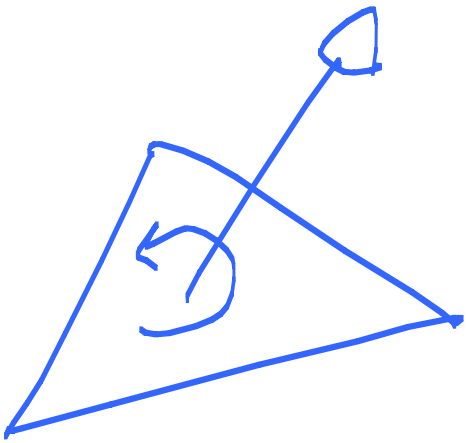
Lecture 8

More Hidden Surface Removal

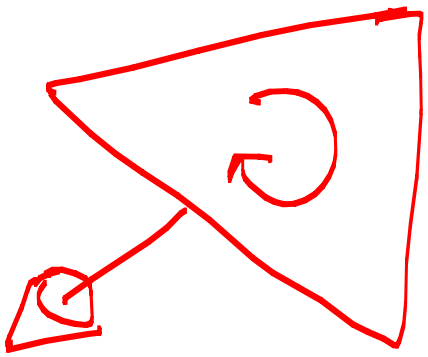
Efficient Painter
- binary space partition (BSP) tree

Efficient Ray Casting
- spatial partitioning (uniform, octrees)
- bounding volumes

Recall last lecture ...



front face



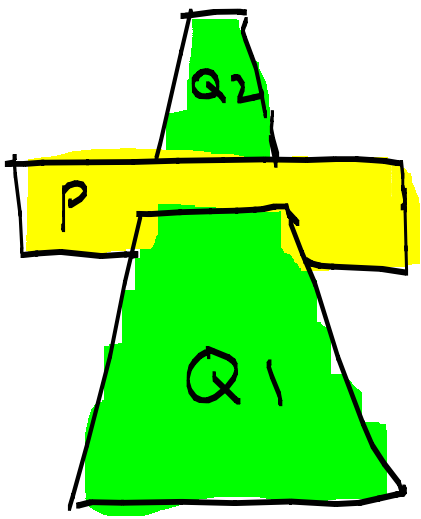
back face

Also last lecture: Painter's Algorithm

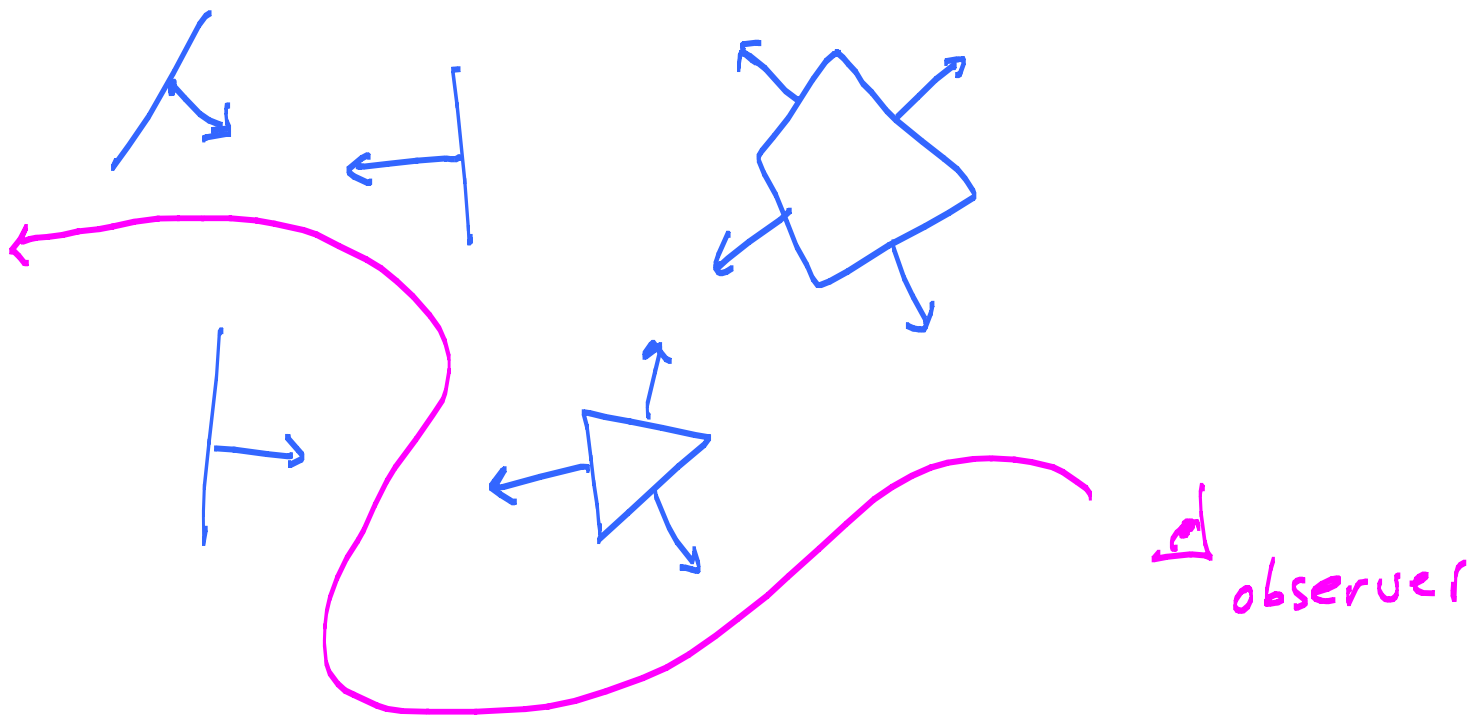
Sort polygons in depth. Use the farthest vertex in each polygon as the sorting key.

Then draw polygons from "farthest" to "nearest" (back to front).

Split polygons when necessary.

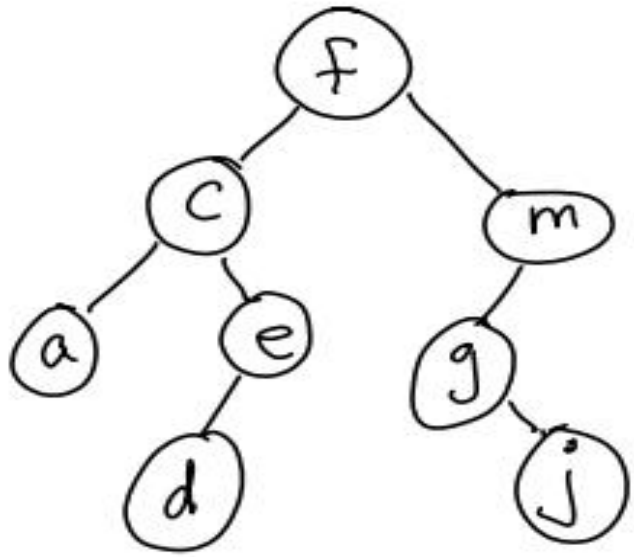


More general problem: moving observer, static scene



We want to quickly find the back-to-front depth ordering <u>AND</u> avoid the problems of the Painter's algorithm

Recall: binary search tree (COMP 250, 251)



How to build? How to use ?

http://www.cim.mcgill.ca/~langer/250.html

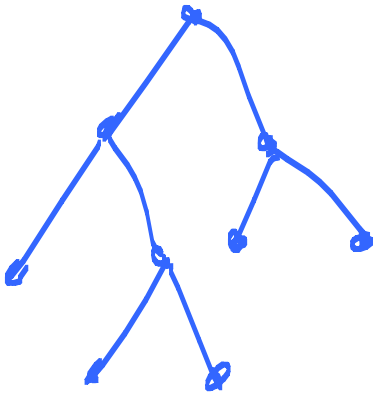
Binary space partition (BSP) tree.

It is a binary tree.

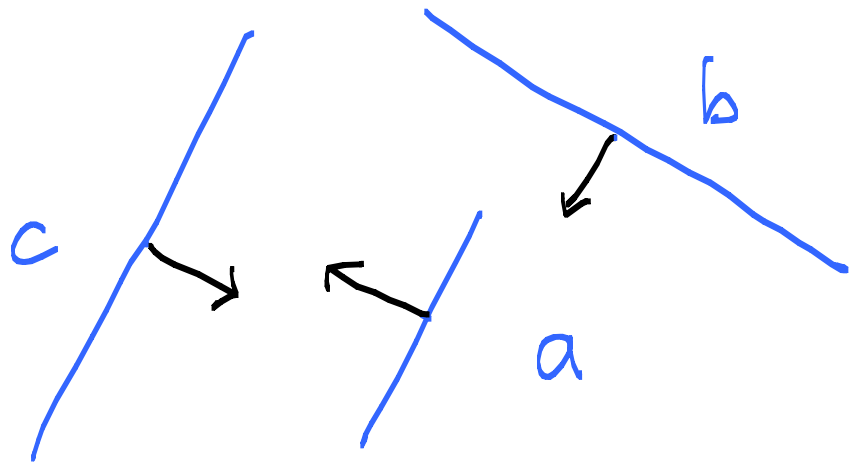
Each node has a polygon P.
(Number of nodes = number of polygons.)

Left descendents of P are in front of P.

Right descendents of P are in back of P.



How to define/build a BSP tree ?

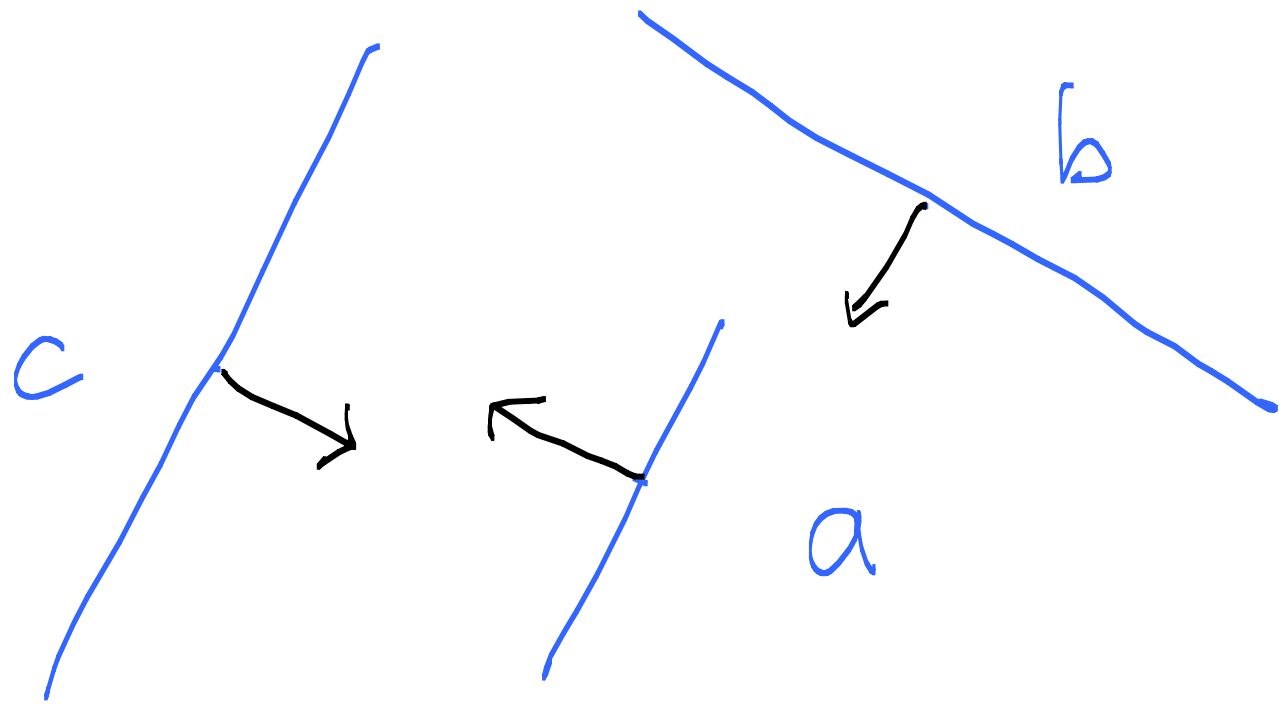


Pick a polygon P. This is the root node of the tree.

