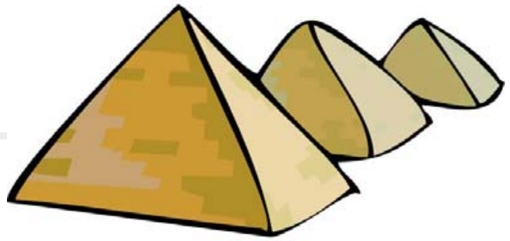
Visible-Surface Detection Methods

Chapter ?
Intro. to Computer Graphics
Spring 2008, Y. G. Shin

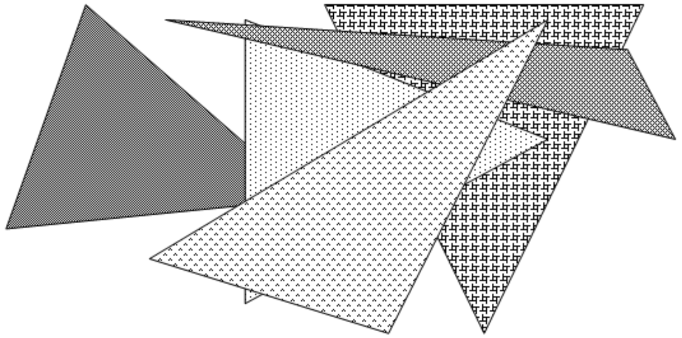
The Visibility Problem



[Problem Statement]

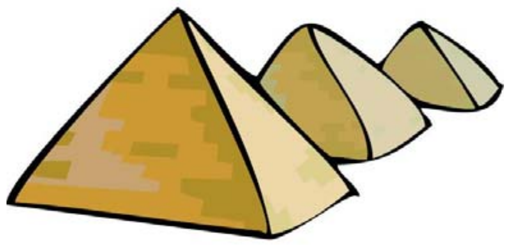
GIVEN: a set of 3-D surfaces, a projection from 3-D to 2-D screen,

DETERMINE: the nearest surface encountered at any point on 2-D screen



- Removal of hidden parts of picture definition
  - Hidden-surface removal : surface rendering
  - Hidden-line removal : line drawing

Techniques



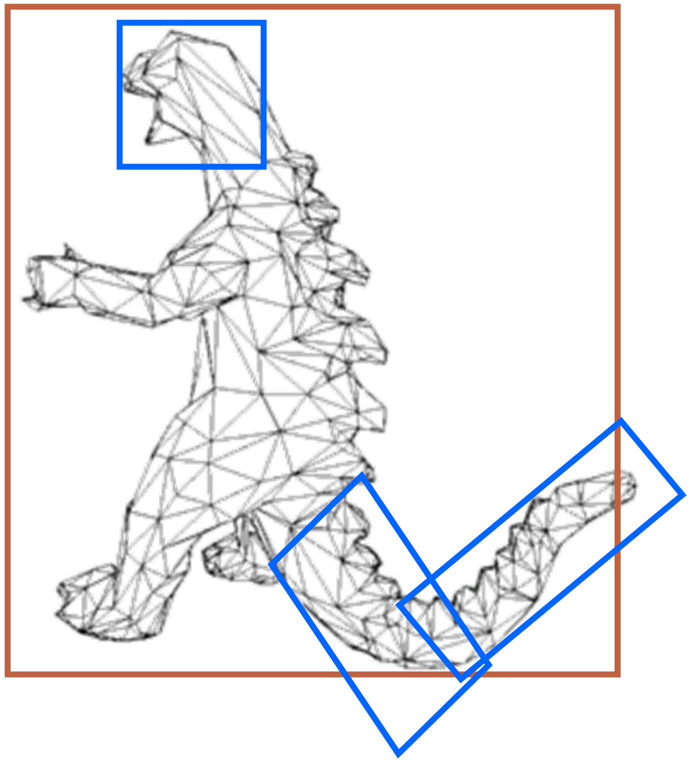
- Visible-surface algorithms are 3D versions of sorting, i.e., depth comparison
- Avoid comparing all pairs of objects using the following coherence.
- Coherence
  - object coherence: no comparison between components of objects if objects are separated each other
  - face coherence: surface properties vary smoothly across a face
  - edge coherence: an edge changes its visibility not frequently

Techniques

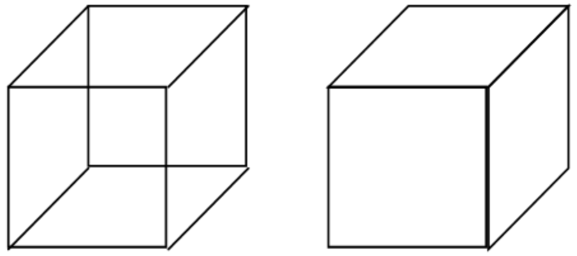
- implied edge coherence: line of intersection of two face can be determined from two intersection points
- scan-line coherence: little change in visible spans from one scanline to another
- area coherence: a group of pixels is often covered by the same visible surface
- span coherence: (special case of area coherence) homogeneous runs in a scanline
- depth coherence: adjacent parts of the same surface are typically close in depth
- frame coherence: animation frames contain small changes from the previous frame

