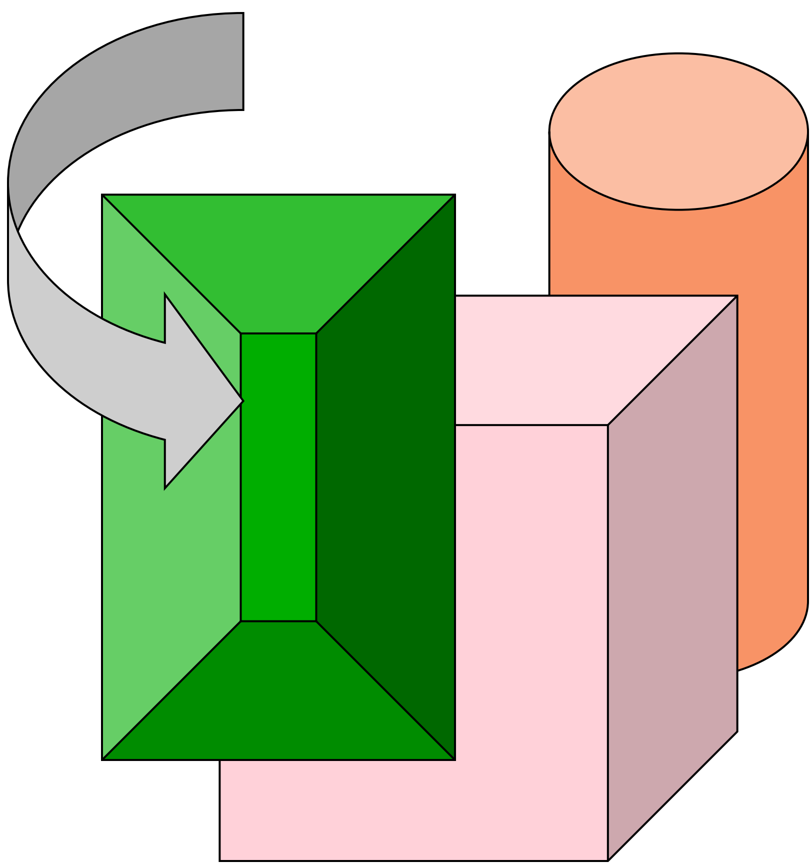
Visible Surface Detection (V.S.D)

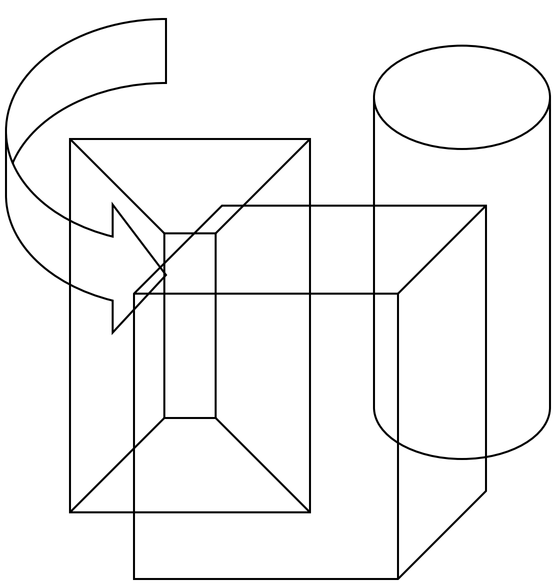
(Chapt. 15 in FVD, Chapt. 13 in Hearn & Baker)

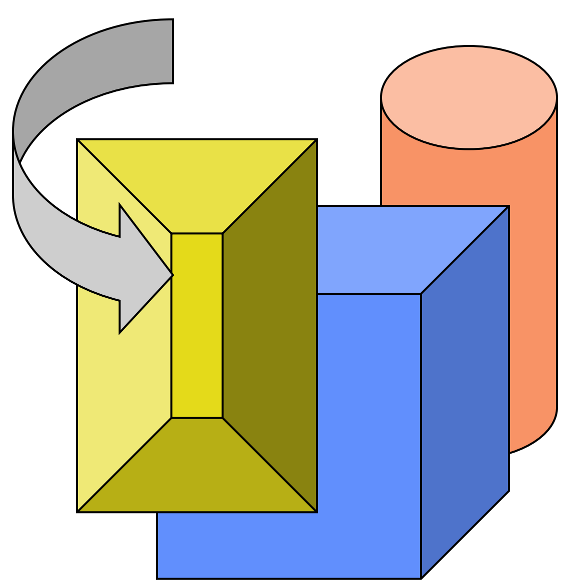


Overview

- Scan conversion
  - Figure out which pixels to fill
- Shading
  - Determine a color for each filled pixel
- Texture Mapping
  - Describe shading variation within polygon interiors
- Visible Surface Determination
  - Figure out which surface is front-most at every pixel

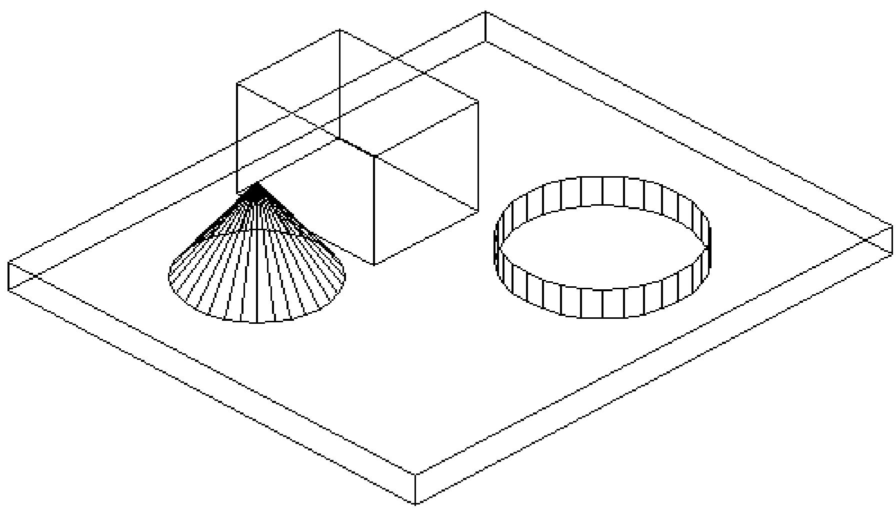
- Problem definition
  - Given a set of 3D objects and a viewing specifications, determine which lines or surfaces of the objects should be visible.
  - A surface might be occluded by other objects or by the same object (self occlusion)
- Two main approaches:
  - Image-precision algorithms: determine what is visible at each pixel.
  - Object-precision algorithms: determine which parts of each object are visible.