Three cases for each remaining polygon:

1) is entirely "in front of" P
2) is entirely "in back of" P, i.e. behind P
3) intersects P's plane... in which case, split into two polygons which gives cases 1) and 2).

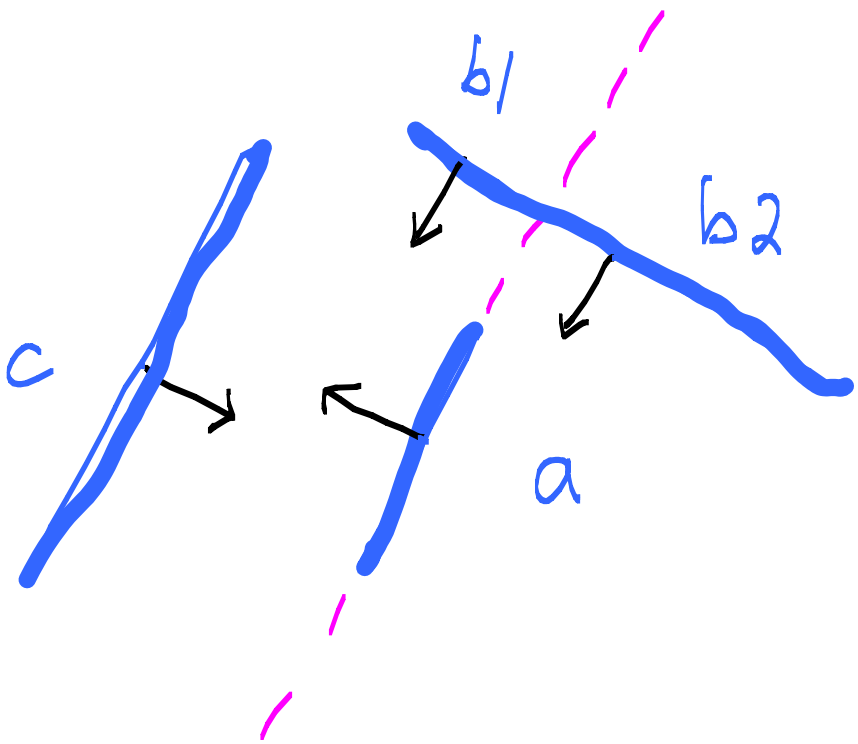
Example: pick a for the root

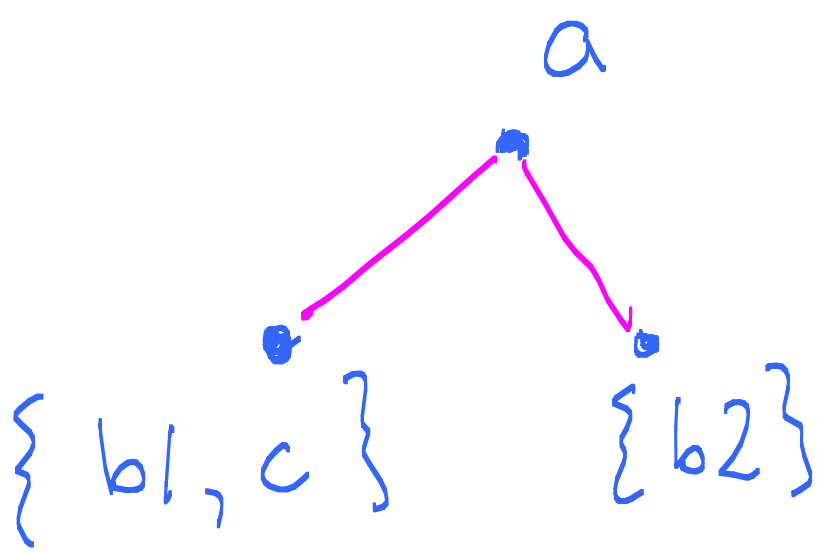


b intersects a's plane, so split b.
c is in front of a.

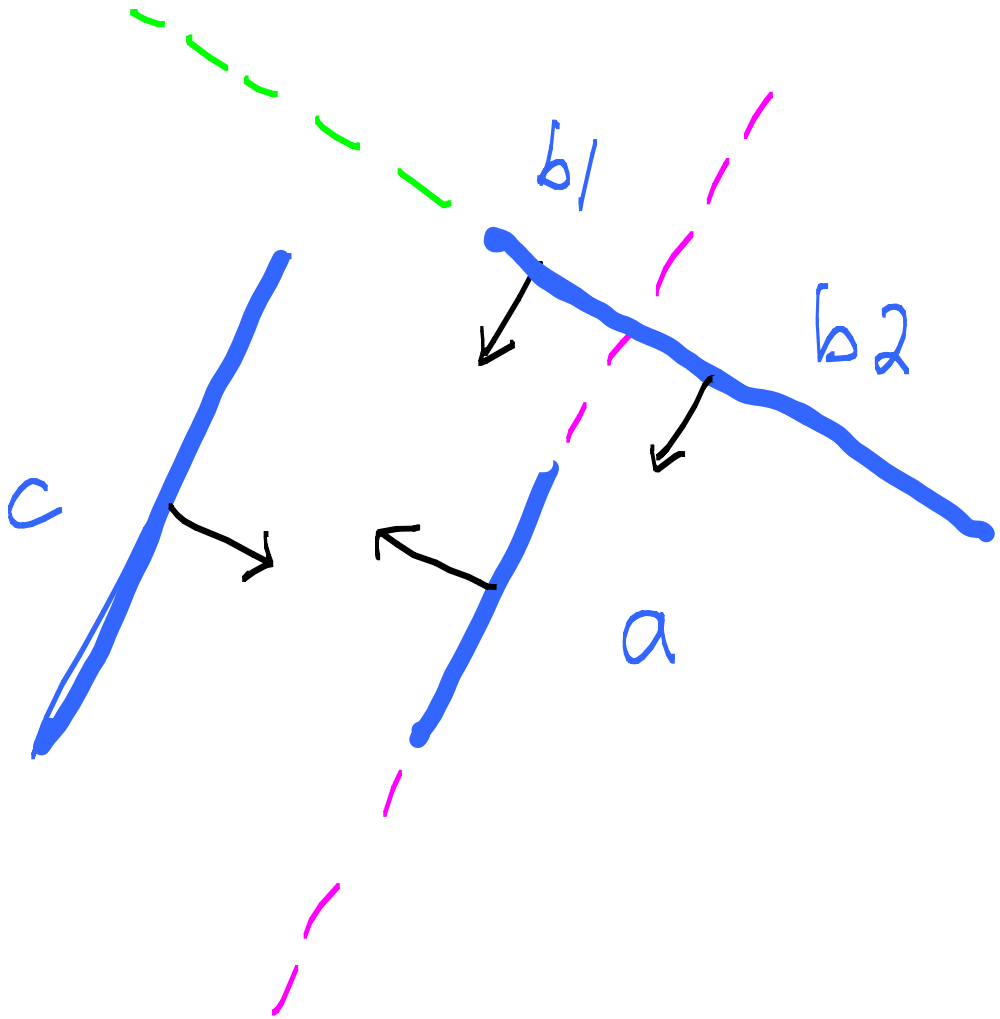
Convention:

Left subtree is in front.
Right subtree is in back.

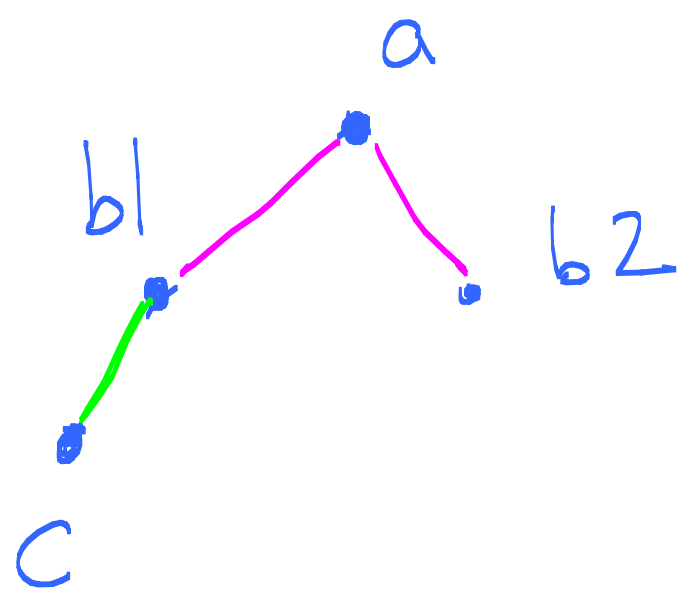




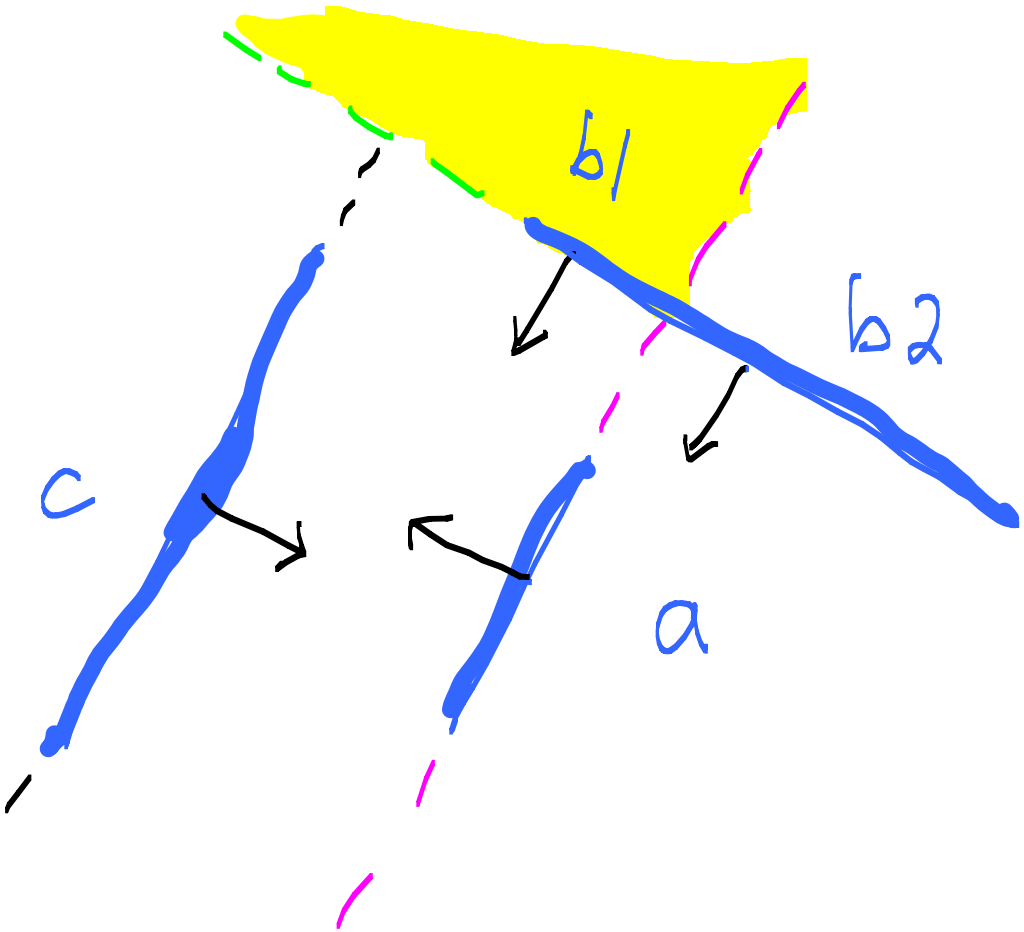
b1 is in front of a.
b2 is in back of a.



