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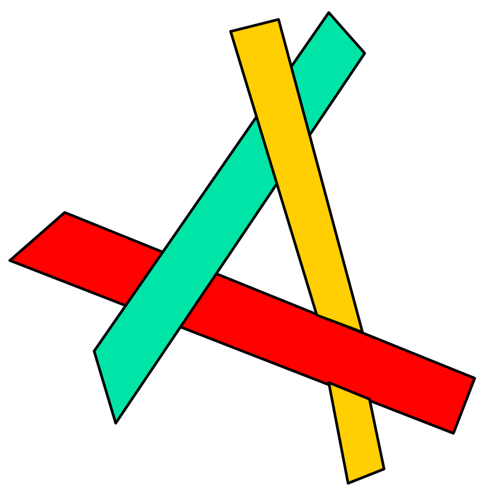
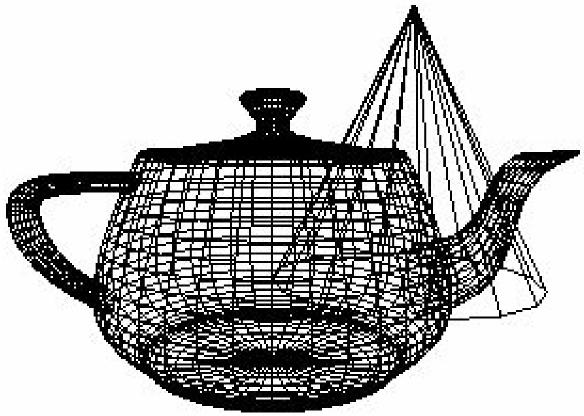
Chapter 10

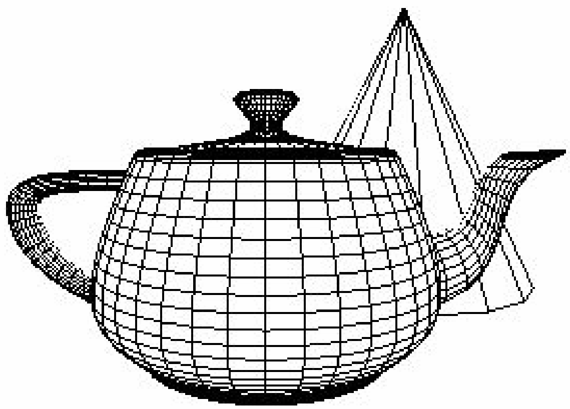
Hidden Surface Removal



Hidden Surface Removal

- Issues
  - Correctness
  - Speed
- Multiple algorithms – cover a few
- Algorithm types
  - Object space
  - Image space
- Remains major research topic in CG





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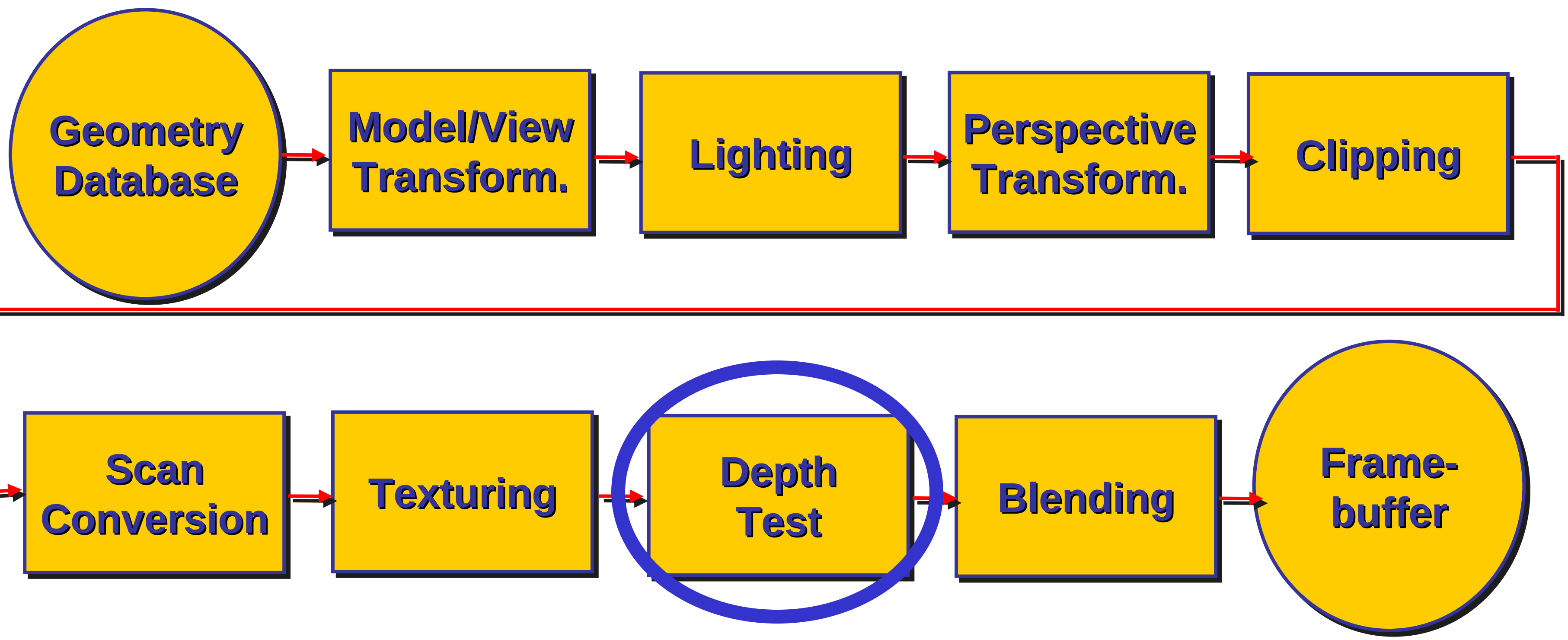
The Rendering Pipeline