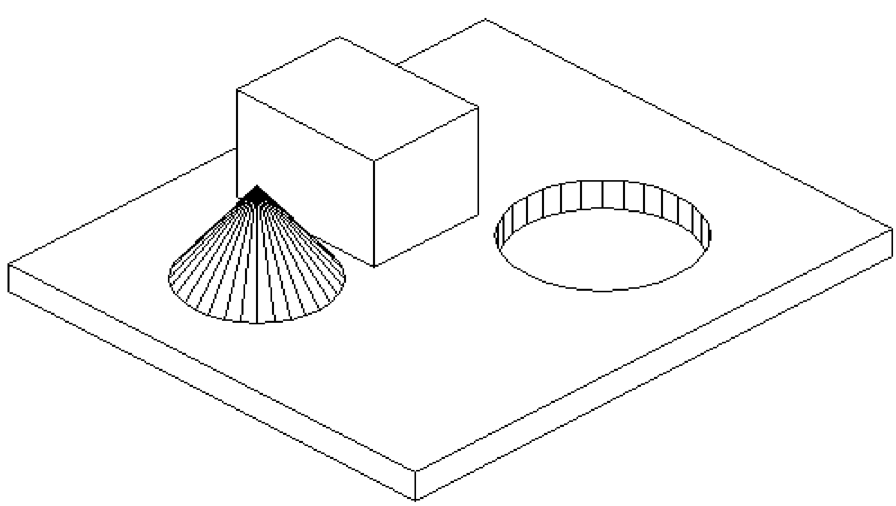


Hidden Lines Removal

Wireframe

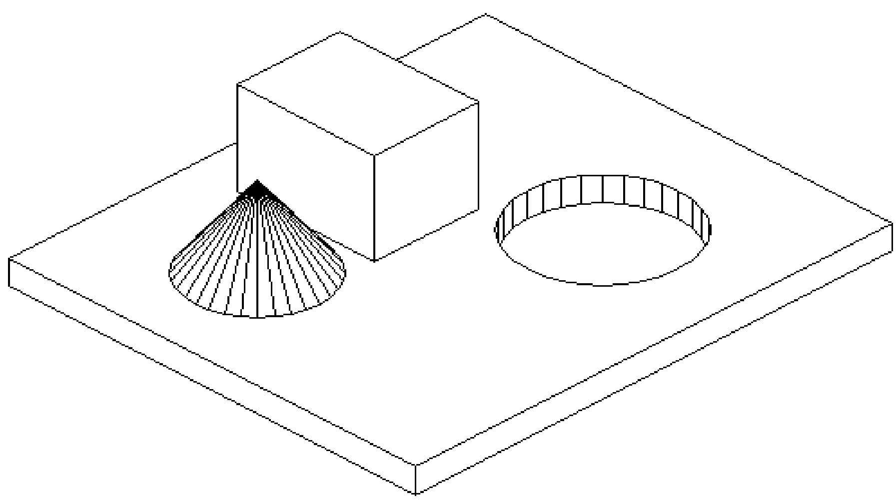


Hidden Line Removal

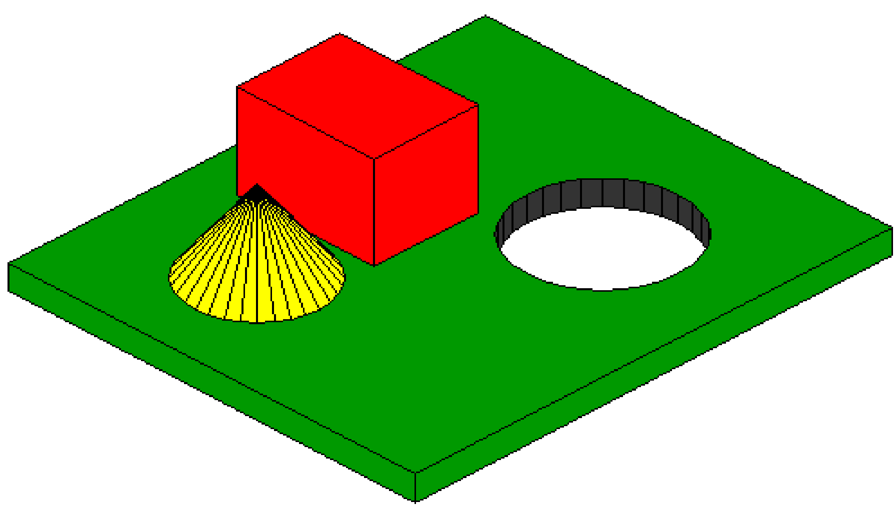


Hidden Surfaces Removed

Hidden Line Removal

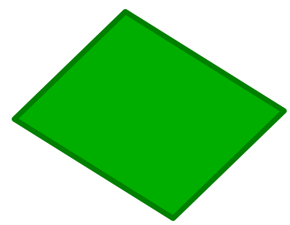


Hidden Surface Removal



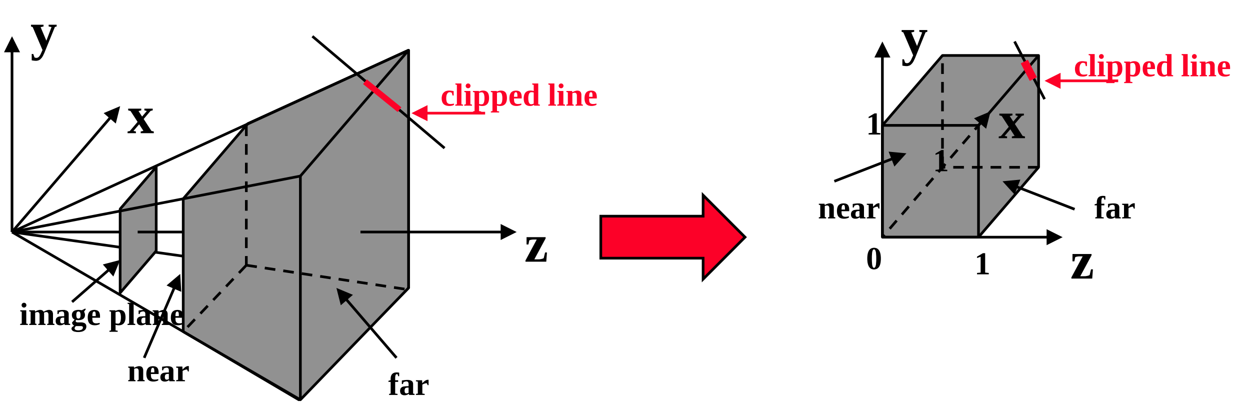
Coherence

- Most methods for V.S.D. use coherence features in the surface:
  - Object coherence.
  - Face coherence.
  - Edge coherence.
  - Scan-line coherence.
  - Depth coherence.
  - Frame coherence.



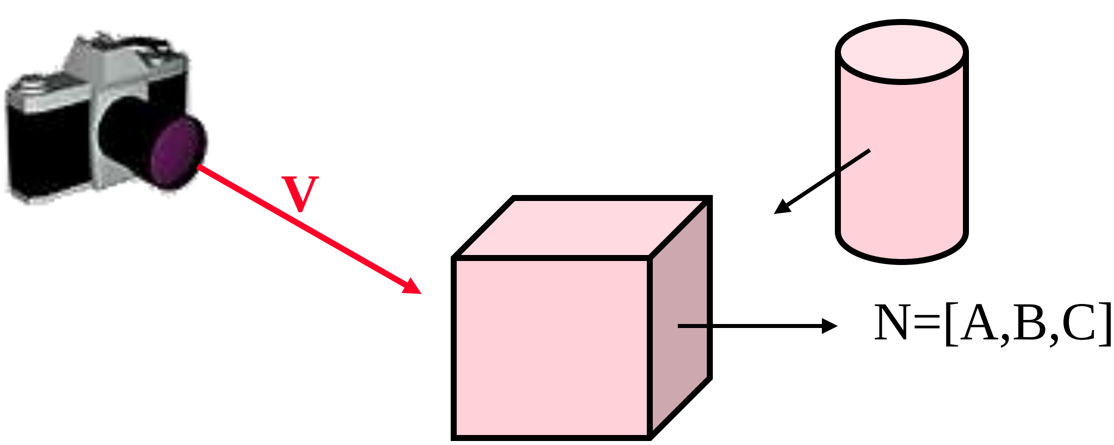
Where Are We ?

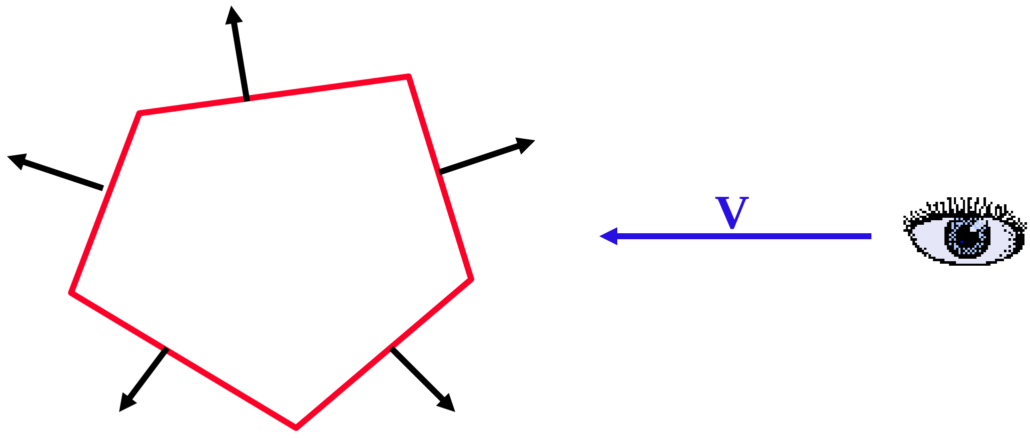
- Canonical view volume (3D image space)
- Clipping done
- division by w
- z > 0



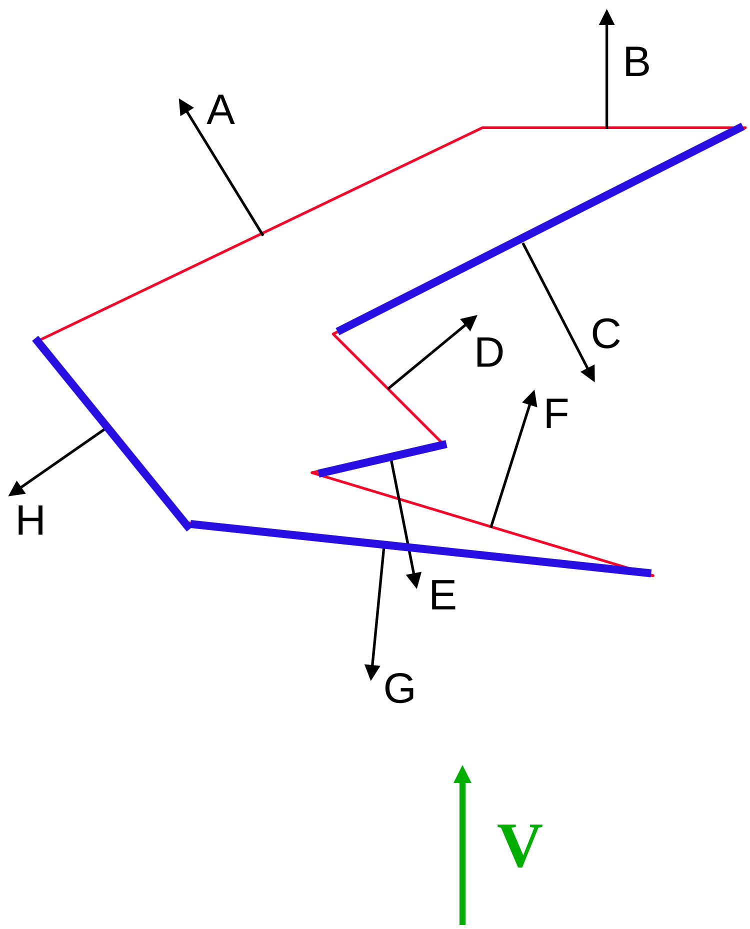
Back Face Detection

- **Observation**: In a volumetric object, you never see the “back” faces of the object (self occlusion).
- Reminder:
  - Plane equation: $Ax+By+Cz+D=0$
  - $N=[A,B,C]^T$ is the plane normal.
  - N points "outside".
- Back facing and front facing faces can be identified using the sign of $V \cdot N$





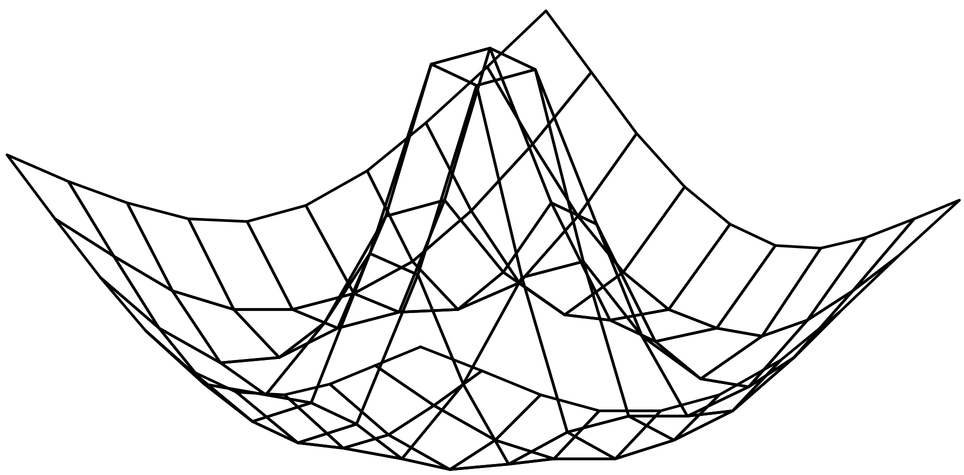
- Three possibilities:
  - V•N> 0 back face
  - V•N< 0 front face
  - V•N= 0 on line of view
- Convex objects
  - For convex objects, *back face detection* actually solves the *visible surfaces problem*.
  - Back face detection is easily applied to convex polyhedral objects.
- In a general object, a front face can be visible, invisible, or partially visible.



