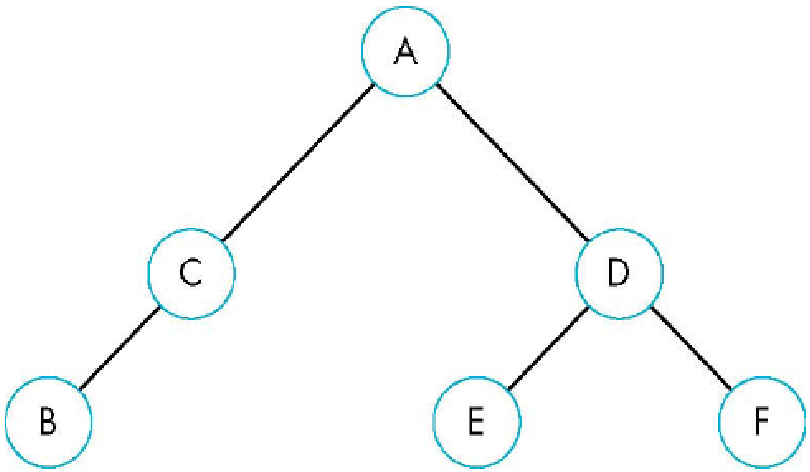
top view

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

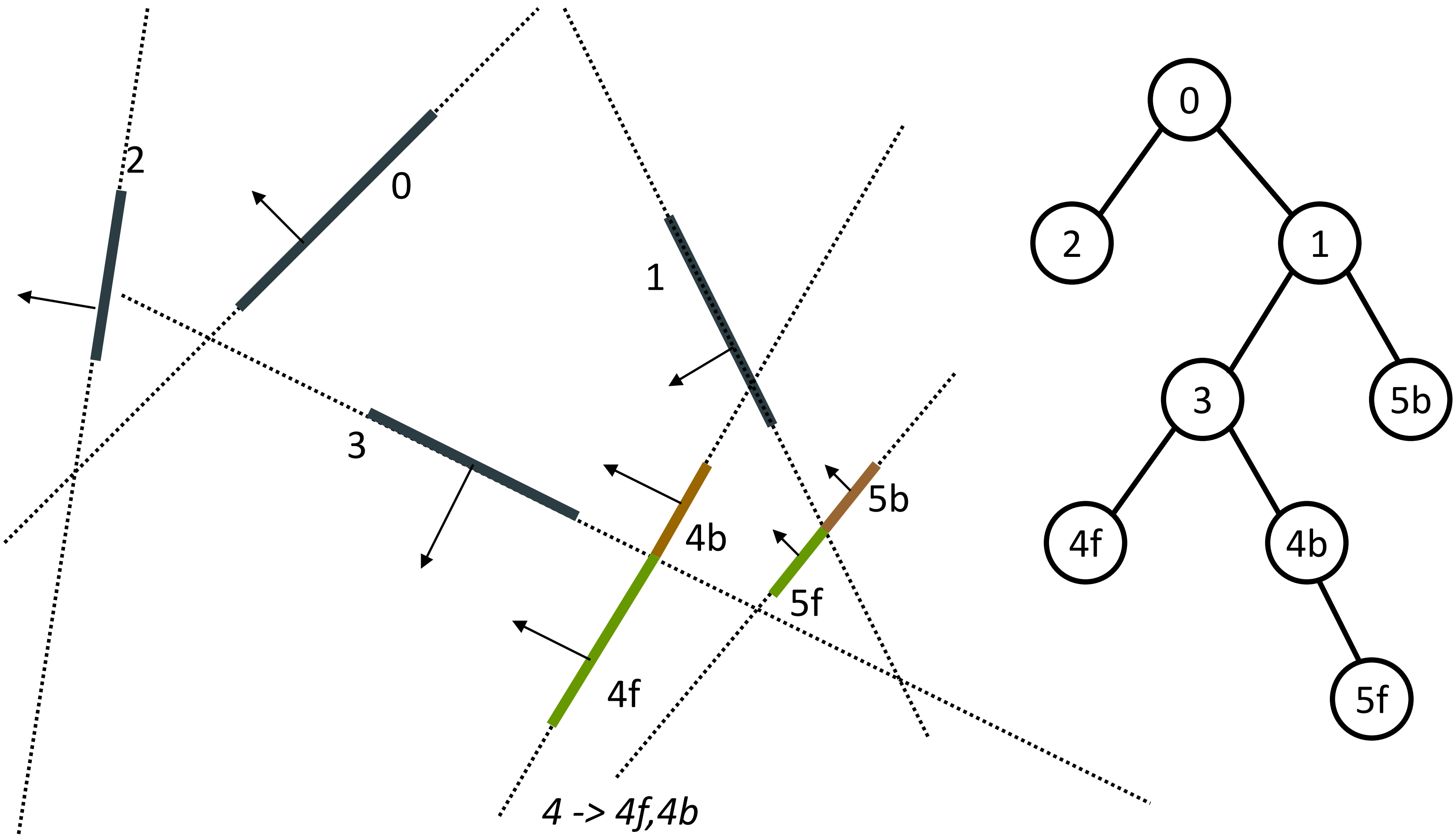
Binary Space Partitioning Tree

- 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