Techniques for Efficient Algorithms

- Bounding volumes
  - approximate objects with simple enclosures before making comparisons.
  - the simplest approximate enclosure is a boundary box

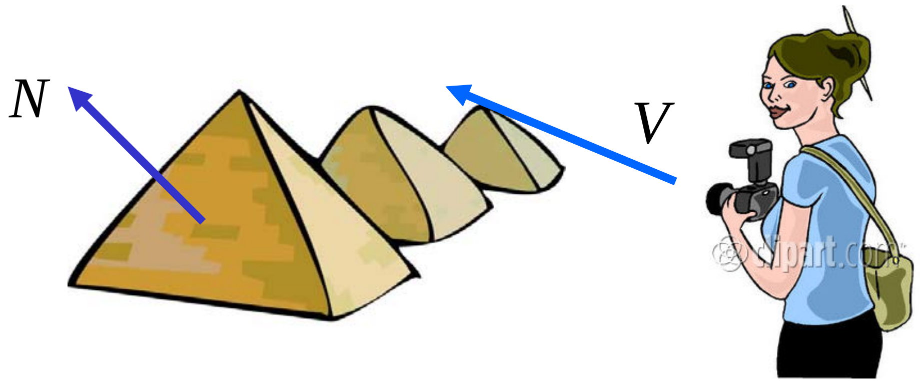


Backface Removal (Backface Culling)



- Remove entire polygons that face away from the viewer
- If we are dealing with a single convex object, culling completely solves the hidden surface problem

Geometric test for the visibility



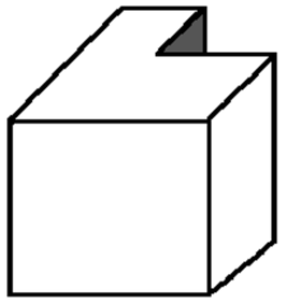
$$V \cdot N < 0 \;\; : \text{visible surface}$$
$$V \cdot N = 0 \;\; : \text{silhouettes}$$

Back-face Culling More..

- Vertex order in surface normal calculation

  ← counterclockwise in the right-handed viewing system

- Backface culling after viewing transformation
  - simpler culling test (consider only z component of normal vectors since COP is at infinity after view-volume normalization)
  - more points to transform
- Partially hidden faces cannot be determined by back-face culling
- Not useful for ray-casting, radiosity



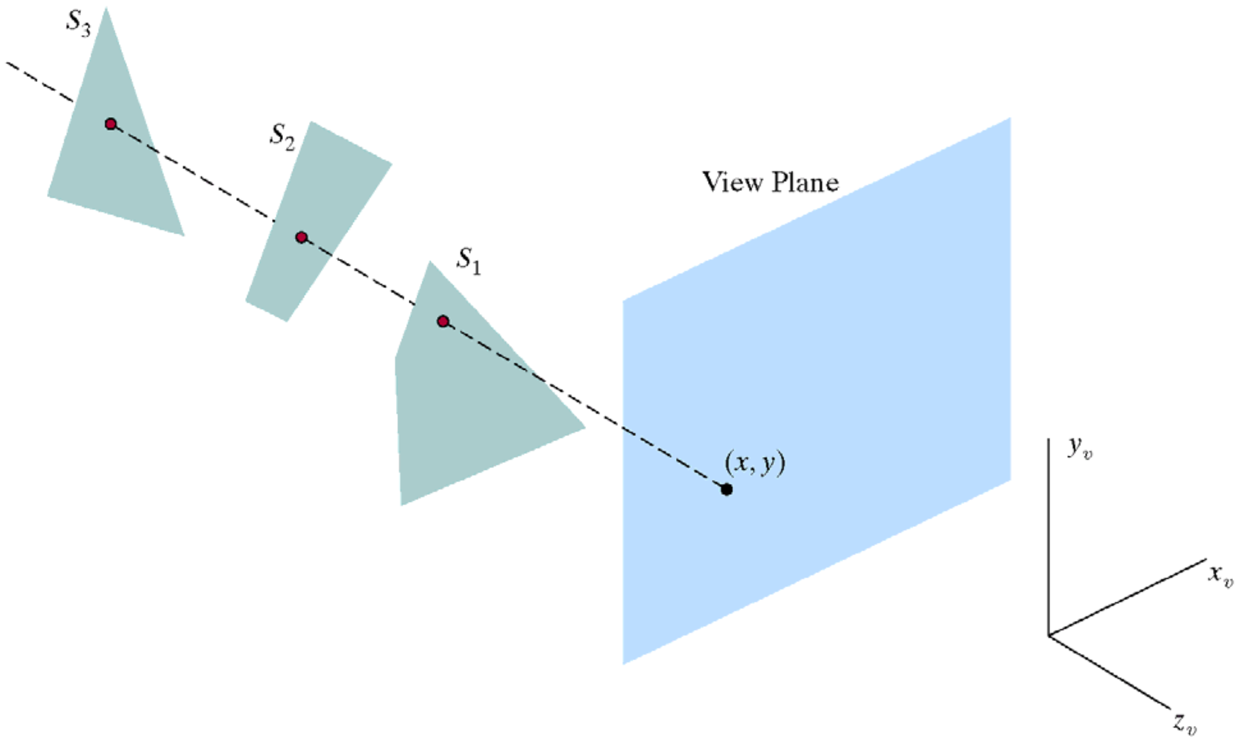
Depth-Buffer (Z-buffer)