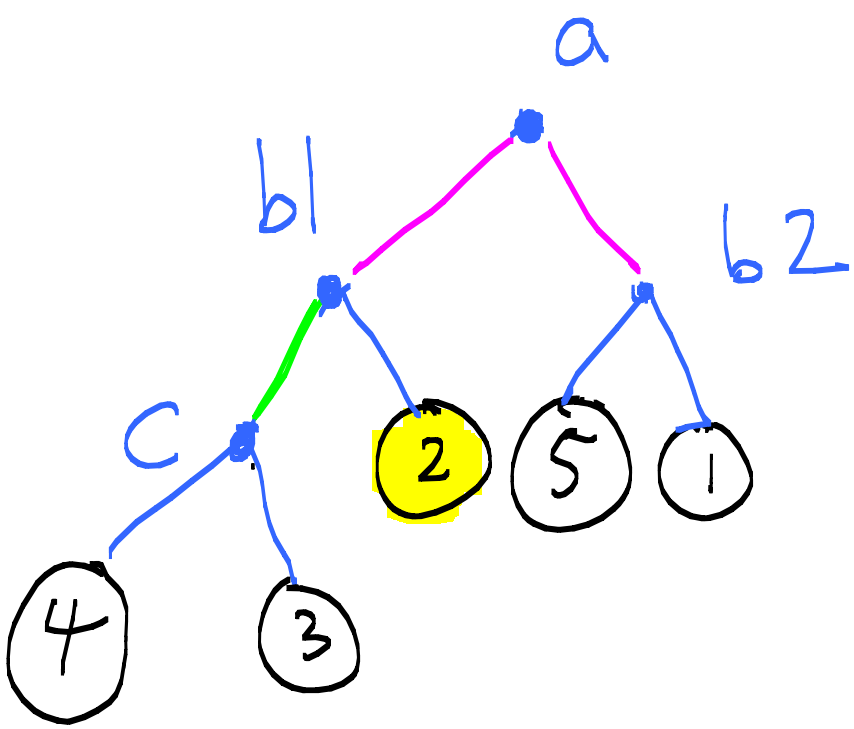
BSP tree



c is in front of b1.

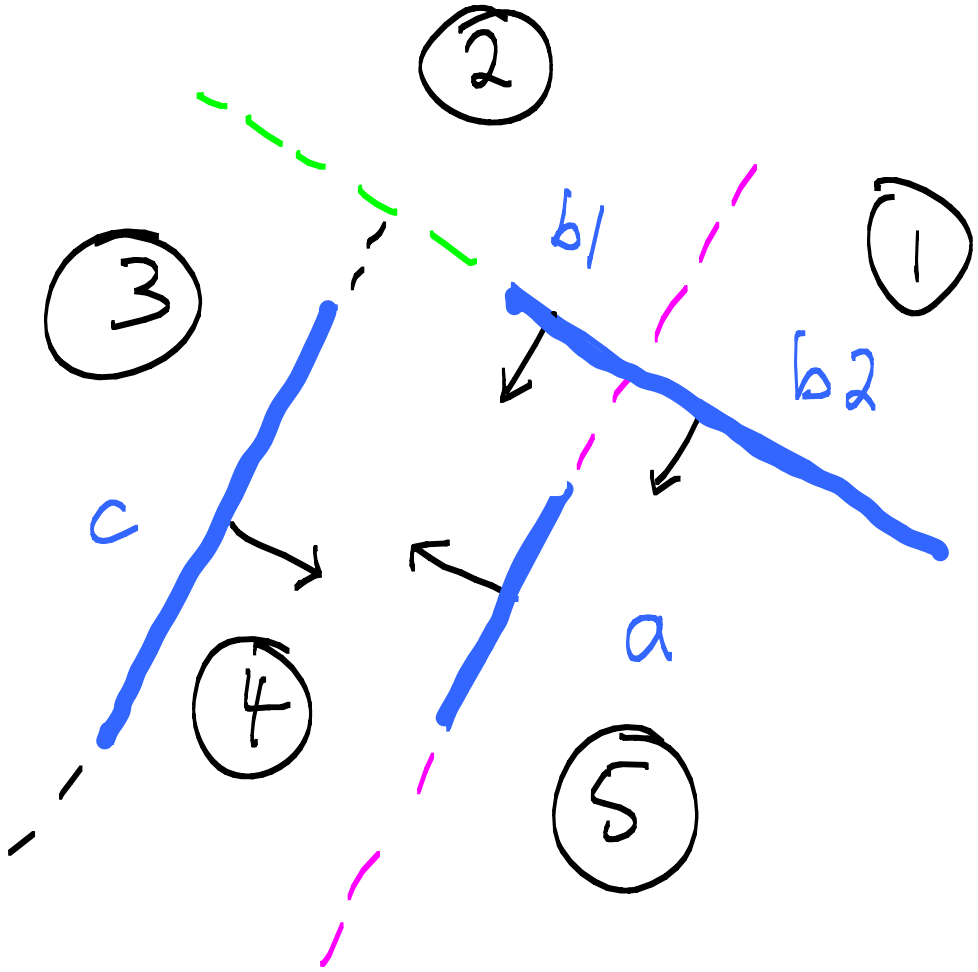


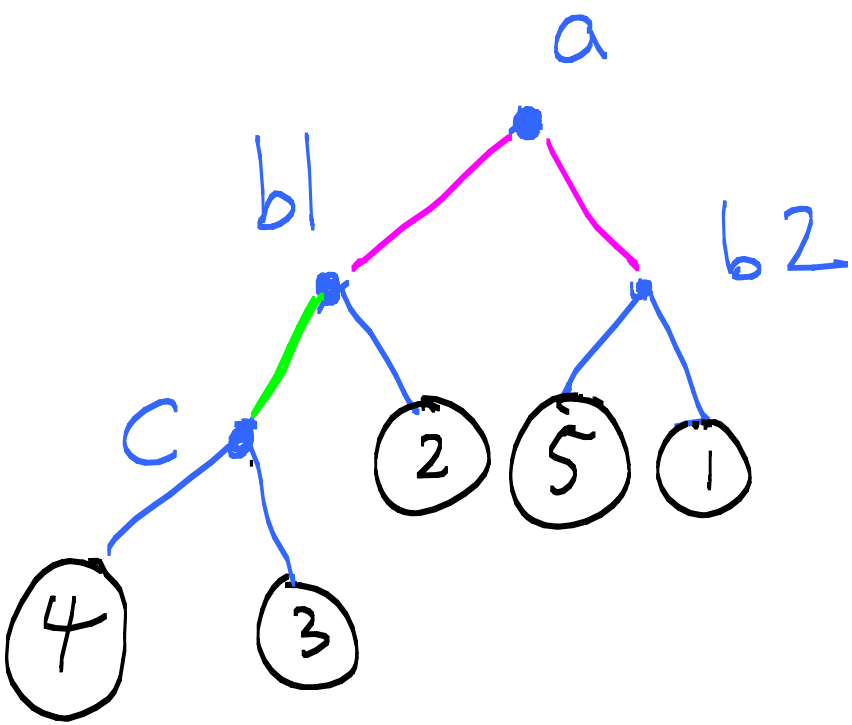
<u>Convention:</u>
Left subtree is in front.
Right subtree is in back.



Space is partitioned into five regions.

How are they numbered ?


2
b1
1
3
b2
c
a
4
5


a
b1
b2
c
2
5
1
4
3

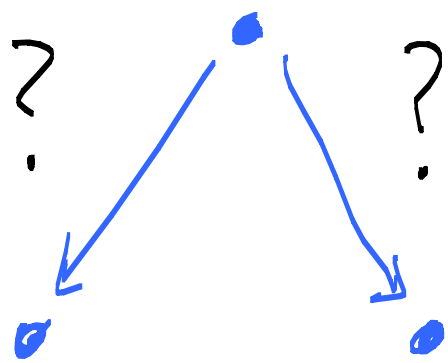
```
makeBSPtree( list of polygons ){
   if list is empty
      return(NULL)
   else {
      select and remove a polygon P from list
      backlist := NULL
      frontlist := NULL
      for each polygon Q in list of polygons
         if all vertices of Q are in front of plane of P
            add Q to frontlist
         else if all vertices of Q are behind plane of P
            add Q to backlist
         else  //  plane P splits Q
            split Q into two polygons and add them to
                  frontlist and backlist, respectively
      return   combine( makeBSPtree(frontlist),  P,
                        makeBSPtree(backlist) )
   }
}
```

Use BSP tree to draw back-to-front

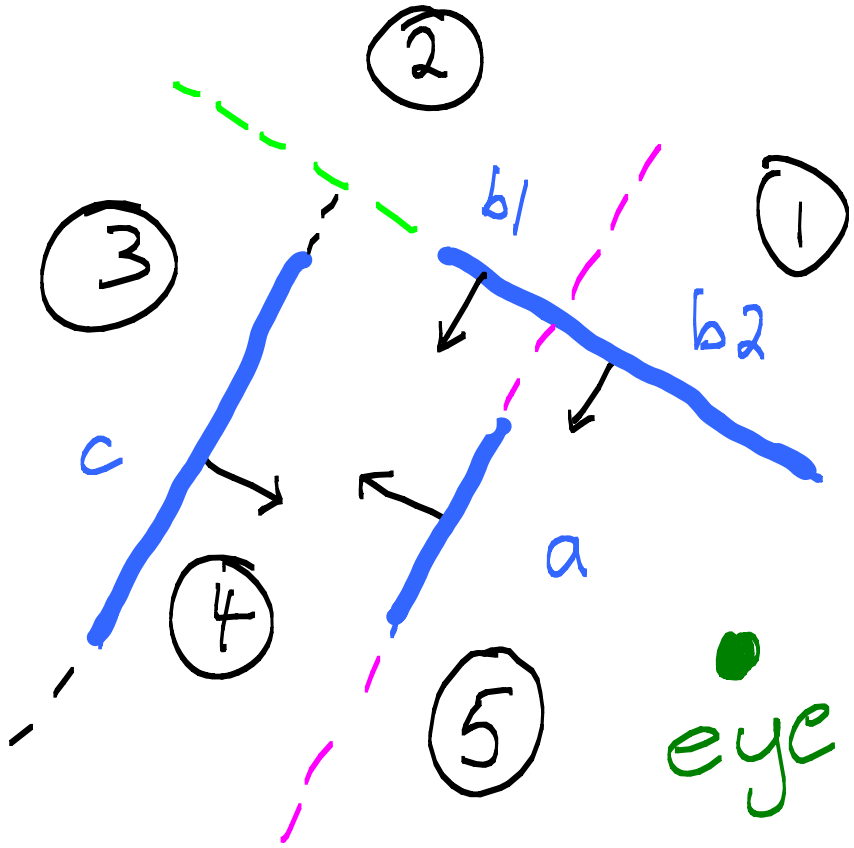
Traverse the BST tree doing depth-first-search, such that:

- draw every polygon (node).