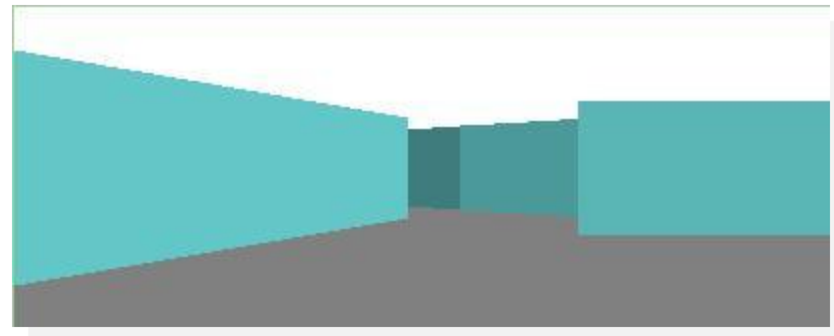


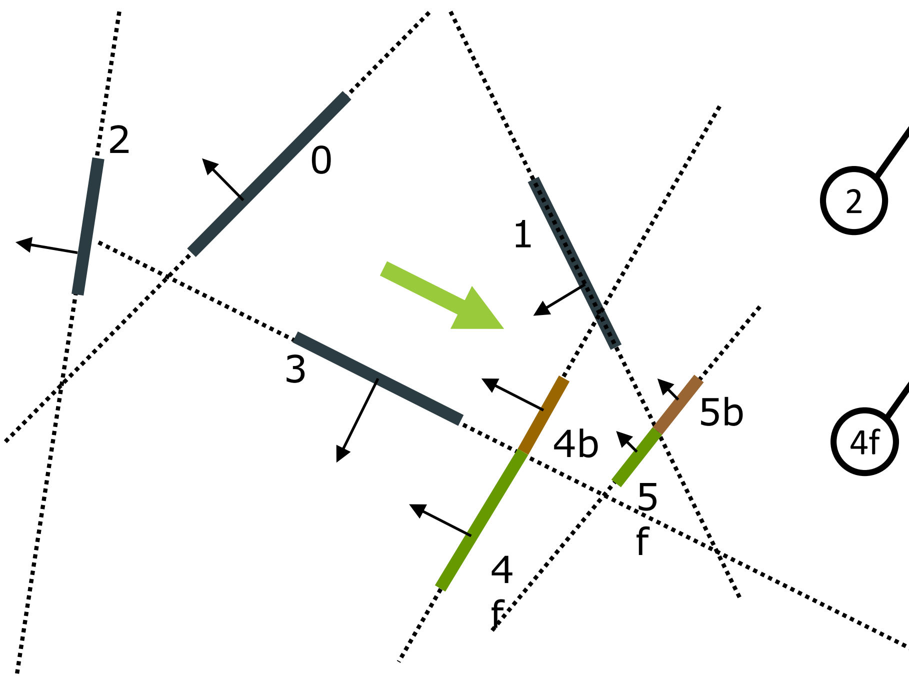
4 -> 4f,4b

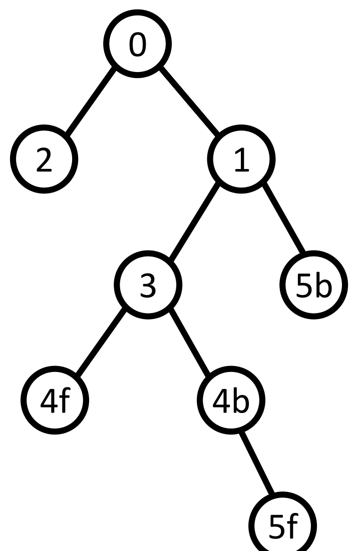
Back-to-Front Render

```
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)
     }
```