- The basic idea is to test the z-depth of each surface to determine the closest (visible) surface
- Use two buffers
  - refresh buffer : image value (intensity)
  - depth buffer (z-buffer) : z-value
- Algorithm

```
loop on objects
   loop on y within y range of this object
       loop on x within x range of this scan line of
                    this object
            if z(x,y) < zbuf[x,y]
                     zbuf[x,y] = z(x,y)
          image[x,y] = shade(x,y)
```

Depth-Buffer (Z-Buffer)

- Z-Buffer has memory corresponding to each pixel location
  - Usually, 16 to 20 bits/location.



Z-Buffer Algorithm

Calculating z values of plane: $Ax + By + Cz + D = 0$

$$z = \frac{-Ax - By - D}{C}$$

Use incremental calculation

$z_{(x,y)}$: the depth of position (x, y)

$$z_{(x+1,y)} = \frac{-A(x+1) - By - D}{C} = z_{(x,y)} - \frac{A}{C}$$

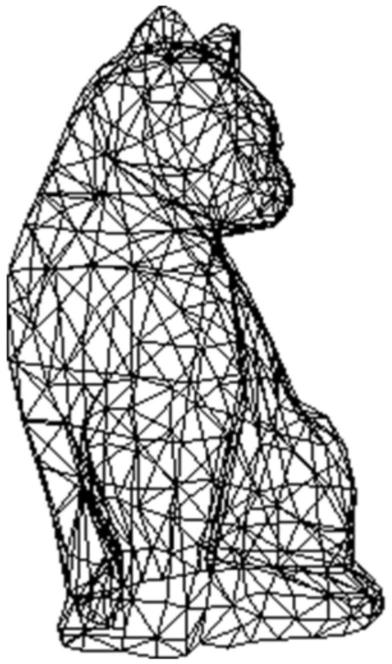
$$z_{(x,y+1)} = \frac{-Ax - B(y+1) - D}{C} = z_{(x,y)} - \frac{B}{C}$$

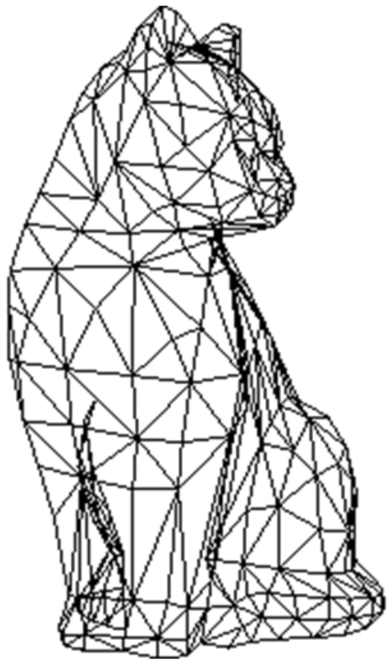
Use interpolation.

Z-Buffer Algorithm

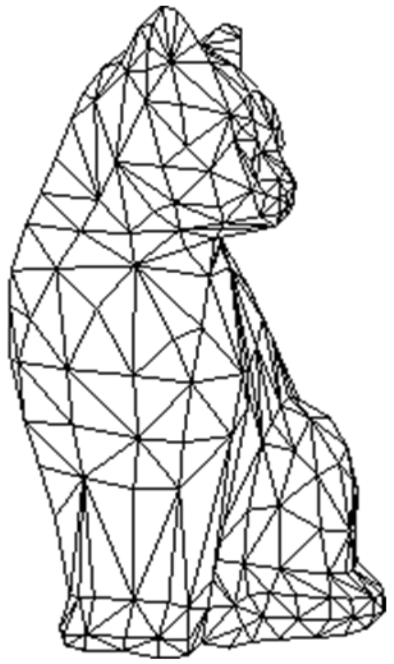
- *pros:*
  - easy implementation (directly in hardware)
  - no sorting of surfaces
  - O(# of objects × pixels)
  - good rendering algorithm with polygon models
- *cons:*
  - additional buffer (z-buffer)
  - aliasing (point-sampling)
  - difficult to deal with transparent object