- draw far surfaces before near surfaces. How ?

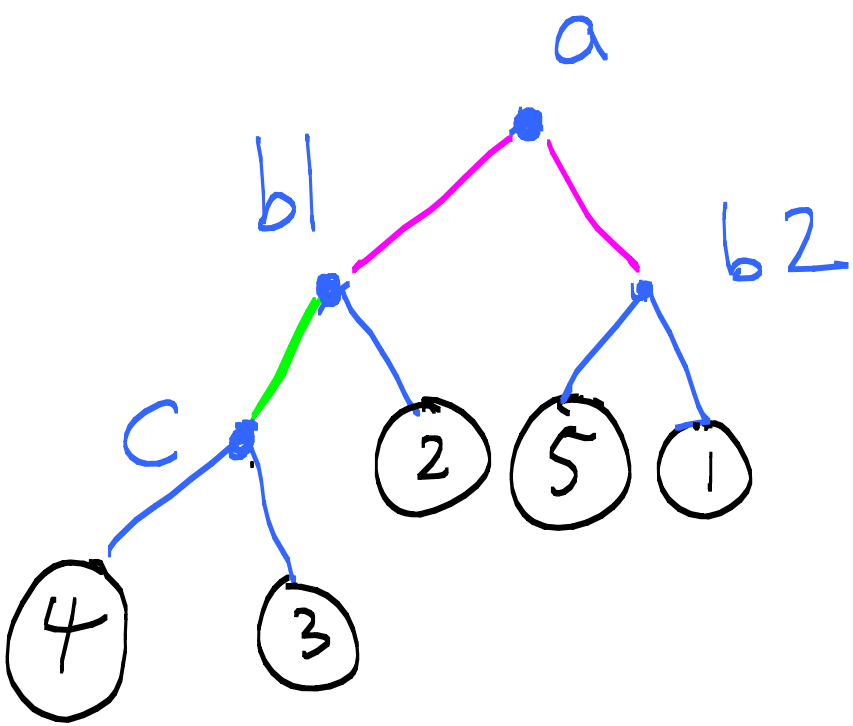


```
displayBSPtree(root, viewer){
  if (root != NULL)
    if (viewer is on the front side of root plane){
      displayBSPtree(backchild, viewer)
      drawPolygon(root)
      displayBSPtree(frontchild, viewer)
    }
    else  {  //  viewer is behind the root note
      displayBSPtree(frontchild,viewer)
      drawPolygon(root)  //  back faced culled,
                              so not necesssary
      displayBSPtree(backchild,viewer)
    }
}
```



Q: What is the order of the leaves visited ?

A: 2, 3, 4, 1, 5



Main advantage of BSP tree method (over Painter or Depth Buffer) ?

If scene is static, then we can precompute the BSP tree.

We can then quickly find back-to-front ordering *from any viewer position*.

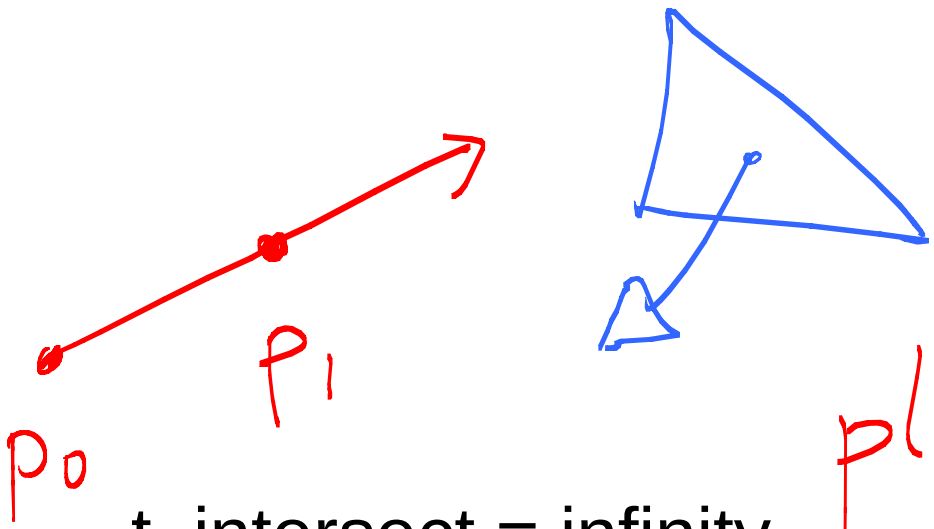
Lecture 8

More Hidden Surface Removal

Efficient Painter
- binary space partition (BSP) tree

Efficient Ray Casting
- spatial partitioning (uniform, octrees)
- bounding volumes

Recall general ray casting

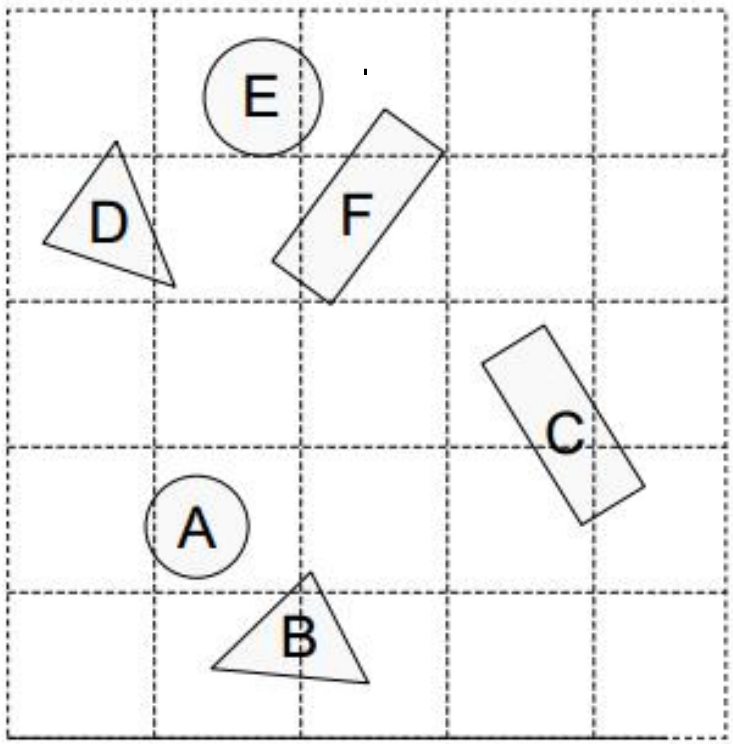


$$p(t) = p_0 + (p_1 - p_0)\,t$$

```
t_intersect = infinity
p  =  NULL
for each polygon {     //  inefficient

        if  (ray intersects the polygon
                and  t_intersect < t_min)
                 t_min = t_intersect
                 p  =  polygon
}
```

Uniform spatial partition

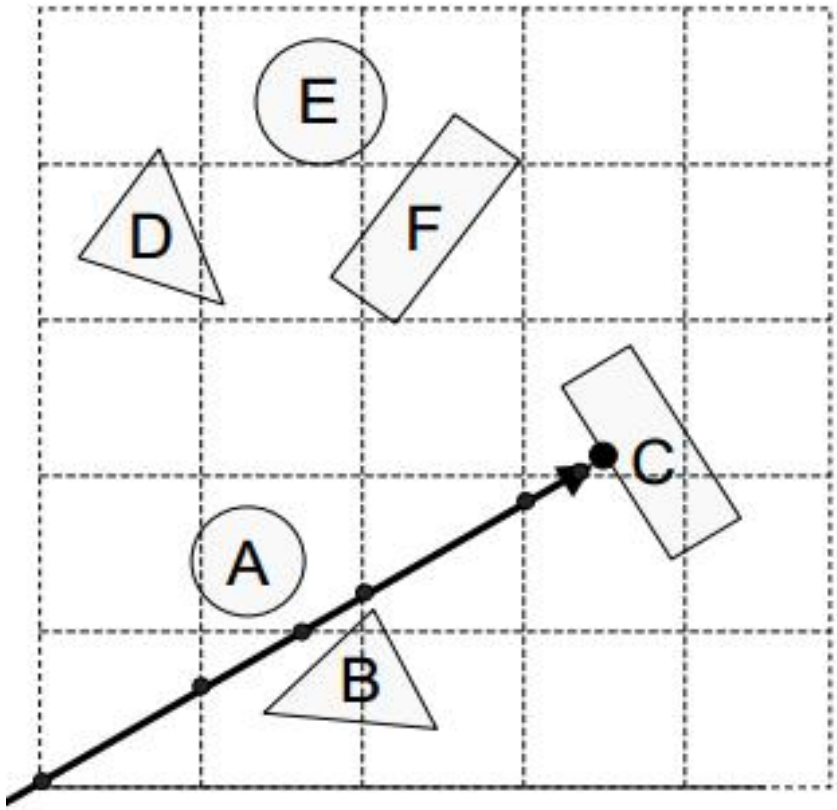


For each spatial cell, maintain a list of objects that intersect it.

Each object may intersect multiple cells.

http://www.cs.princeton.edu/courses/archive/spring14/cos426/lectures/12-ray.pdf
starting at slide 56