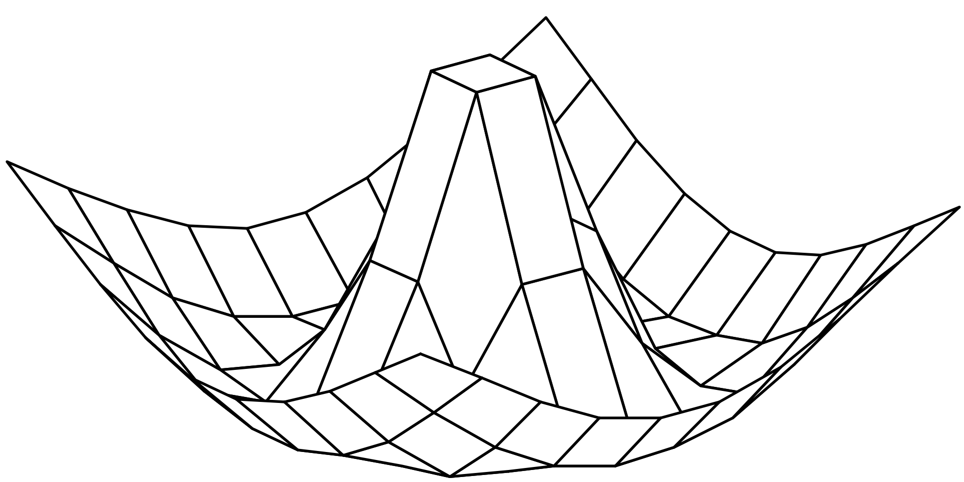
Back Face Polygons: A, B, D, F

Front Face Polygons: C, E, G, H

Single Valued Function of two variables



Without Hidden-Line Removal



With Hidden-Line Removal

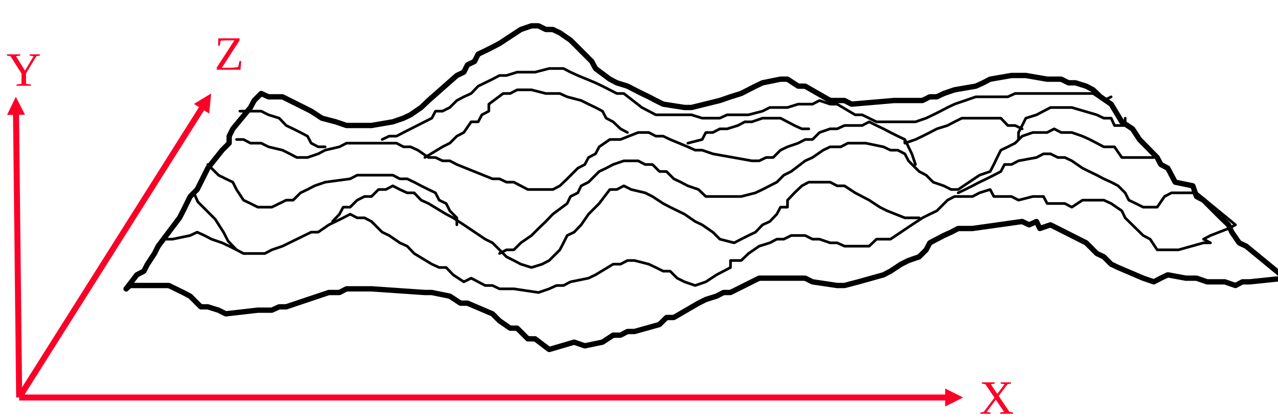
Floating Horizon Algorithm

- Implicit Function: Y=f(X,Z).
- Represent as 2D array of x and z values, each entry is the corresponding y-value.
- Surface = many polylines; Each polyline is constant in Z.

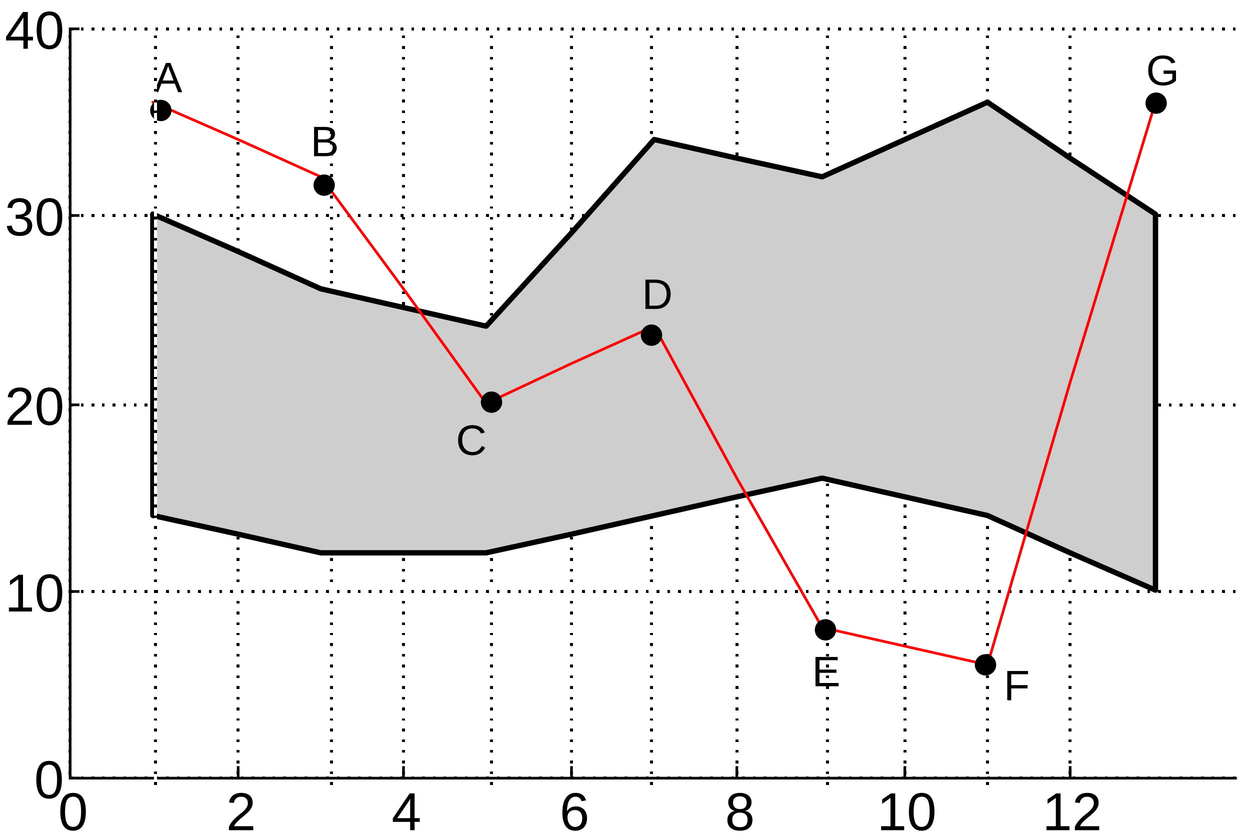
<u>Algorithm:</u>

Draw polylines of constant z from front (near z) to back (far z).

Draw only parts of polyline that are visible: ie above/below the silhouette (horizon).

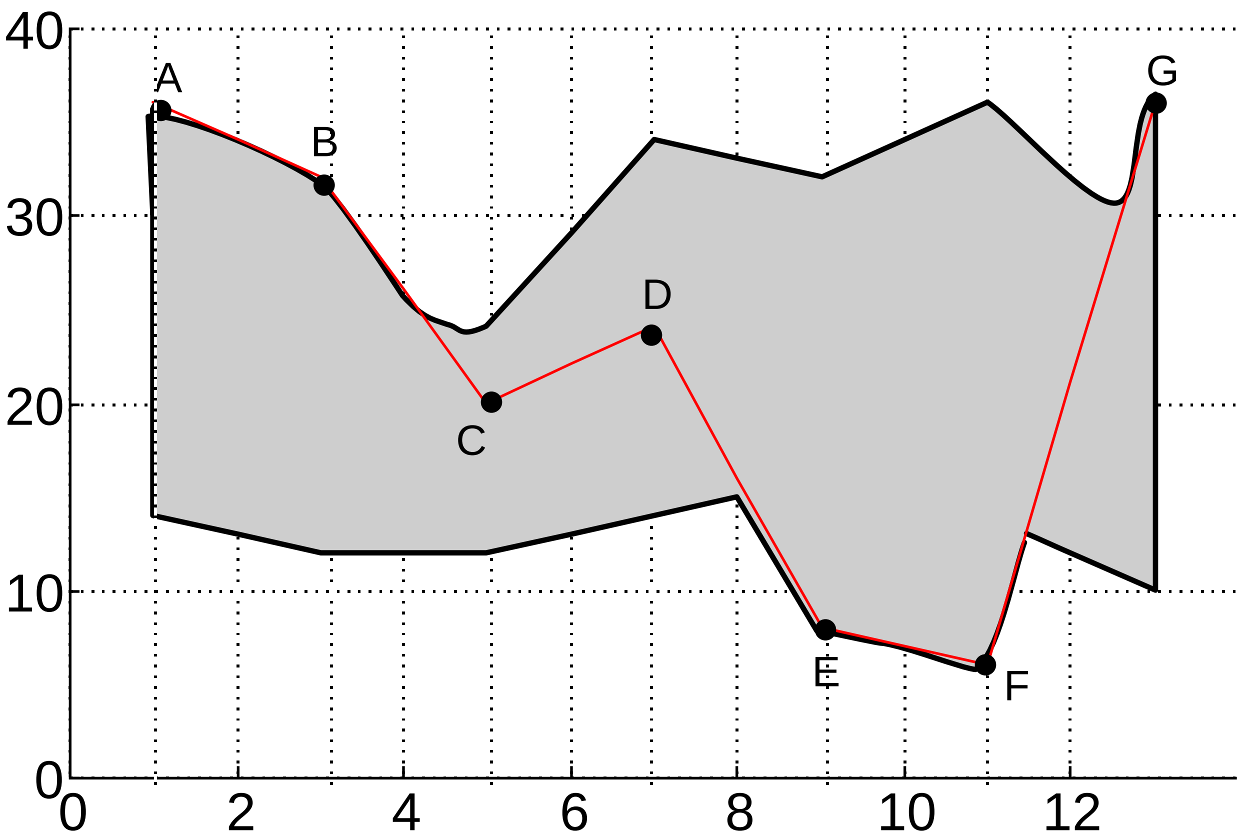


Use 2 1D arrays YMIN and YMAX (with 1 entry for each x). When drawing a polyline of constant z, for each x-value, test if above/below YMAX/YMIN (at x location) and update arrays.