Z-Buffer Algorithm





Backface culling



Z-buffer algorithm

Accumulation Buffer (A-Buffer)

- An extension of the depth-buffer for dealing with anti-aliasing, area-averaging, transparency, and translucency
- The depth-buffer method identifies only one visible surface at each pixel position
  - Cannot accumulate color values for more than one transparent and translucent surfaces
- The same resolution as z-buffer
- Part of OpenGL and DirectX
- Costly for real-time rendering

Accumulation Buffer (A-Buffer)

- Each position in the A-buffer has two fields
  - Depth field: Stores a depth value
  - Surface data field
    - RGB intensity components
    - Opacity parameter (percent of transparency)
    - Depth
    - Percent of area coverage
    - Surface identifier
- Even *more* memory intensive
- Widely used for high quality rendering

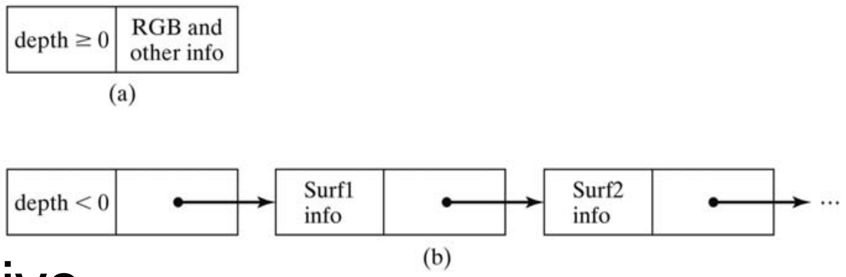


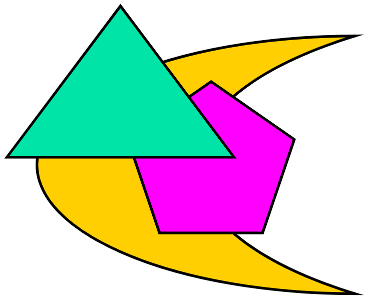
Figure 9-9

Two possible organizations for surface information in an A-buffer representation for a pixel position. When a single surface overlaps the pixel, the surface depth, color, and other information are stored as in (a). When more than one surface overlaps the pixel, a linked list of surface data is stored as in (b).

Painter's Algorithm

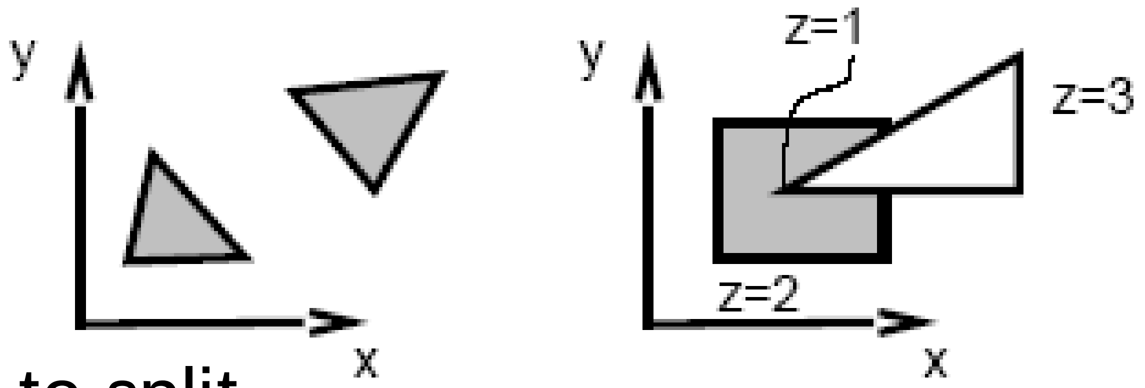
- Draw polygons as an oil painter might: The farthest one first. (Used in PostScript)
- [Algorithm]

```
sort objects by depth, splitting if necessary to
handle intersections
loop on objects (drawing from back to front)
    loop on y within y range of this object
        loop on x within x range of this
        scan line of this object
            image[x,y] = shade(x,y)
```

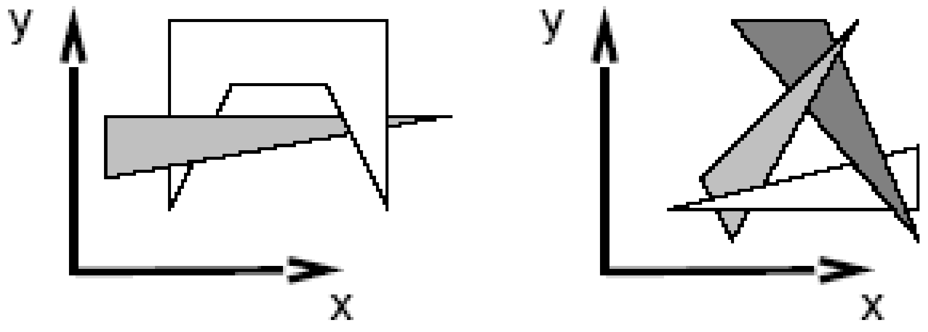


Pinter’s Algorithm (z-overlap case)