Ray casting

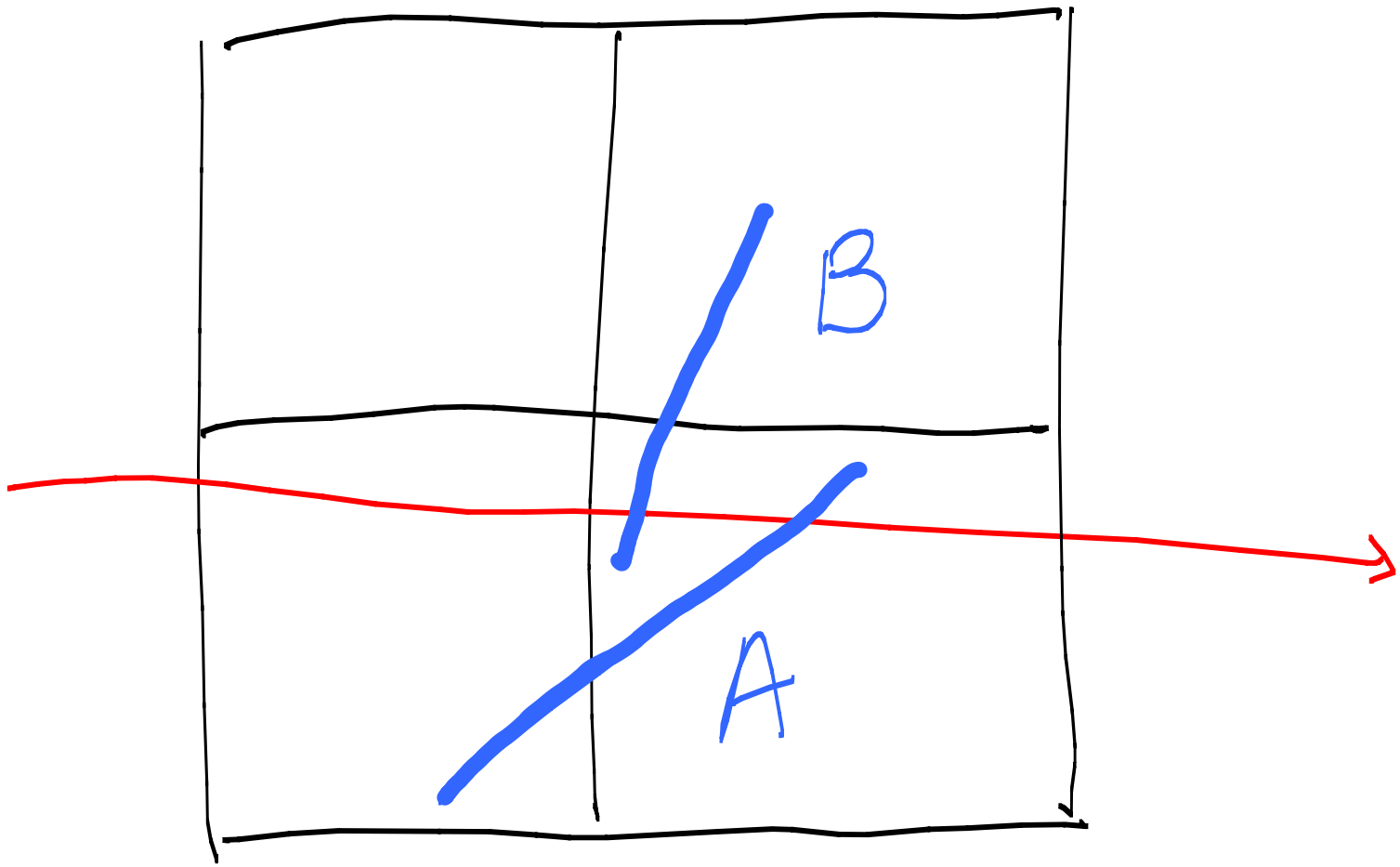


Examine only cells that the ray intersects.

```
t =  infinity
p = NULL

current_voxel = voxel containing the starting point of ray
while (t == infinity)
    for each surface in current voxel {
        t_intersect = distance to surface along ray
        // infinite if no intersection

        if (t_intersect < t)  {
            t = t_intersect
            p = surface
            }
    }
    current voxel = next voxel hit by the ray
}
```

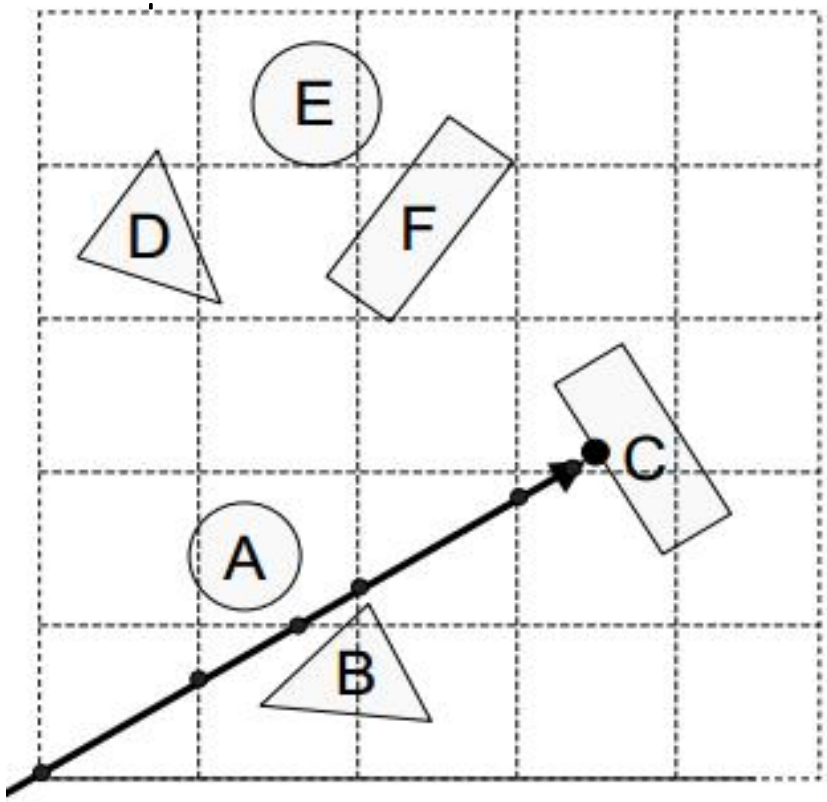

B
A

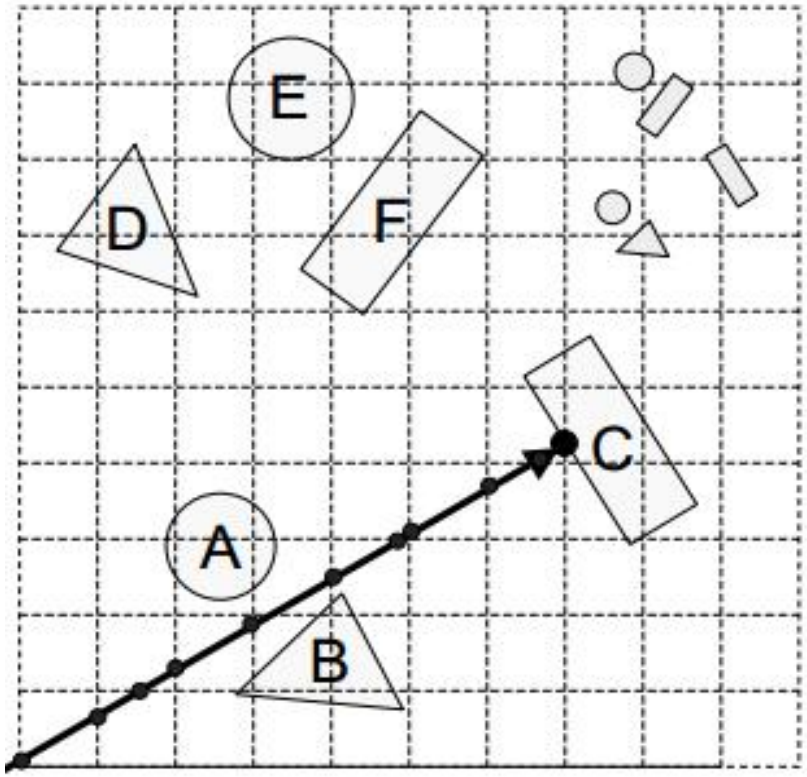
```
t =  infinity
p = NULL

current_voxel = voxel containing the starting point of ray
while (t == infinity)
    for each surface in current voxel {
        t_intersect = distance to surface along ray
        // infinite if no intersection

        if (t_intersect < t) and
            (intersection point belongs to current voxel) {
            t = t_intersect
            p = surface
        }
    }
    current voxel = next voxel hit by the ray
}
```

ASIDE: In the lecture, I doubted the stopping condition of the algorithm. But everything was fine. The "while loop" condition is that t == infinity. As soon as you find an intersection point that is within the current voxel, t will get assigned a finite value and the algorithm will stop.

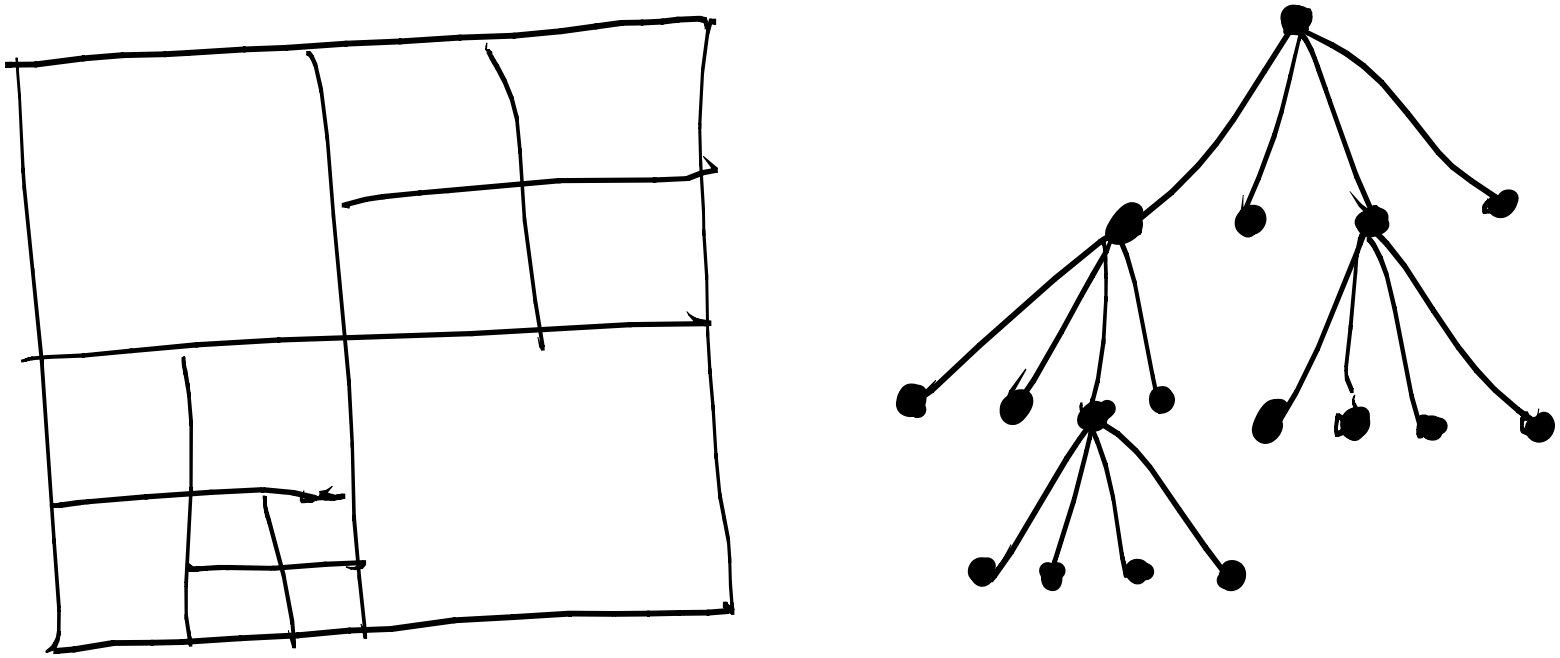




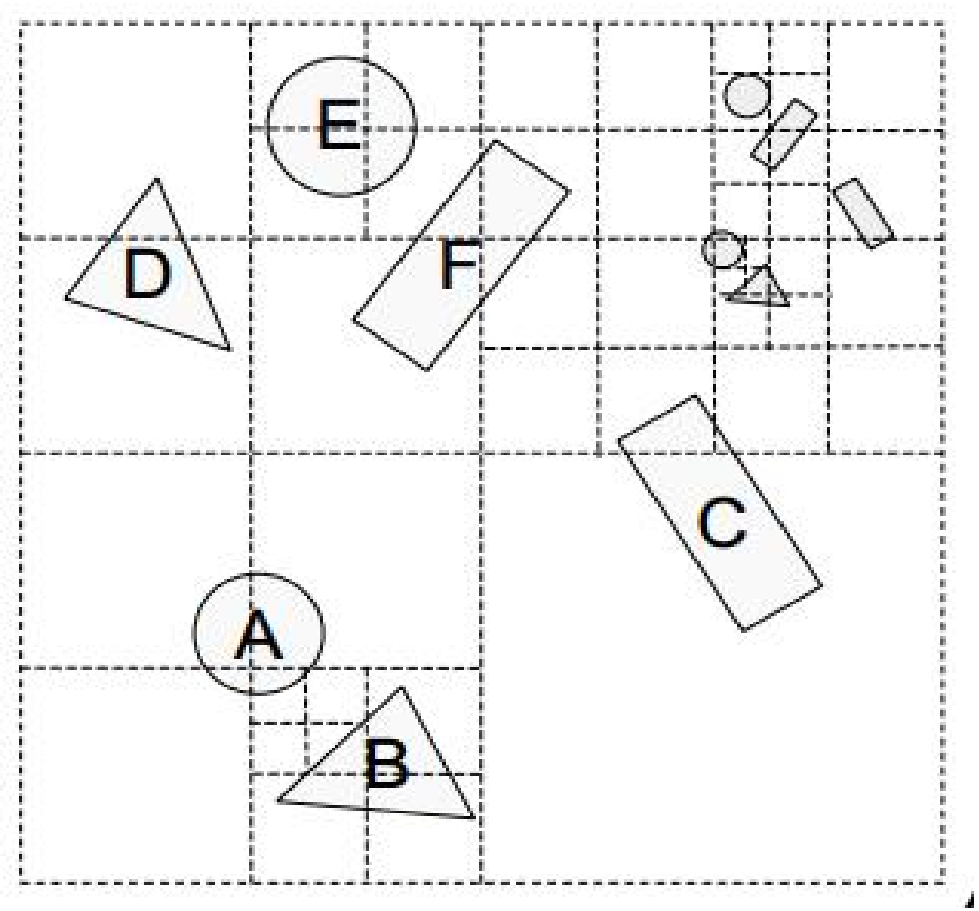
Using a coarser grid means there are typically more surfaces per voxel (bad), but fewer voxels (good).