old YMAX	30	28	26	25	24	29	34	33	32	34	36	33	30
old YMIN	10	12	14	15	16	15	14	13	12	12	12	13	14
polyline	36	34	32	26	20	22	24	16	8	7	6	21	36
	A		B		C		D		E		F		G
new YMAX	36	34	32	26	24	29	34	33	32	34	36	33	36
new YMIN	10	12	14	15	16	15	14	13	8	7	6	13	14

Use 2 1D arrays YMIN and YMAX (with 1 entry for each x). When drawing a polyline of constant z, for each x-value, test if above/below YMAX/YMIN (at x location) and update arrays.



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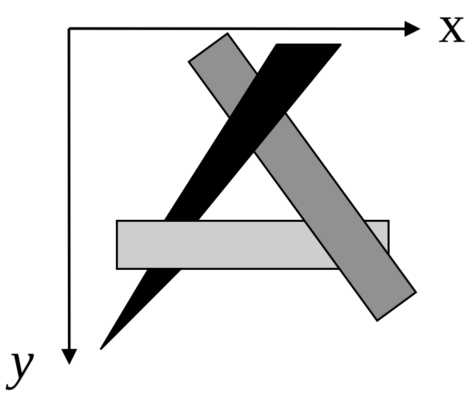
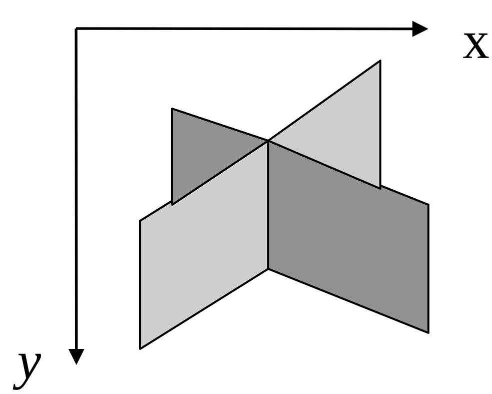
polyline	36	34	32	26	20	22	24	16	8	7	6	21	36
	A		B		C		D		E		F		G
new YMAX	36	34	32	26	24	29	34	33	32	34	36	33	36
new YMIN	10	12	14	15	16	15	14	13	8	7	6	13	14

- <u>Floating Horizon Characteristics</u>:
  - Applied in image space (image precision).
  - Limited to explicit functions only.
  - Exploiting edge coherence.
  - Applicable for free-form surfaces.

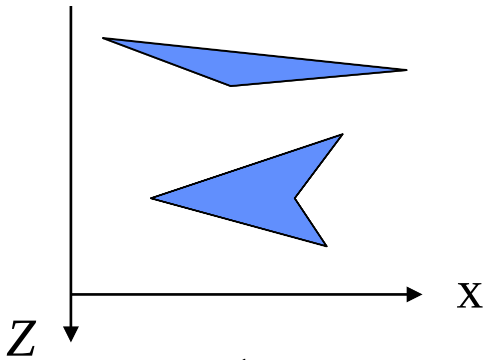
Depth Sort
(Painter Algorithm)

- Sort all of the polygons in the scene by their depth.
- Draw them back to front.
- **Question**: Does a depth ordering always exist? Unfortunately, no.
  - For polygons with constant *Z* value, this sorting clearly works.
  - For example: window systems.

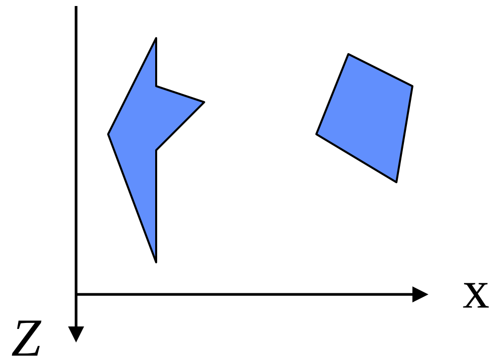




- **Question**: What if polygons are not *Z* constant?
- **Observation**: Given two polygons P and Q, an order may be determined between them, if at least one of the following holds:
  - 1. *Z* values of P and Q do not overlap.
  - 2. The bounding rectangle in the x,y plane for P and Q do not overlap.
  - 3. P is totally on one side of Q’s plane.
  - 4. Q is totally on one side of P’s plane.
  - 5. The bounding rectangles of Q and P do not intersect in the projection plane.



1



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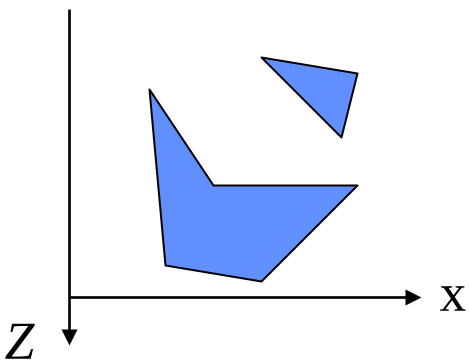
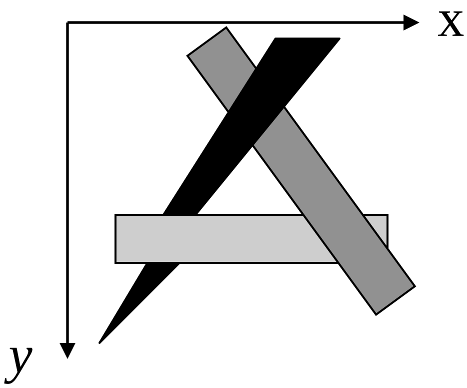
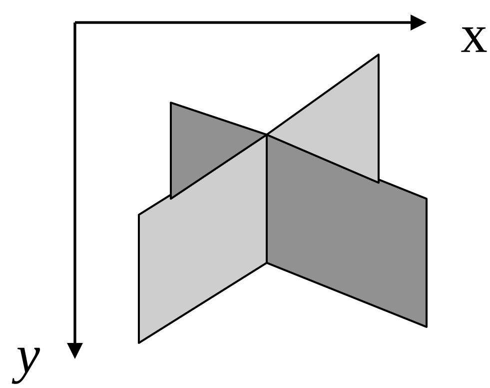


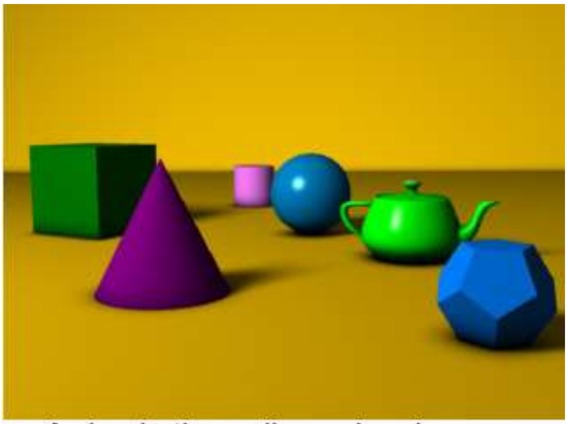
3 and 4

- If all the above conditions do not hold, P and Q may be split along intersection edge into two smaller polygons.



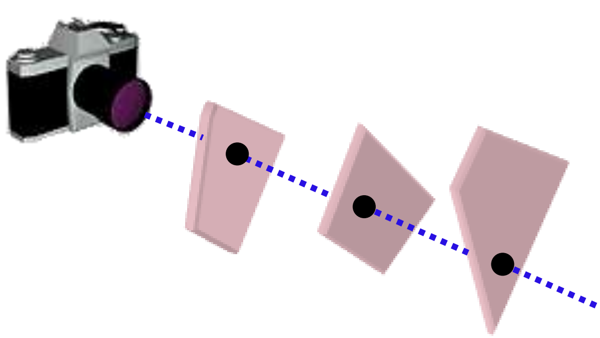


Z-buffer Method


A simple three dimensional scene


Z-buffer representation

- In addition to the frame buffer (keeping the pixel values), keep a Z-buffer containing the depth value of each pixel.
- Surfaces are scan-converted in an arbitrary order. For each pixel (x,y), the Z-value is computed as well. The (x,y) pixel is overwritten only if its Z-values is closer to the viewing plane than the one already written at this location.