- Easy case of depth comparison

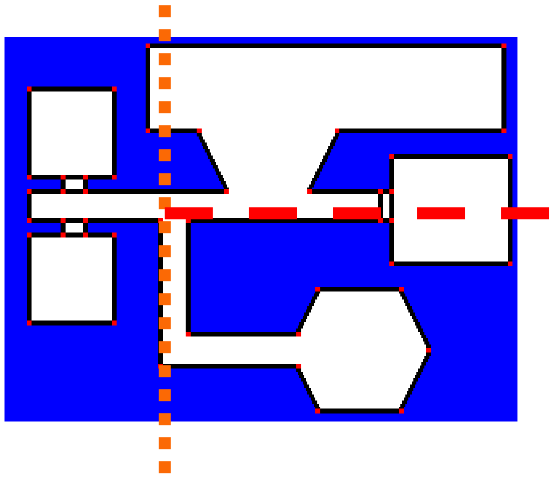
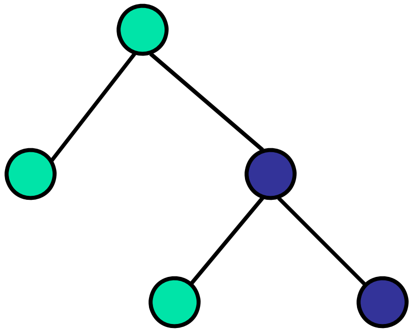