Non-uniform spatial partition

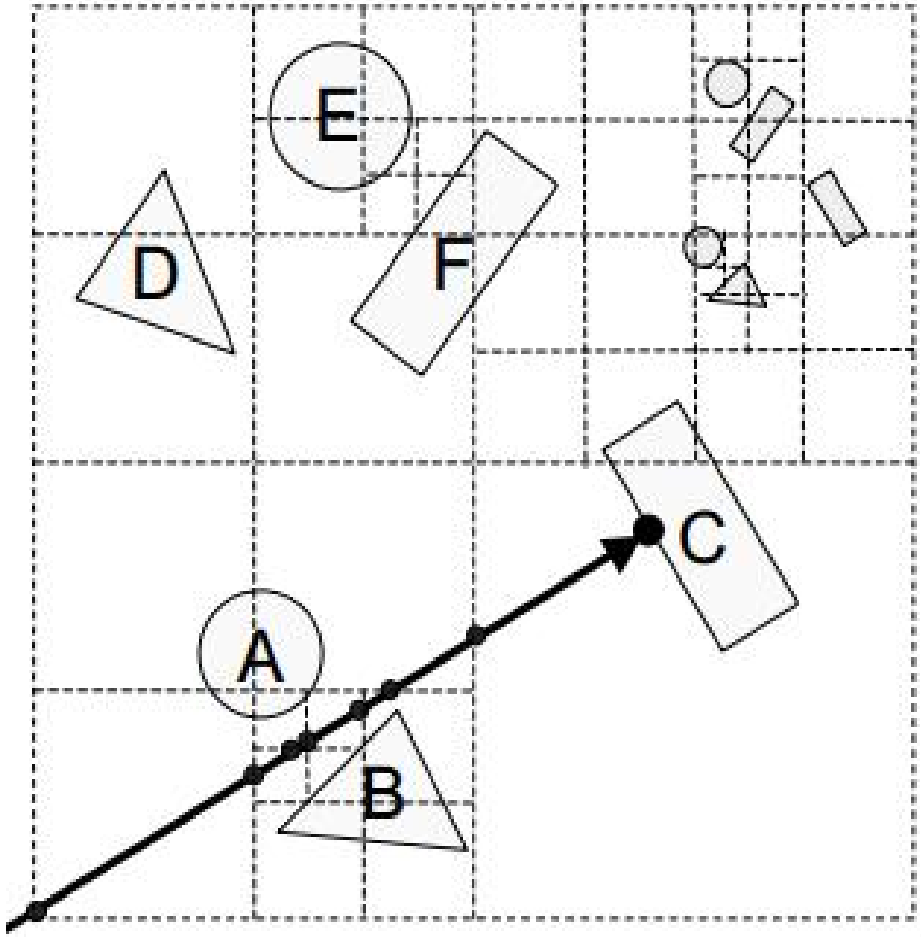
2D - "quadtree"



2D - "quadtree"

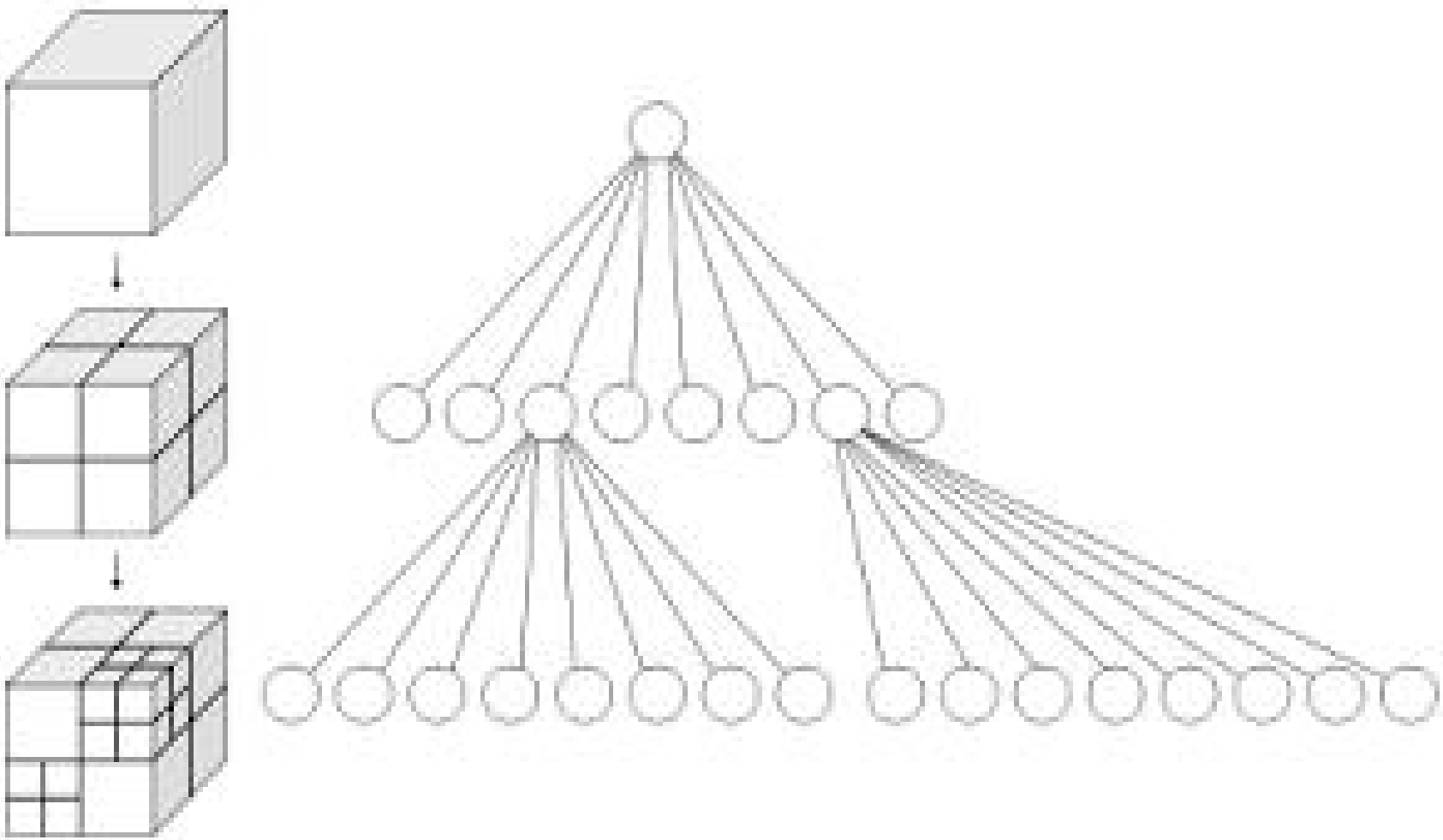


Again, for each spatial cell, maintain a list of objects that intersect it.

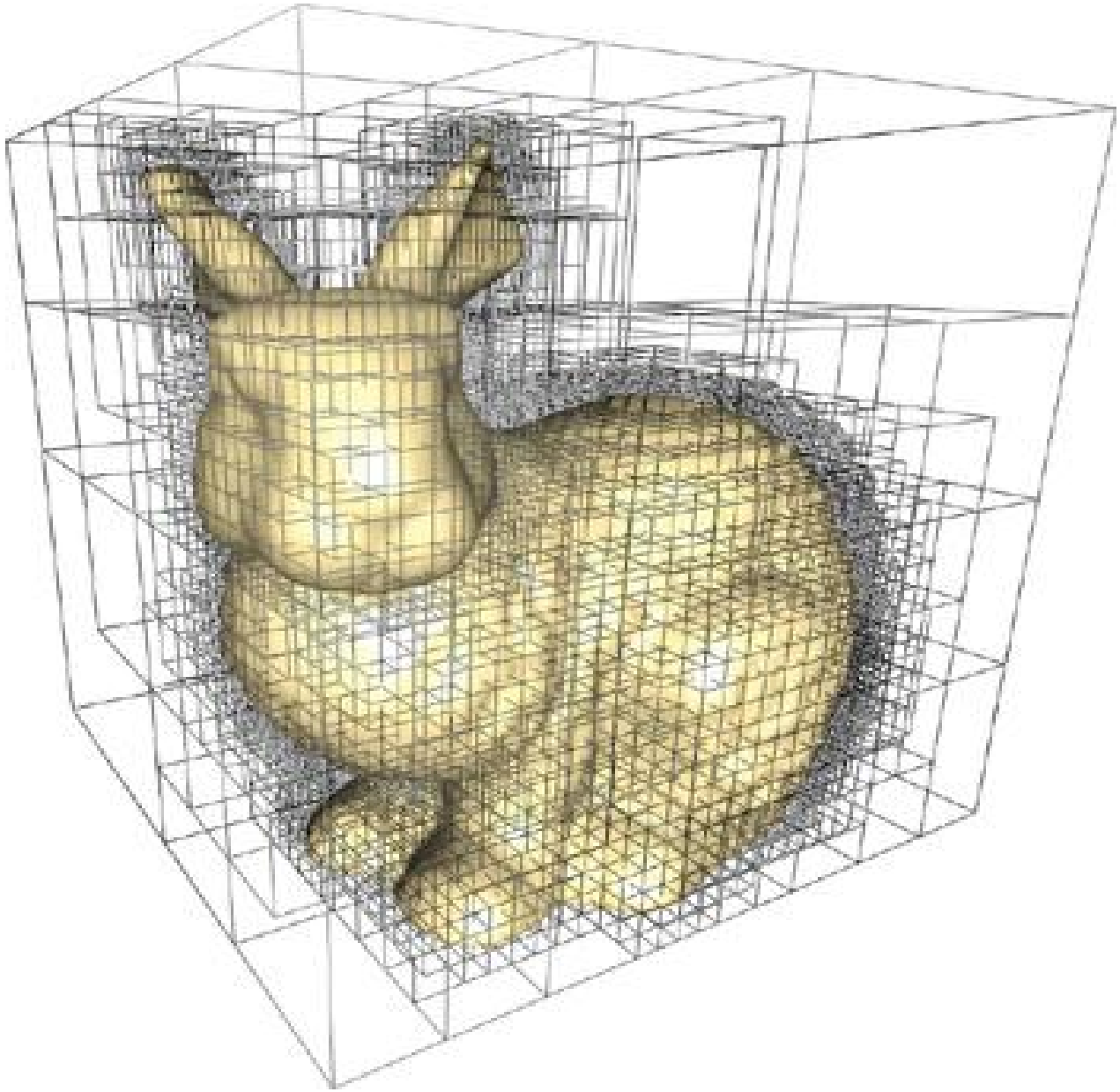


The same ray casting algorithm works fine.
But we need to specify how to compute next voxel.
(Not obvious -- Exercise.)