Algorithm:

– Initialize the *z*-buffer and the frame-buffer:

  $depth(x,y)=MAX\_Z$; $I(x,y)=I_{background}$

– Calculate the depth Z for each (x,y) position on any surface:

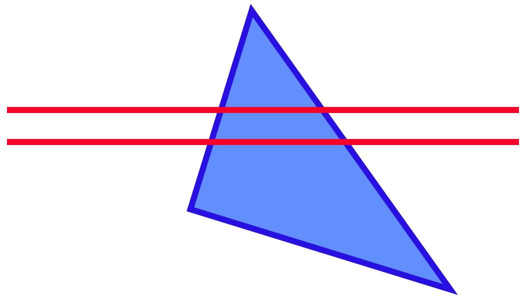
  - If $z<depth(x,y)$, then set

    $depth(x,y)=z$; $I(x,y)=I_{surf}(x,y)$

- For polygon surfaces, the depth-buffer method is very easy to implement using polygon scan line conversion, and exploiting face coherence and scan-line coherence :
  - $Z = -(Ax+By+D)/C$
  - Along scan lines

    $Z' = -(A(x+1)+By+D)/C = Z - A/C$
  - Between successive scan lines:

    $Z' = -(Ax+B(y+1)+D)/C = Z - B/C$

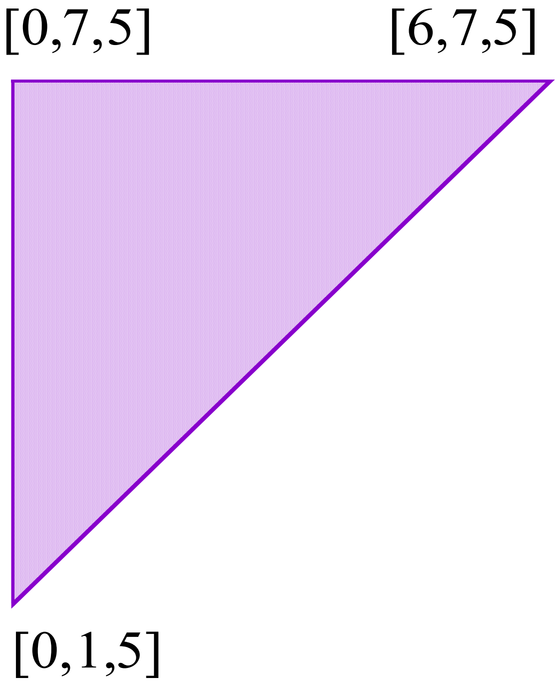


Z-buffer - Example

∞	∞	∞	∞	∞	∞	∞	∞
∞	∞	∞	∞	∞	∞	∞	∞
∞	∞	∞	∞	∞	∞	∞	∞
∞	∞	∞	∞	∞	∞	∞	∞
∞	∞	∞	∞	∞	∞	∞	∞
∞	∞	∞	∞	∞	∞	∞	∞
∞	∞	∞	∞	∞	∞	∞	∞
∞	∞	∞	∞	∞	∞	∞	∞

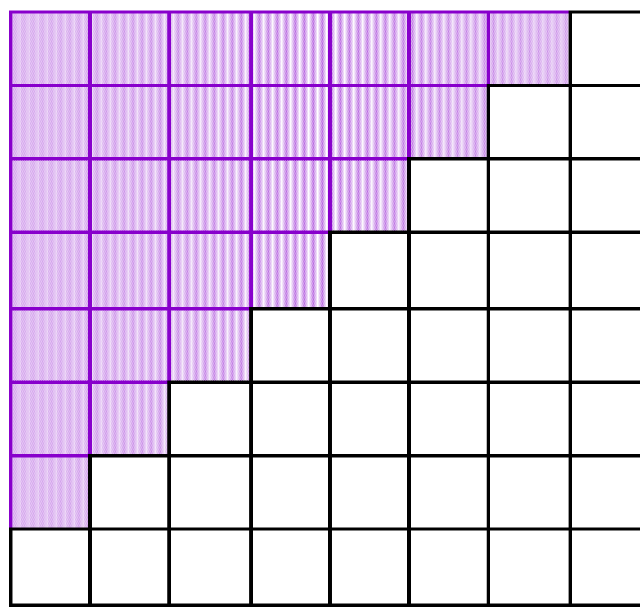
Z-buffer

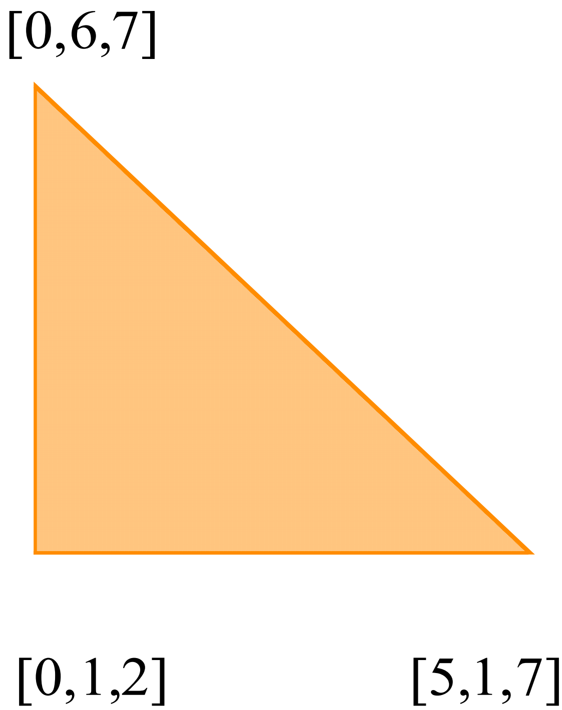
Screen



5	5	5	5	5	5	5
5	5	5	5	5	5	
5	5	5	5	5		
5	5	5	5			
5	5	5				
5	5					
5						

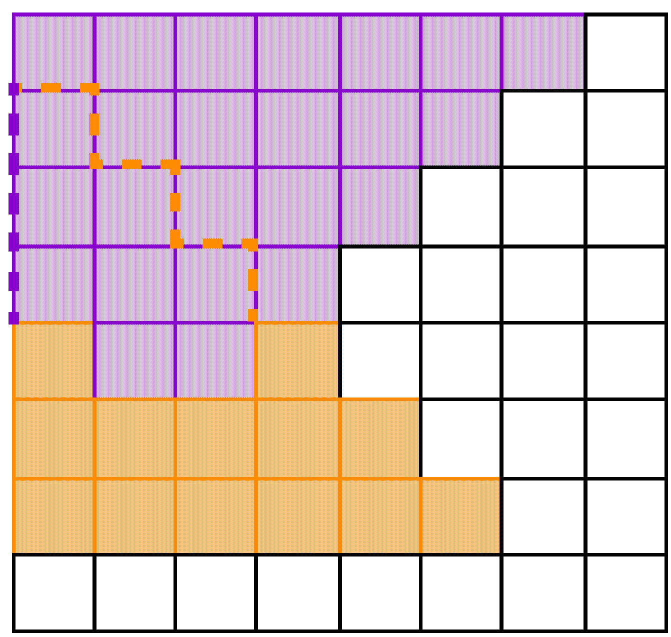
5	5	5	5	5	5	5	∞
5	5	5	5	5	5	∞	∞
5	5	5	5	5	∞	∞	∞
5	5	5	5	∞	∞	∞	∞
5	5	5	∞	∞	∞	∞	∞
5	5	∞	∞	∞	∞	∞	∞
5	∞	∞	∞	∞	∞	∞	∞
∞	∞	∞	∞	∞	∞	∞	∞





7					
6	7				
5	6	7			
4	5	6	7		
3	4	5	6	7	
2	3	4	5	6	7

5	5	5	5	5	5	5	∞
5	5	5	5	5	5	∞	∞
5	5	5	5	5	∞	∞	∞
5	5	5	5	∞	∞	∞	∞
4	5	5	7	∞	∞	∞	∞
3	4	5	6	7	∞	∞	∞
2	3	4	5	6	7	∞	∞
∞	∞	∞	∞	∞	∞	∞	∞