- Need to split

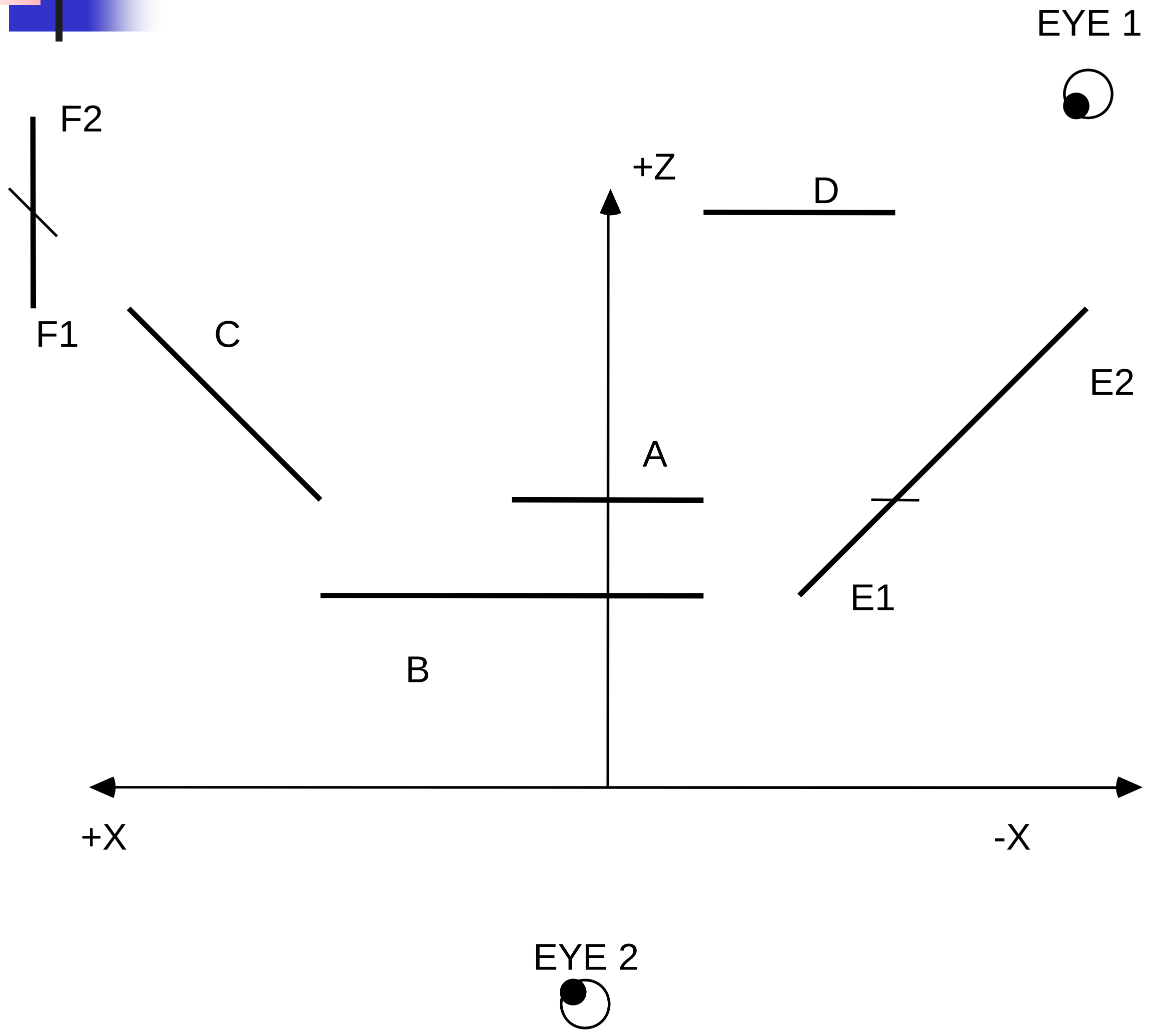


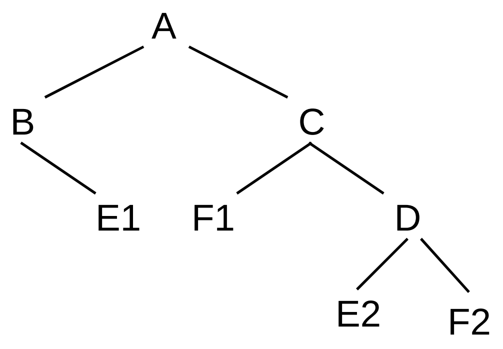
Binary Space-Partitioning Trees (BSP trees)

- Binary Space Paritition is a relatively easy way to sort the polygons relative to the eyepoint
- Fuchs, Kedem, and Naylor
- The scan conversion order is decided by building a binary tree of polygons, the BSP tree.
- Fast traversal and viewpoint independent order
- Clusters that are on the same side of the plane as the eye-point can obscure clusters on the other side.

BSP tree



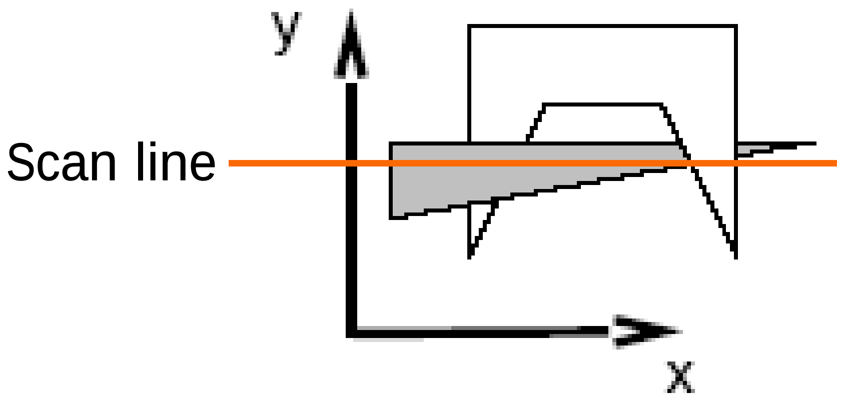


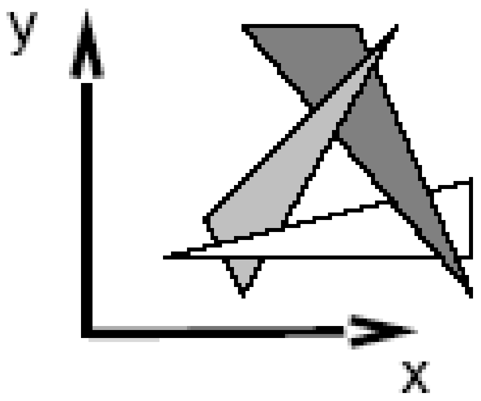
BSP trees

- Disadvantages
  - significantly more than input polygons - more polygon splitting may occur than in Painter's algorithm
  - appropriate partitioning hyperplane selection is quite complicated and difficult (ref. Chen in SigGraph96)

Scan-Line Method

- An extension of scan-line polygon filling (multiple surfaces)
- Idea is to intersect each polygon with a particular scanline. Solve hidden surface problem for just that scan line.
- Requires a depth buffer equal to only one scan line
- The cost of tiling scene is roughly proportional to its depth complexity
- Efficient way to tile shallowly-occluded scenes
- May need to split