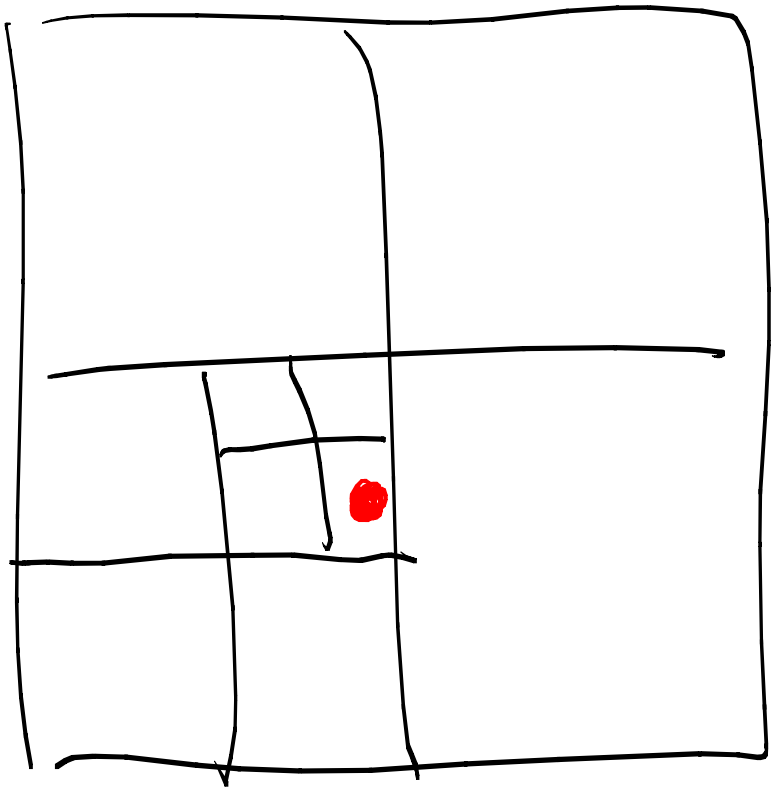
3D - "octree"



3D - "octree"



Octrees can be an unstable representation when surfaces move e.g. animation.



e.g. what happens when the red surface moves to the right ?

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Efficient Ray Casting
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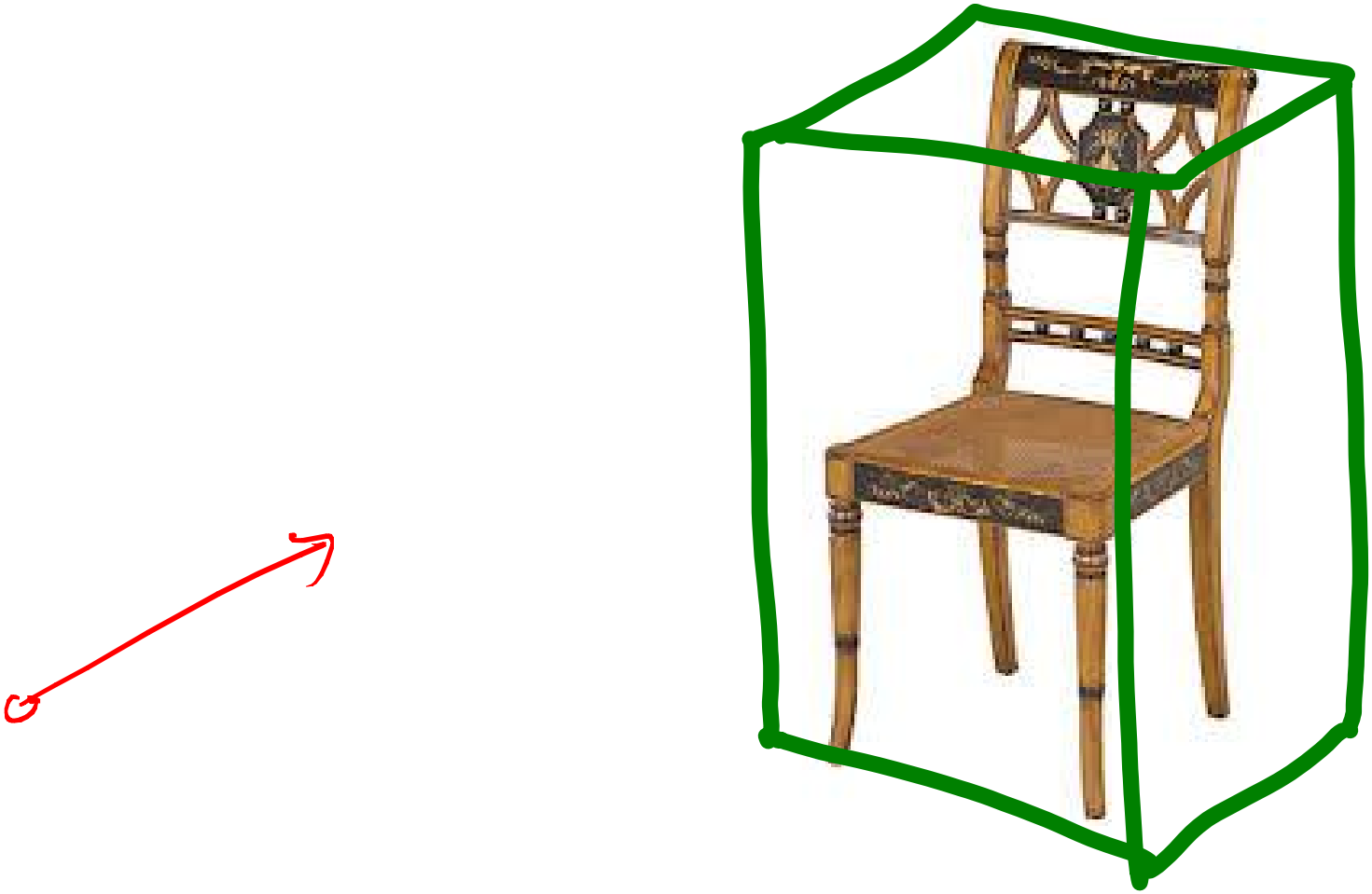
- bounding volumes

Bounding Volumes

Does the ray intersect the chair ?

Bounding Volumes



IF the ray intersects the chair,
THEN it intersects the bounding volume.

IF the ray intersects the chair,
THEN it intersects the bounding volume.

$\neq$

IF the ray intersects the bounding volume
THEN the ray intersects the chair.

[Second statement is false]

IF the ray intersects the chair,
THEN it intersects the bounding volume.

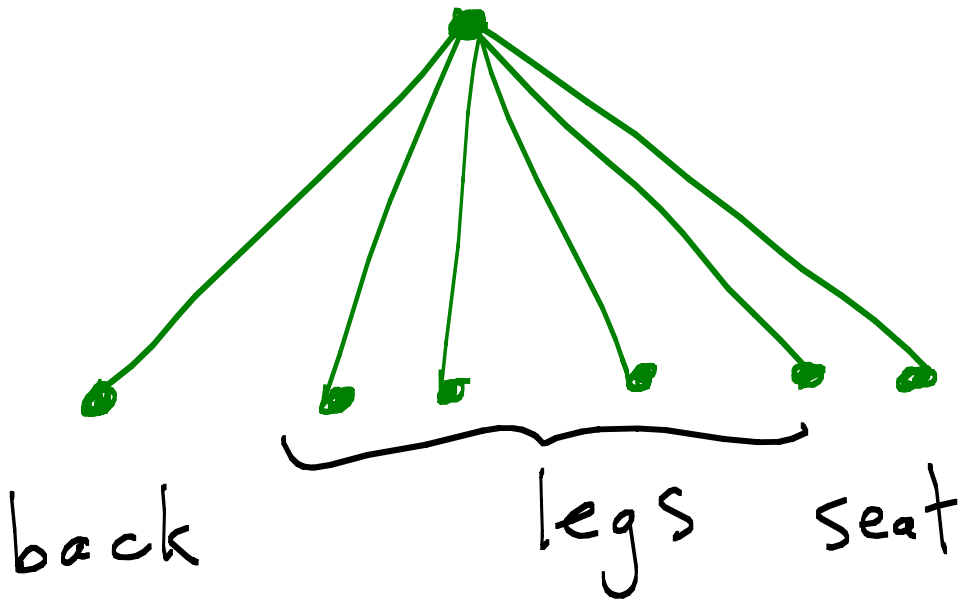
$\simeq$

IF the ray <u>doesn't</u> intersect the bounding volume
THEN the ray <u>doesn't</u> intersect the chair.

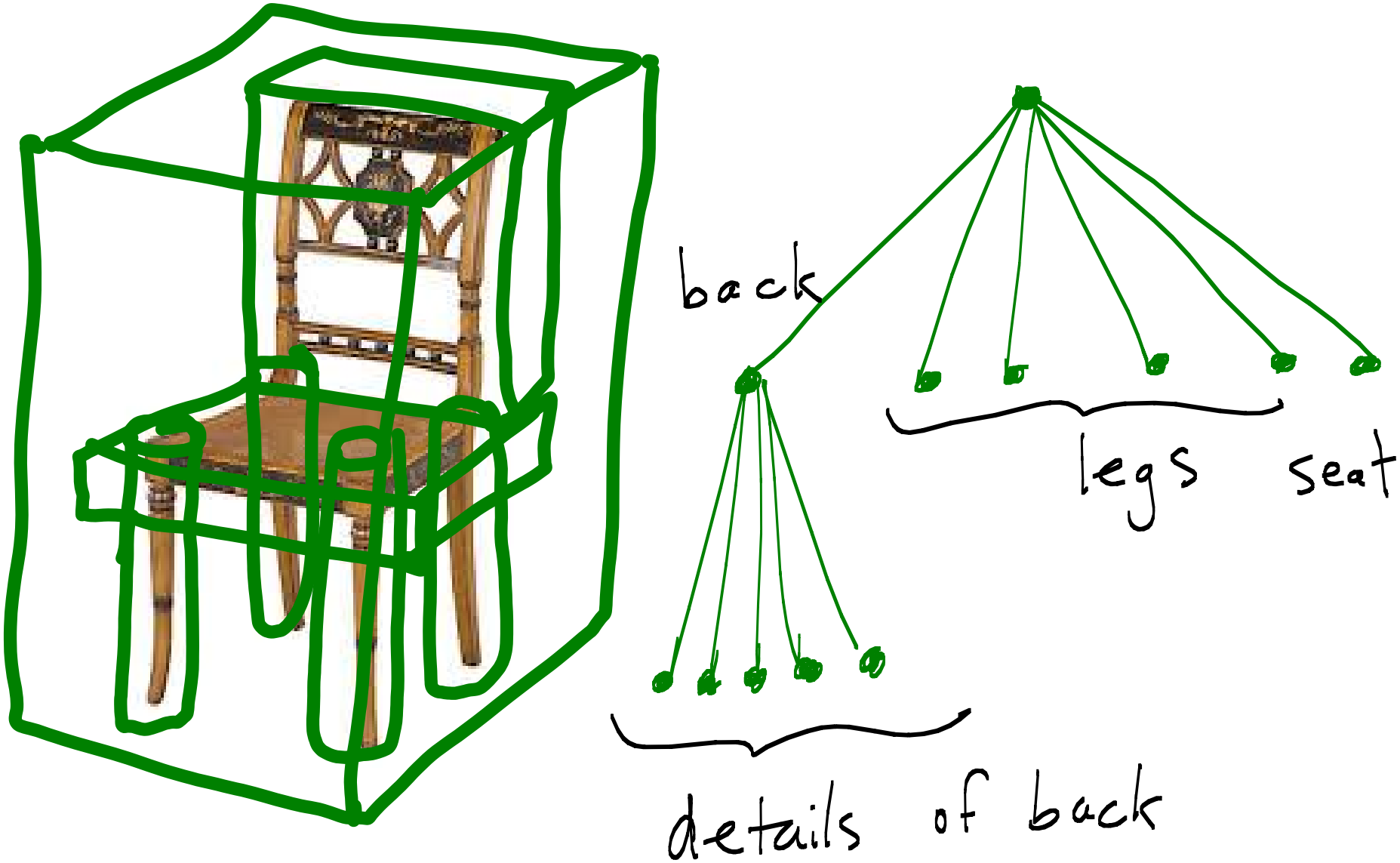
Note the analogy to Cohen Sutherland line clipping.