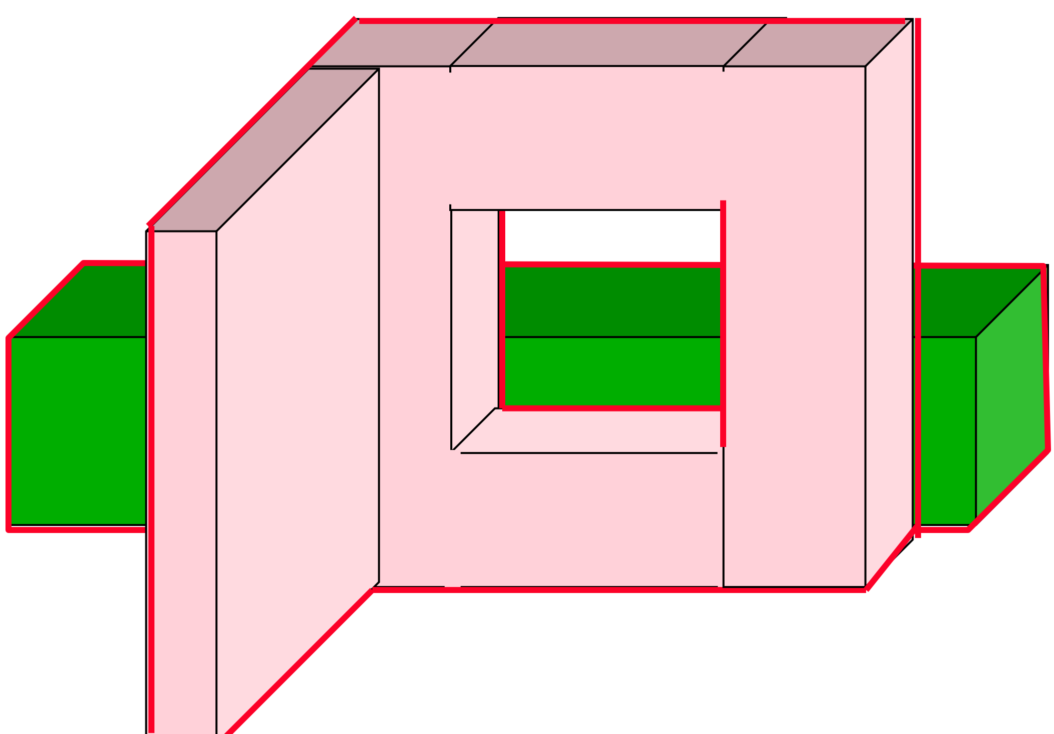


Z-buffer Characteristics

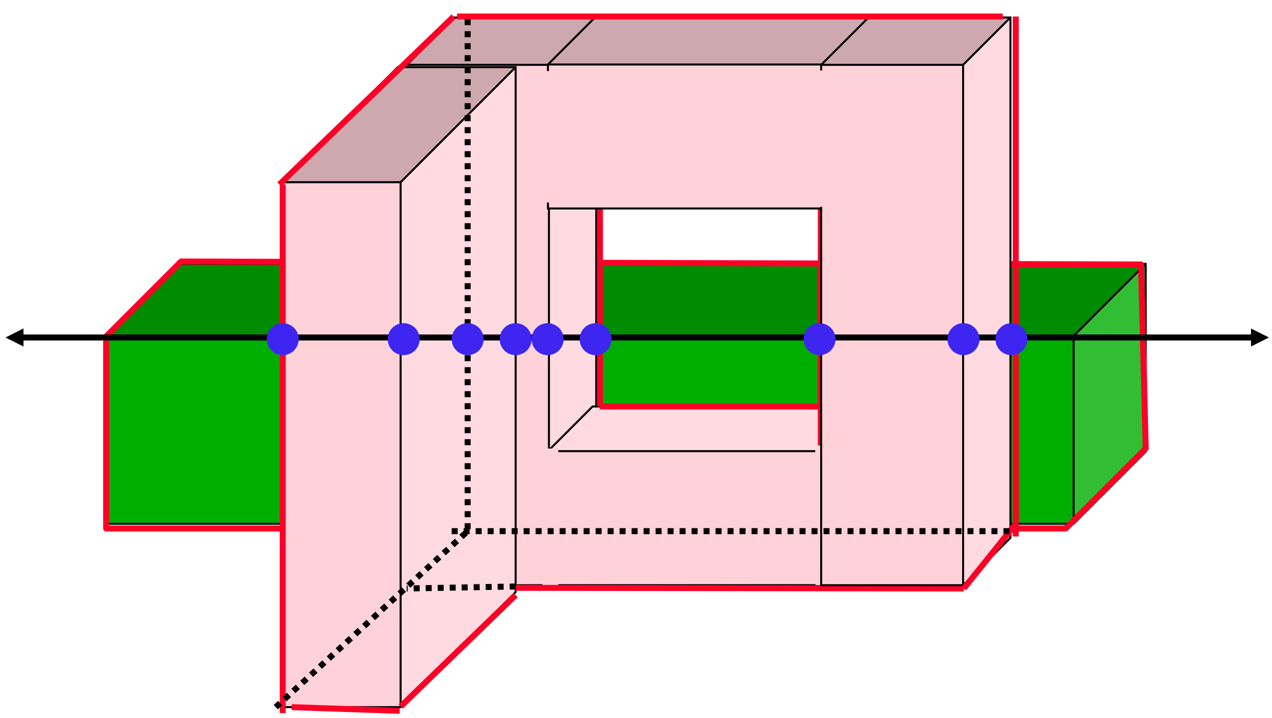
- Implemented in the image space.
- Very common in hardware due its simplicity (SGI's for example).
- 32 bits per pixel for *Z* is common.
- Advantages:
  - Simple and easy to implement.
- Disadvantages:
  - Requires a lot of memory.
  - Finite depth precision can cause problems.
  - Might spend a lot of time rendering polygons that are not visible.
  - Requires re-calculations when changing the objects scale.
  - Does not do transparency easily

Scan Line Algorithm

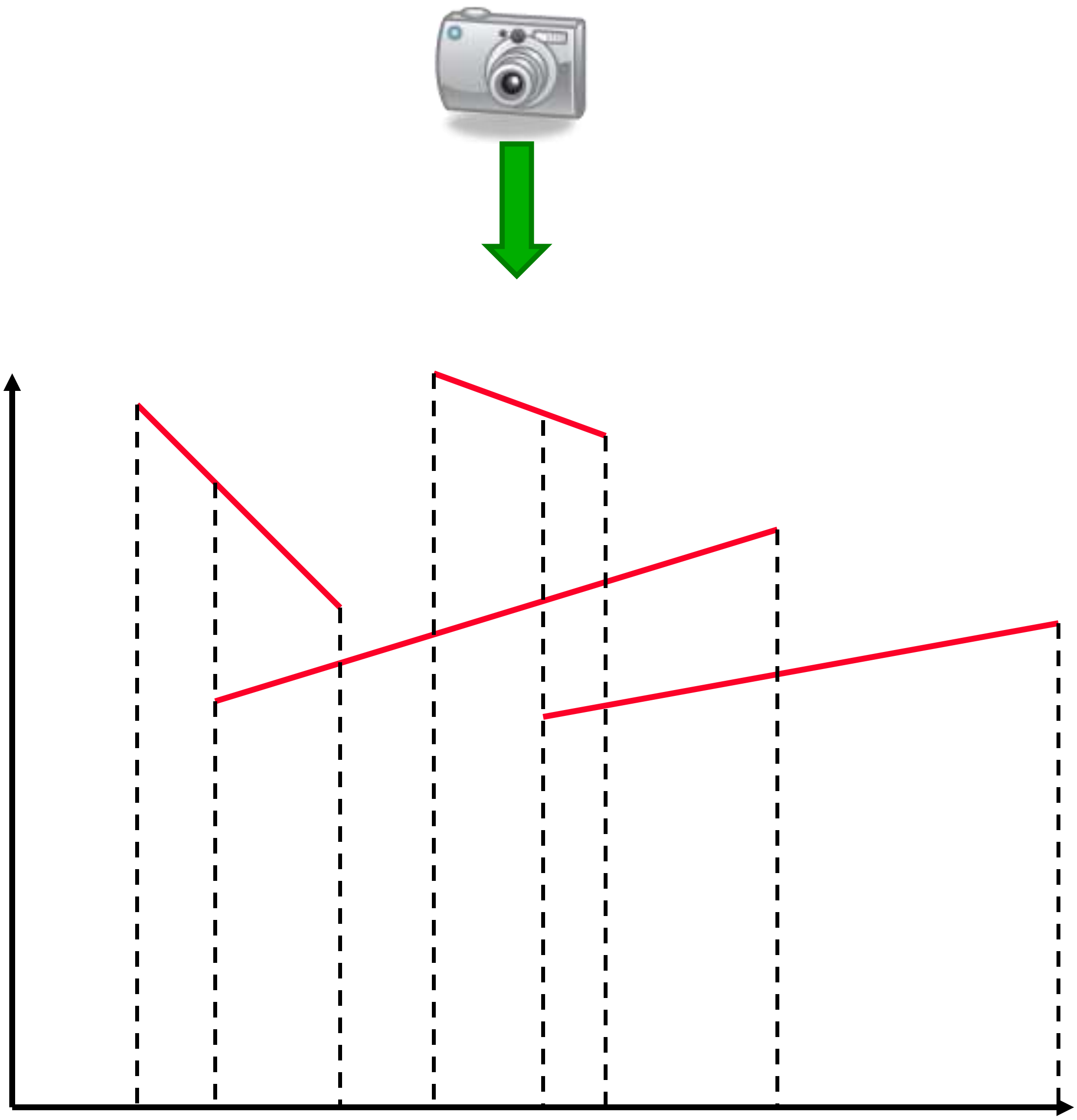
- An extension of the polygon scan conversion algorithm
- It uses the ET and AET, but for more than one polygon.
- The edge record has a link into a polygon table, which contains:
  - The plane equation (a,b,c,d)
  - The shading coefficients
  - A in/out bit

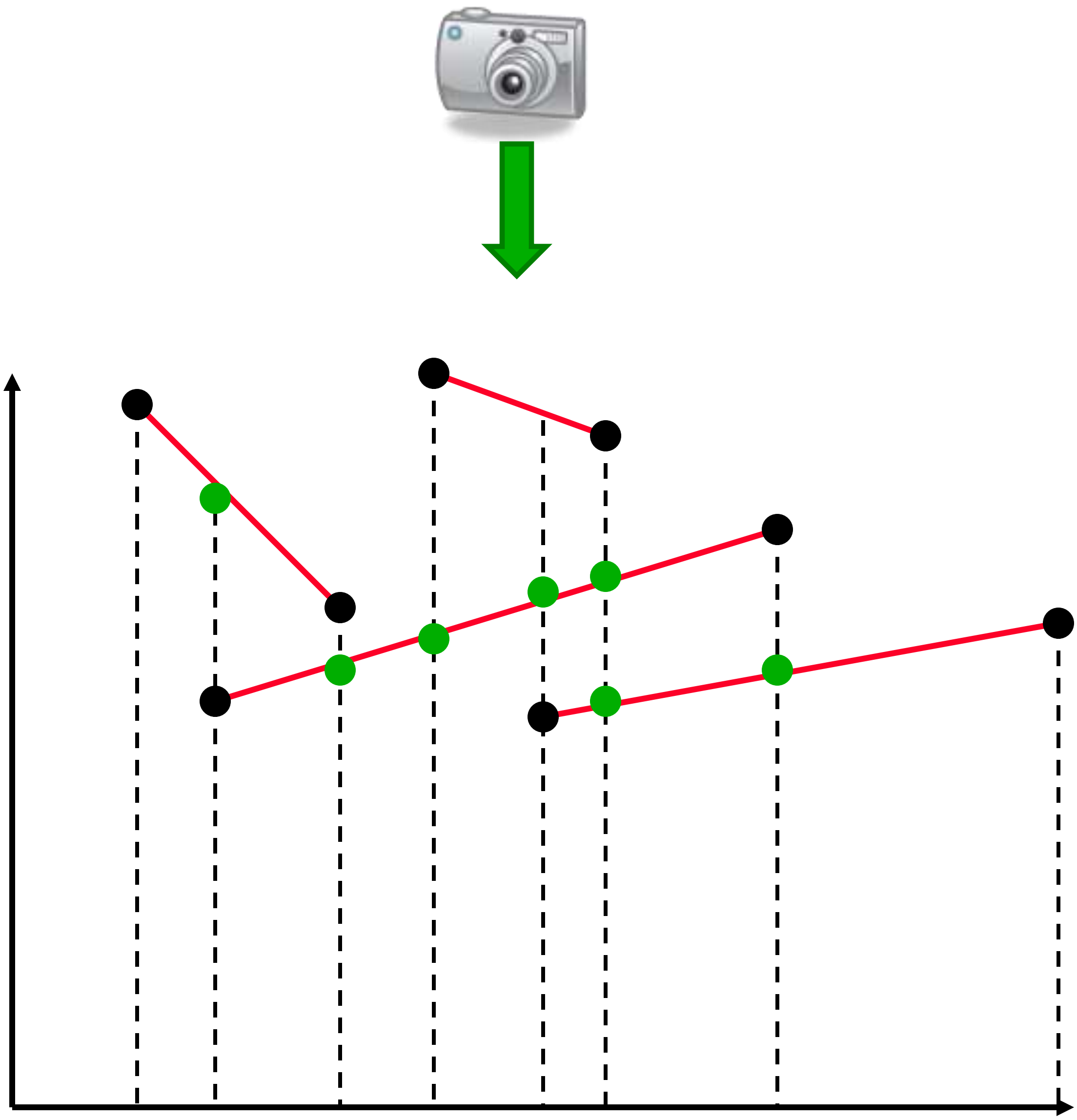


- The *active edges* are those that intersect the current horizontal slice.
- **Observations**: The visibility of an span can be changed only where it intersects an *active* edge .