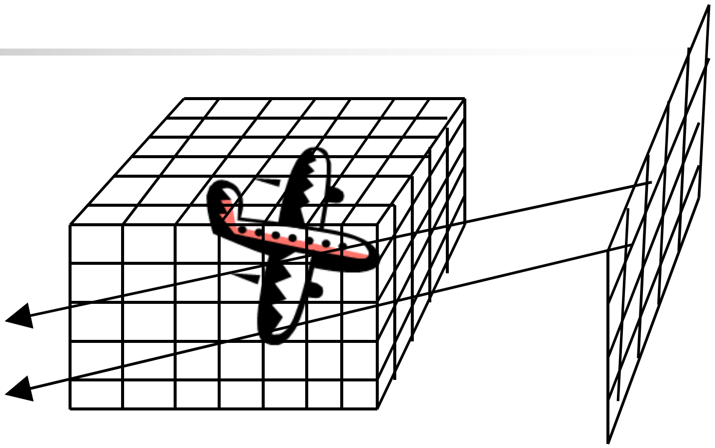


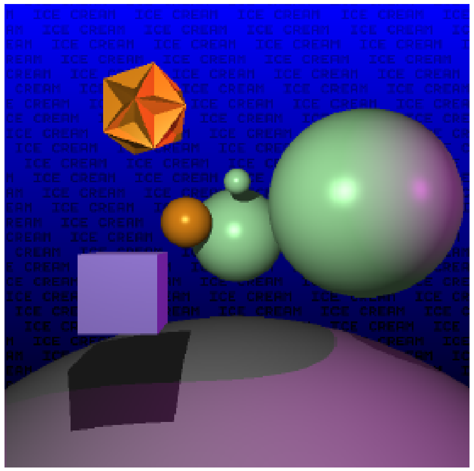


Ray Casting

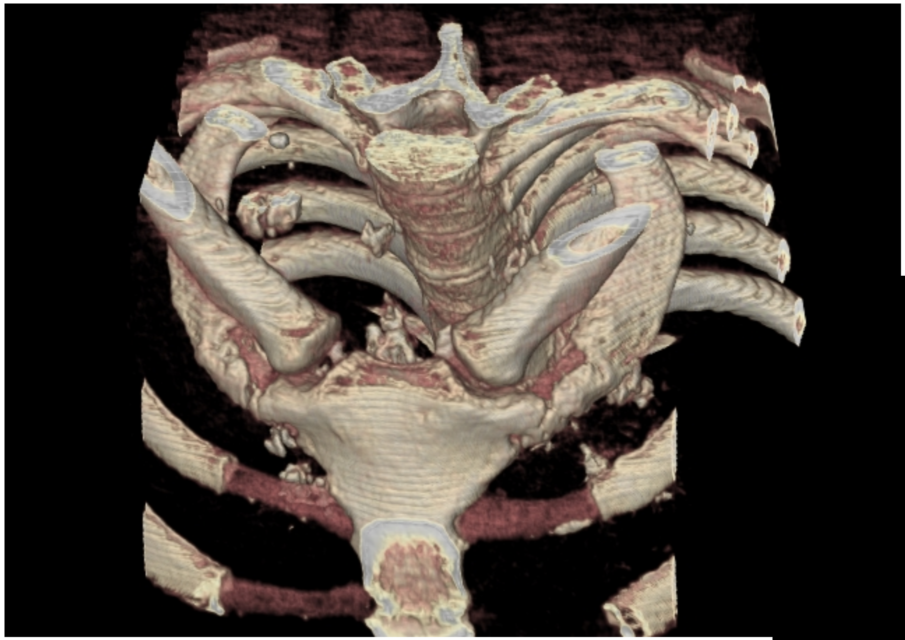
- rendering + visibility
- ALGORITHM

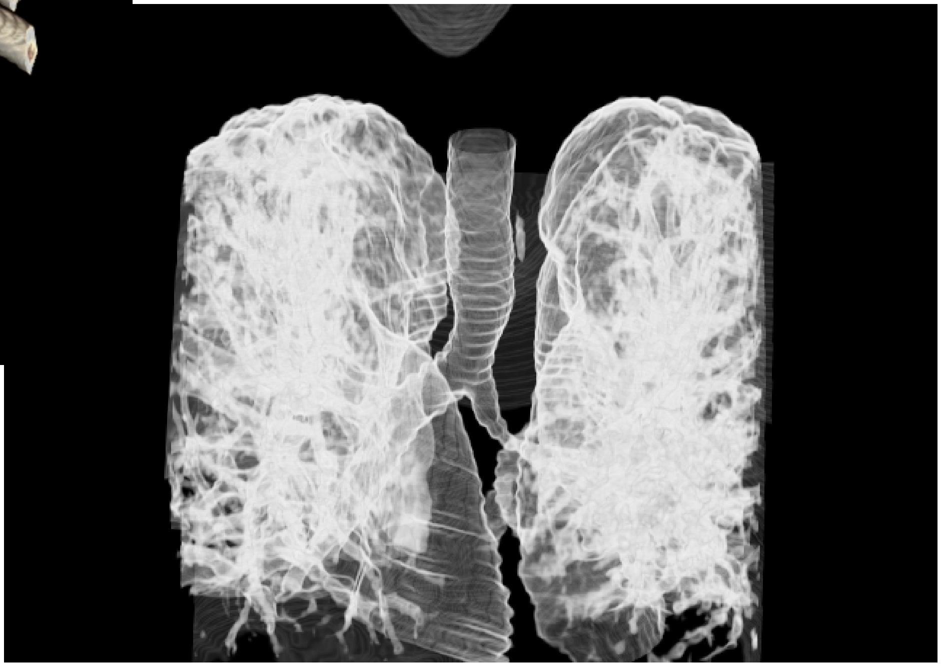
```
loop y
    loop x
        shoot ray from eye point through
                pixel (x,y) into scene
        intersect with all surfaces, find
                first one the ray hits
        shade that point to compute the
                color of pixel (x,y)
```