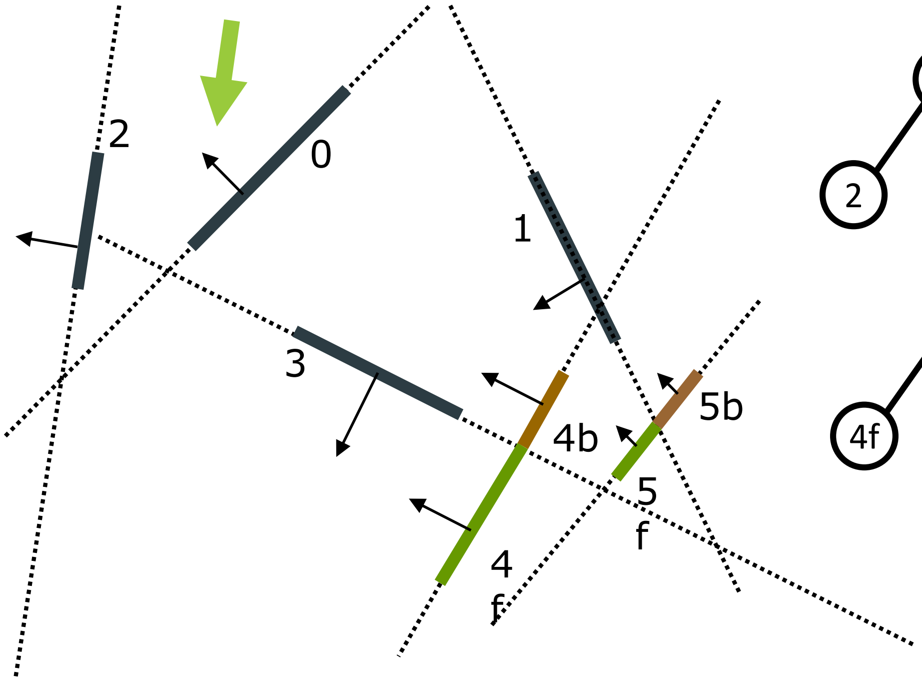
Back-to-Front Render

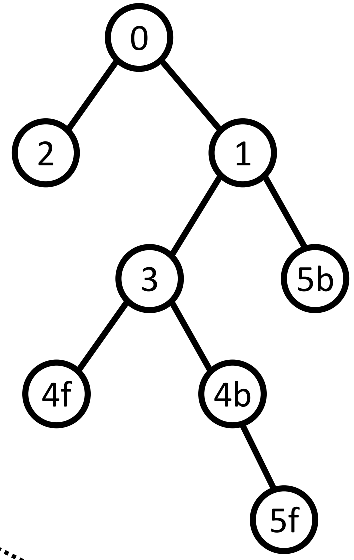






Back-to-Front Render





BSP-based Culling

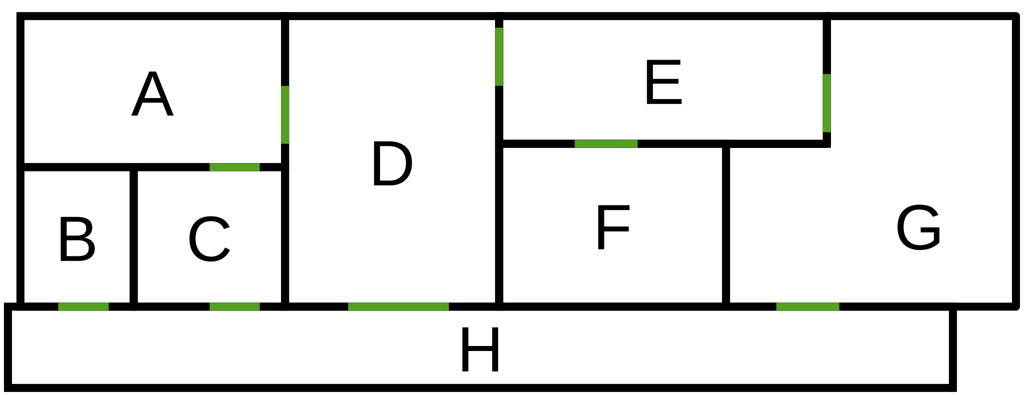
- Pervasively used in first person shooting games.
  - Doom, quake....etc.

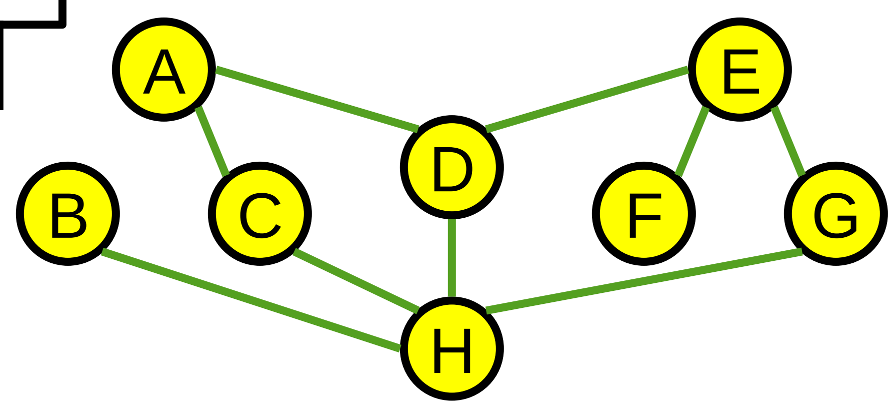
- Visibility test
- Skip objects that are “occluded”.

a screen shot from Doom

Other Culling Methods

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





Ref: www.cse.ohio-state.edu/~hwshen