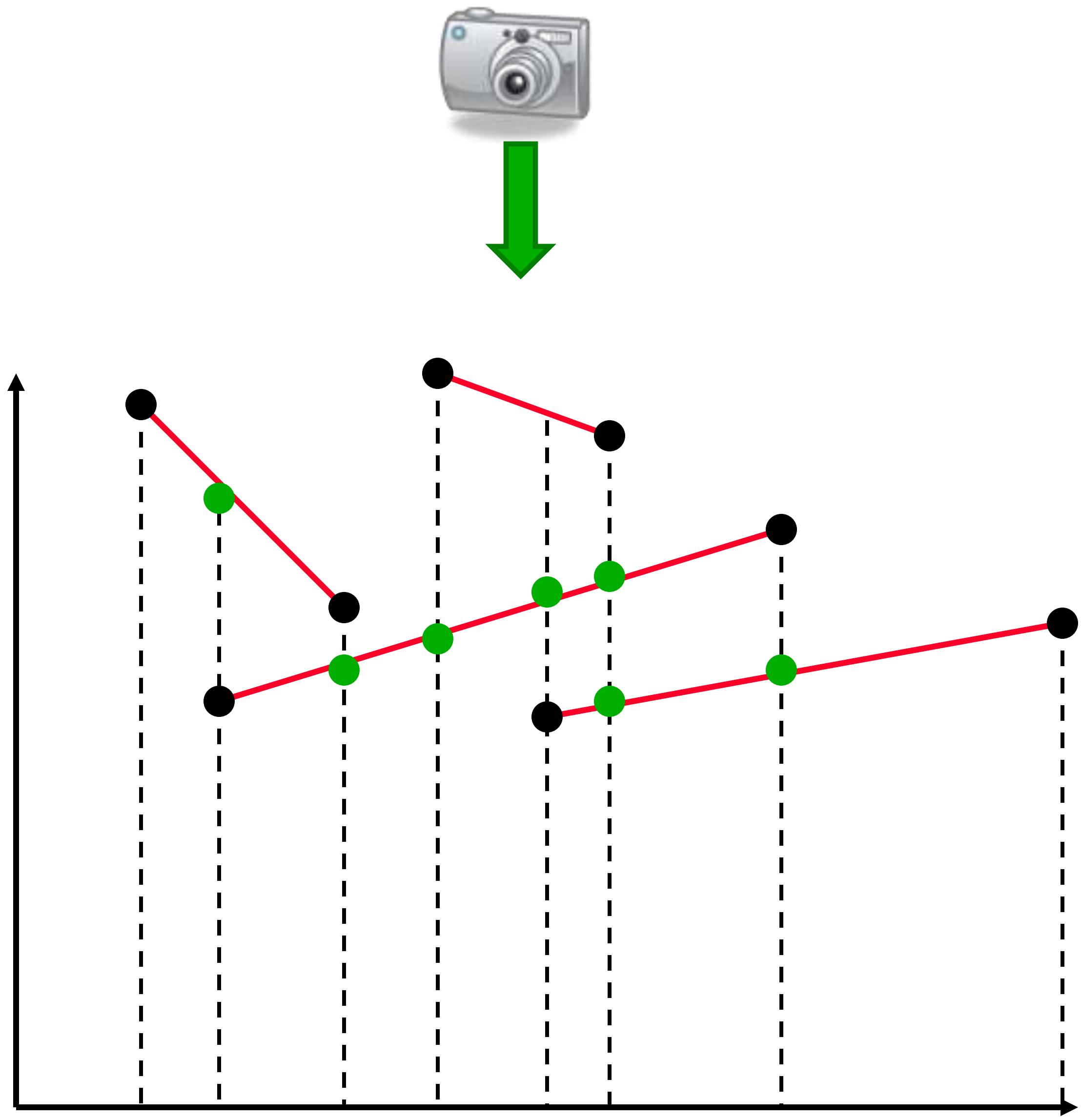


Active line segments produce span boundaries





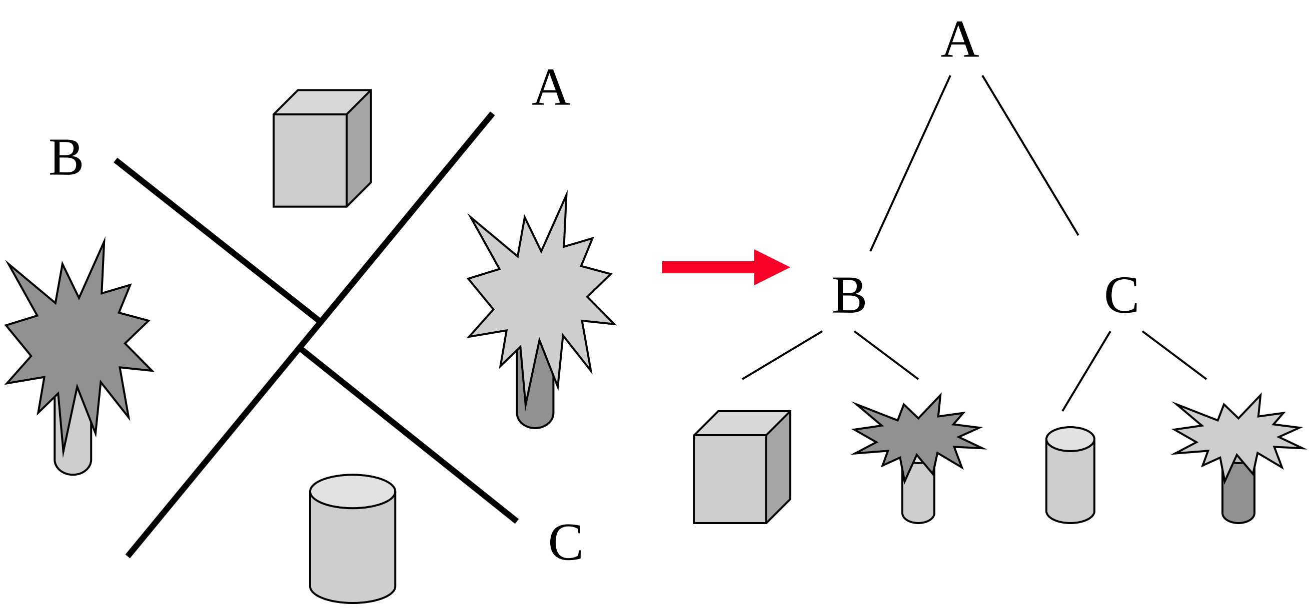
- The span are used to subdivide the segments
- The span endpoints are *an event*



- In an event the closest segment is detected.
- **Question**: Among who?

The BSP Tree

- BSP = Binary Space Partitioning.
- Interior nodes correspond to partitioning planes.
- Leaf nodes correspond to convex regions of space.