Ray Casting

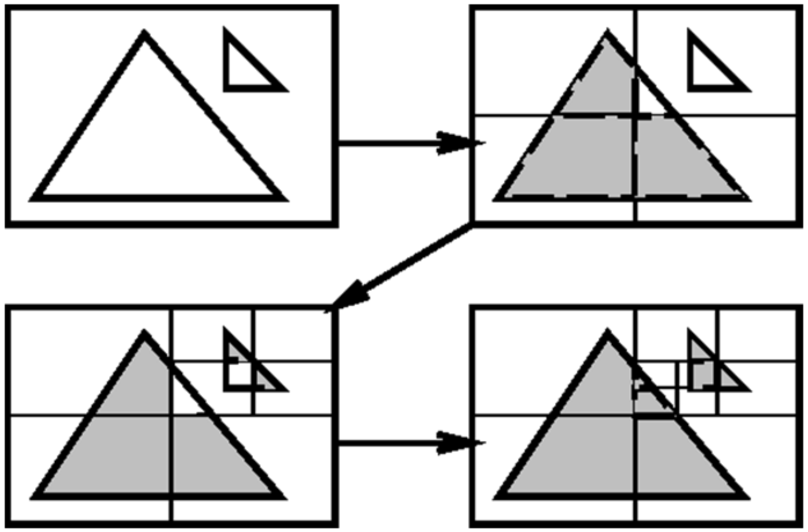




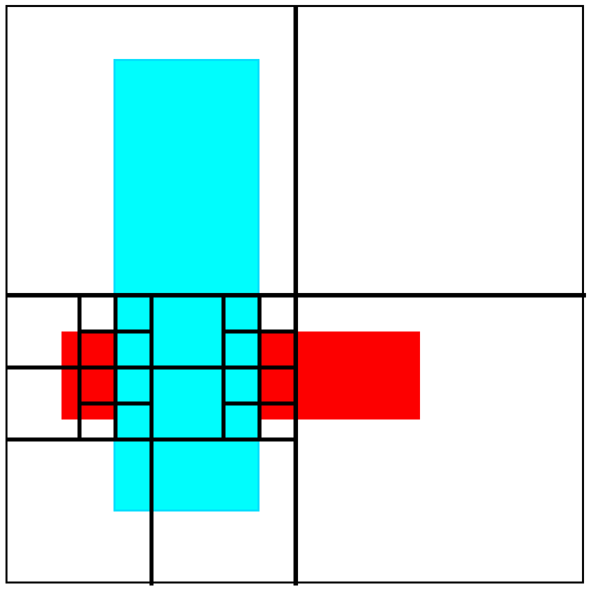
Warnock's algorithm

- Area Subdivision Algorithms
  - ✓ image space algorithms
  - ✓ divide-and-conquer : area coherence

1. Take a given section of the screen (the entire screen, in the first pass)
2. Check to see if it is "simple enough"
3. If it is, display it
4. If it isn't, subdivide the screen into four sections and check each of the new sections (starting at step 1)



Warnock's algorithm



- Runtime: $O(p \times n)$

  p : number of pixels

  n : number of polygons

Comparisons of Hidden-Surface Algorithms

- **Z-buffer:**
  - memory: used for image buffer & z-buffer
  - implementation: moderate, requires scan conversion. It can be put in hardware.
  - speed: fast, unless depth complexity is high
  - generality: very good
- **Painter's:**
  - memory: used for image buffer
  - implementation: moderate, requires scan conversion; hard if sorting & splitting needed
  - speed: fast only *if objects can be sorted a priori*
  - generality: splitting of intersecting objects & sorting make it clumsy for general 3-D rendering

Comparisons of Hidden-Surface Algorithms

- **Ray casting:**
  - memory: used for object database
  - implementation: easy, but to make it fast you need spatial data structures
  - speed: slow if many objects: cost is O((#pixels)´(#objects))
  - generality: excellent, can even do non-polygon models, shadows, transparency.
- **Others (scanline, object space):** tend to be hard to implement, and very hard to generalize to non-polygon models