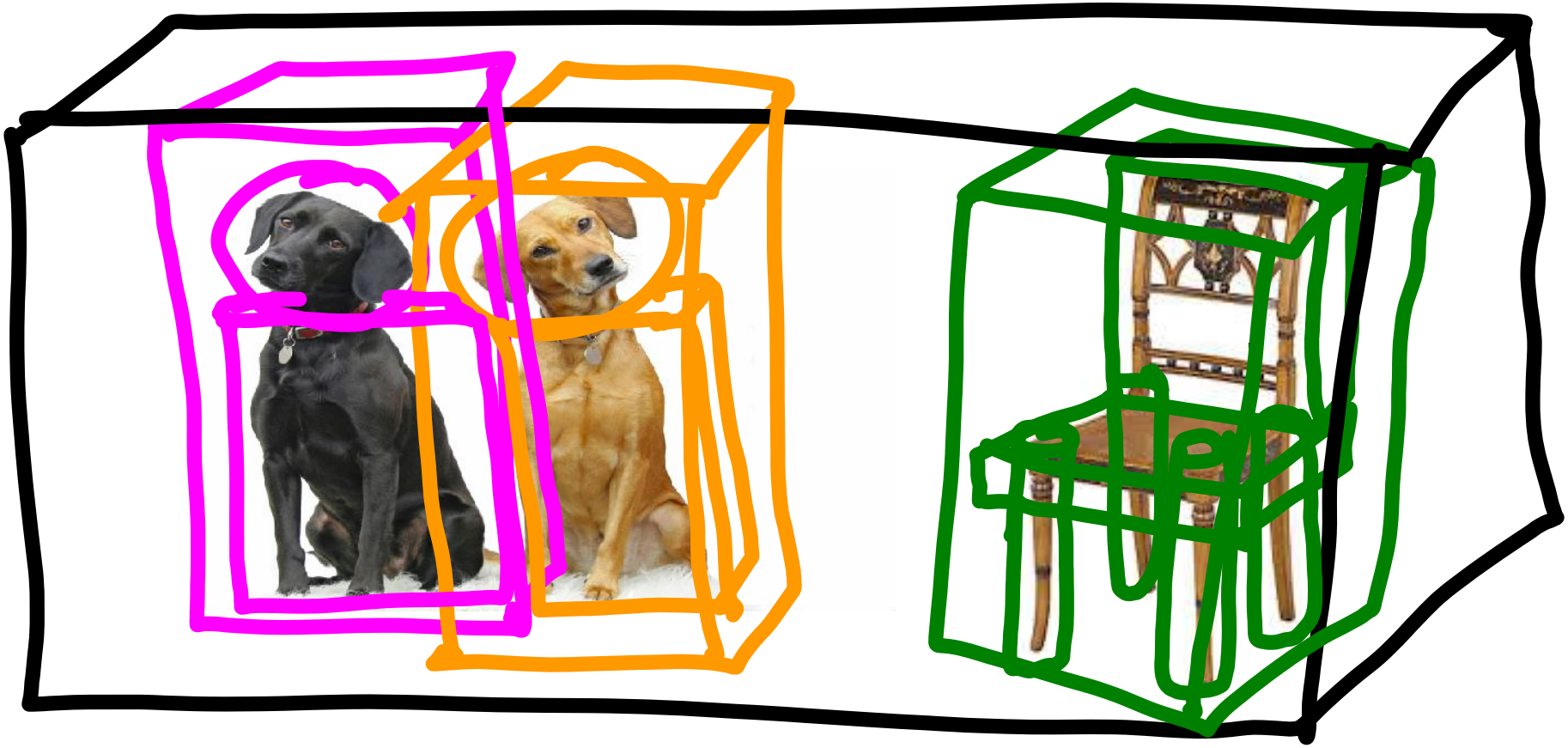
A quick test can be used for trivial rejection.

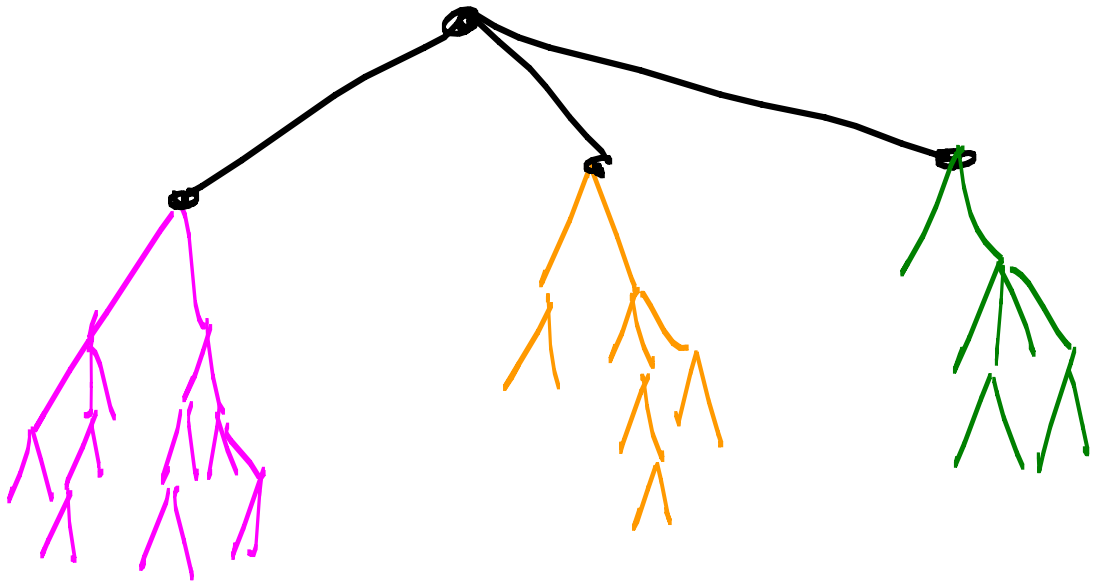
Bounding Volume Hierarchy



2ND level shown


back
legs
seat
details of back

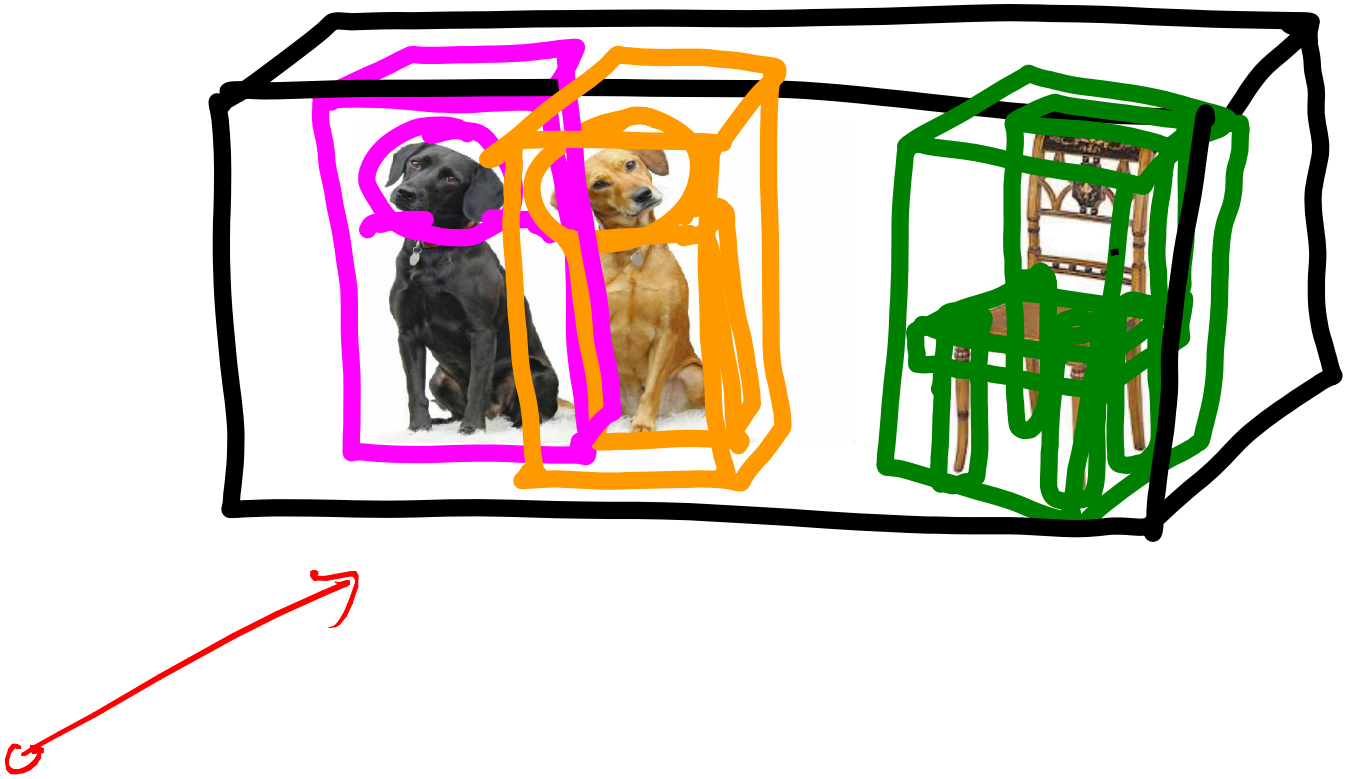




Internal nodes represent bounding volumes
Leaves represent bounding volume of a single polygon.

Q: What is the BV relationship between child and parent ?
A: The child's BV is contained in the parent's BV.

Q: What is the BV relationship between siblings ?
A: none



To cast a ray and find the closest object, we traverse the bounding volume hierarchy tree *of the whole scene*.

Use depth first search.

Q: What are we searching for?

Q: What does it mean to visit a node?

```
p  =  NULL      //   pointer to polygon
t  =  infinity  //   closest point on ray

void  traverseBVH( ray, node){
    intersect ray with node's bounding volume
    if    0 <=  t_intersect < t   {

        if (node is a leaf)
            compute t_intersect
            if (0 <=  t_intersect < t)
                update p and t

        else    // node is a bounding volume
            for each child of node
              traverseBVH( ray, child)
    }
}
```

Q: How to make this more efficient ?

A: "for each child of node" loop should test closest child nodes first. (See Exercises.)

Reminder:

A1 is due Monday at 11:59 PM.