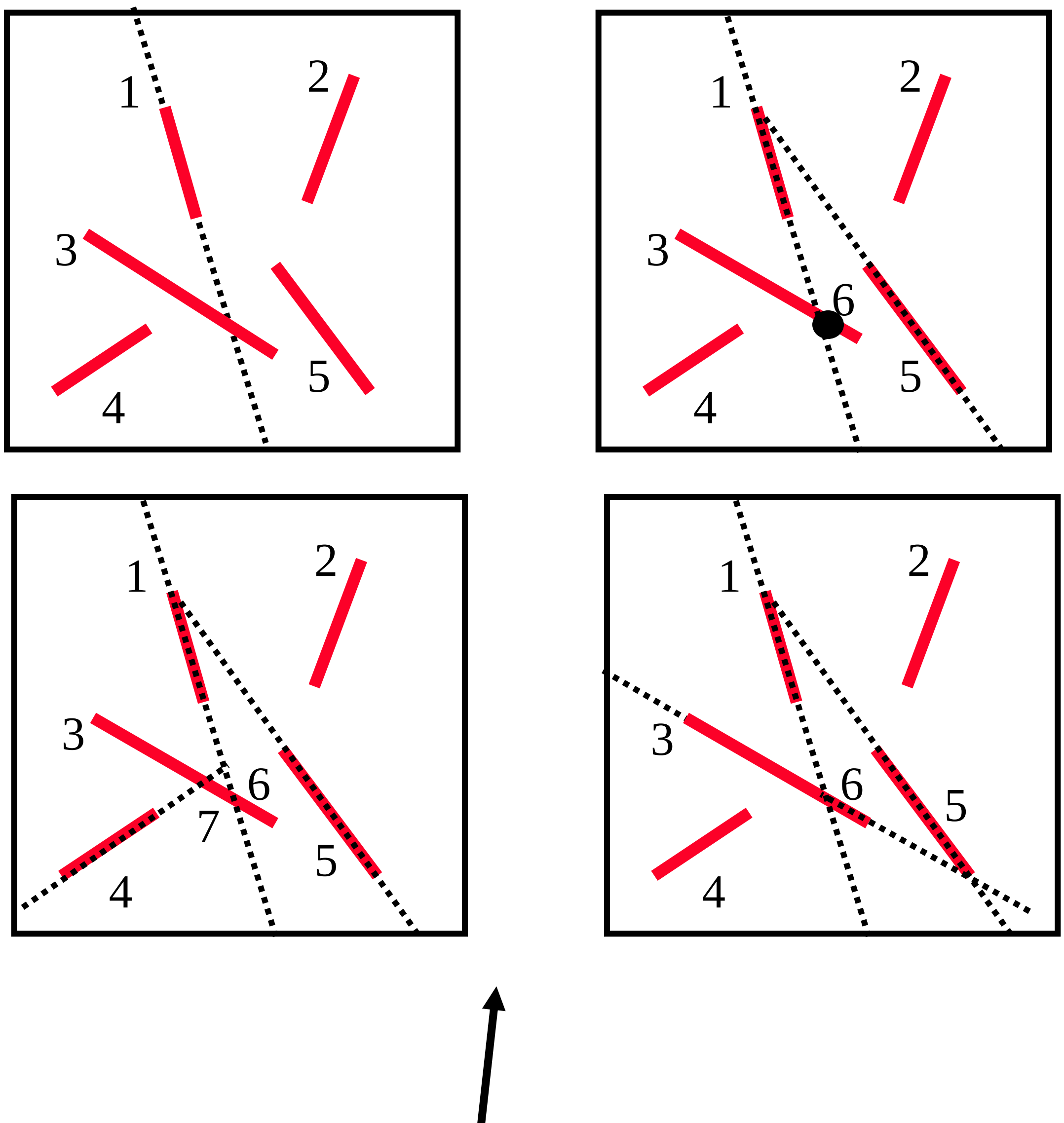
- Tests 3 and 4 in *Depth Sort* technique can be exploited efficiently:
- Let L_p be the pla space may be div three groups:

> 3. P is totally on one side of Q’s plane.
> 4. Q is totally on one side of P’s plane.

  - Polygons in front of L_p.
  - Polygons behind L_p.
  - Polygons intersecting L_p.
- Polygons in the third class are split, and classified into the first two.
- As a result of the subdivision with respect to L_p:
  - The polygons behind L_p cannot obscure P, so we can draw them first.
  - P cannot obscure the polygons in front of L_p so we can draw P second.
  - Finally we draw the polygons in front of P.

The BSP-Tree Algorithm

- Construct a BSP tree:
  - Pick a polygon, let its supporting plane be the root of the tree.
  - Create two lists of polygons: these in front, and those behind (splitting polygons as necessary).
  - Recurse on the two lists to create the two sub-trees.
- Display:
  - Traverse the BSP tree back to front, drawing polygons in the order they are encountered in the traversal.



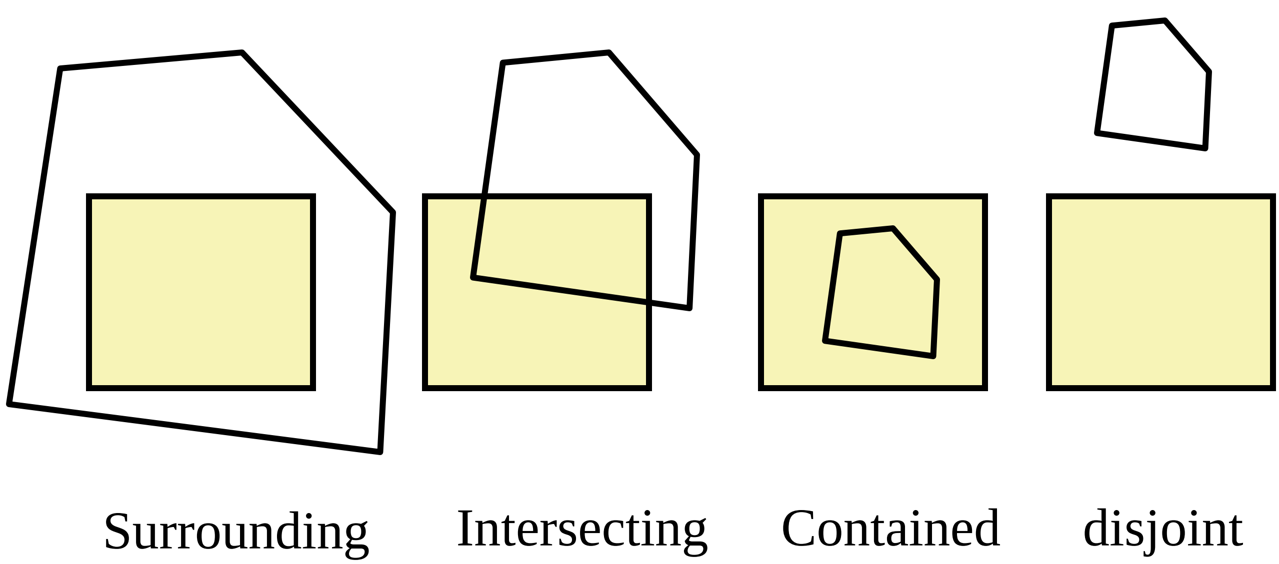
Should be prepared from the beginning !

BSP Properties:

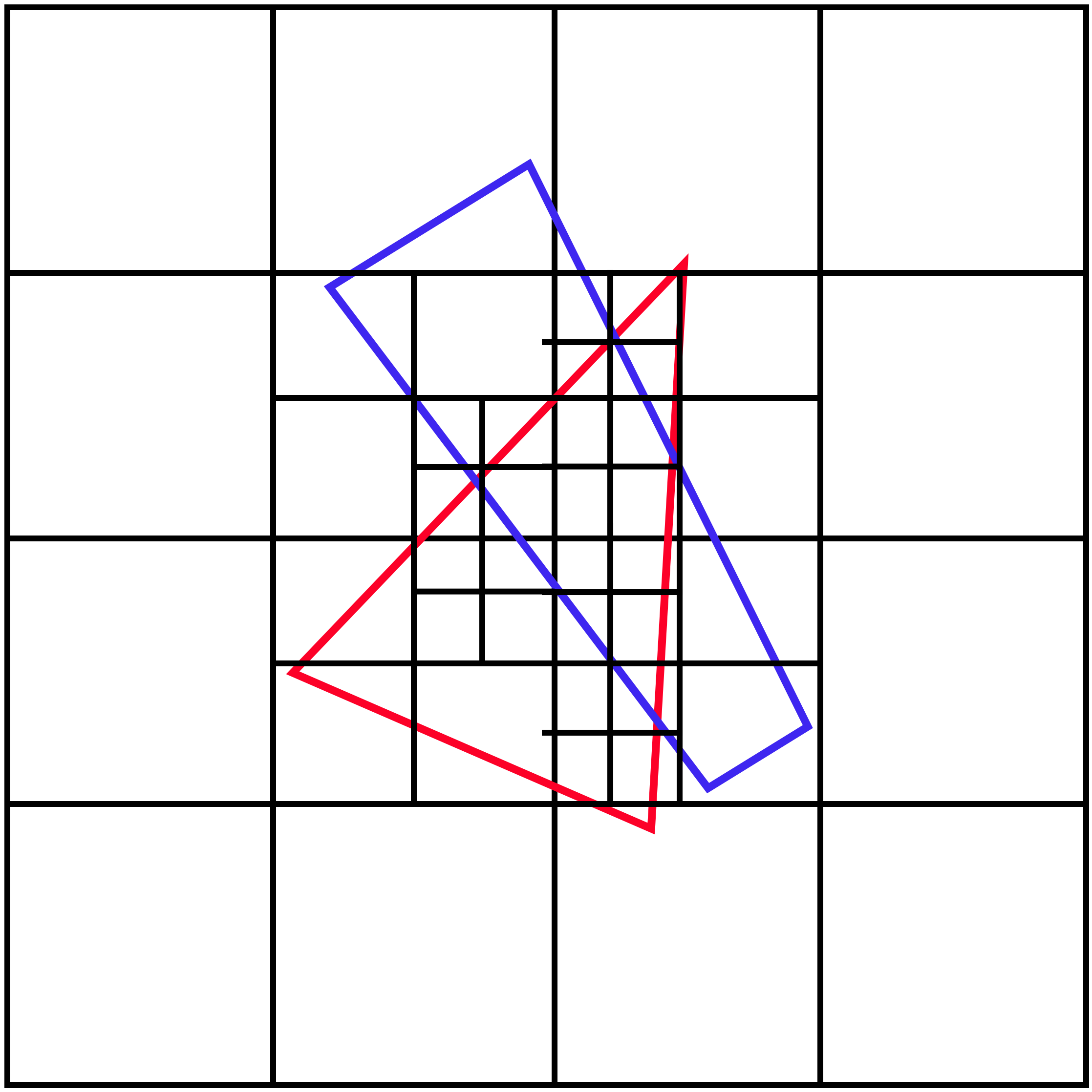
- The BSP tree is *view independent*!
- The BSP tree is constructed using the geometry of the object only.
- The tree can be used for hidden surface removal at an arbitrary direction.
- BSP = Object-precision alg.

Area Subdivision Technique (Warnock 1969)

- Subdivide screen area recursively, until visible surfaces are easy to determine.
- Each polygon has one of four relationships to the area of interest:



- If all polygons are disjoint from the area, fill area with background color.
- Only one intersecting or contained polygon: First fill with background color, then scan convert polygon.
- Only one surrounding polygon: Fill area with polygon’s color.
- More than one polygon is surrounding, intersecting, or contained, but one surrounding polygon is in front of the rest: Fill area with polygon’c color.
- If none of the above cases occurs: Subdivide area into four, and recurse.
- Area subdivision = Image precision technique.



When the resolution of the image is reached, polygons are sorted by their Z-values at the center of the pixel, and the color of the closest polygon is used.