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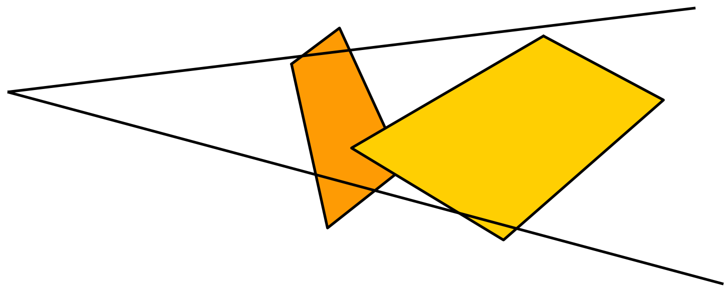
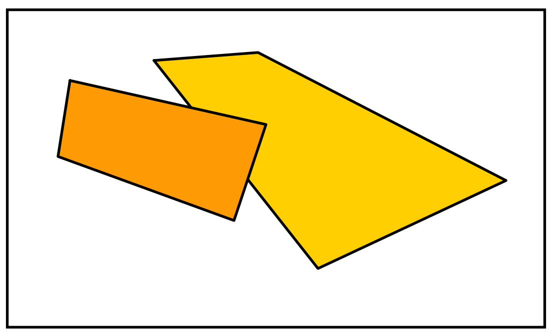
Hidden Surface Removal for Polygonal Scenes

- Input: Set of polygons in three-dimensional space + viewpoint (possibly at infinity)



- Output: Drawing order
  - Two-dimensional image of projected polygons, containing only visible portions



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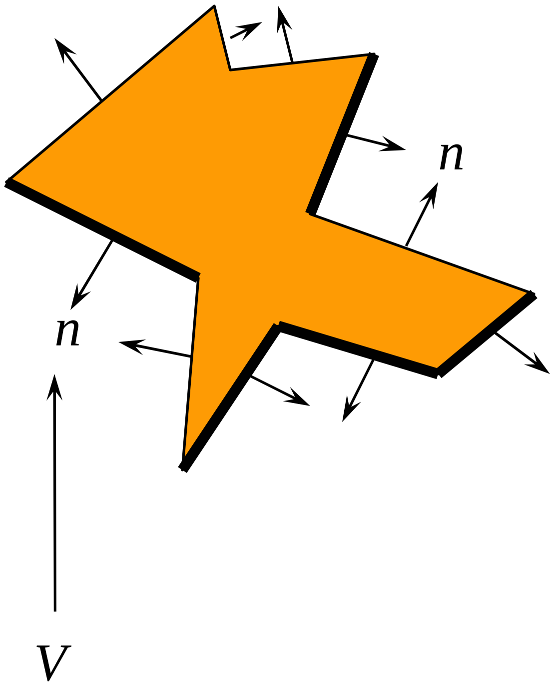
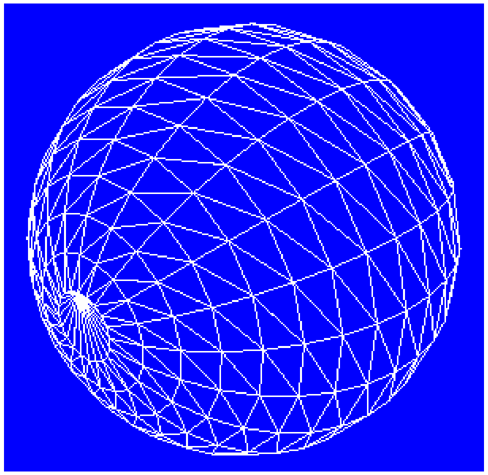
Back Face Culling (object space)



- In closed polyhedron you don’t see object “back” faces

- Assumption
  - Normals of faces point *out* from the object



Back Face Culling

- Determine back & front faces using sign of inner product nv

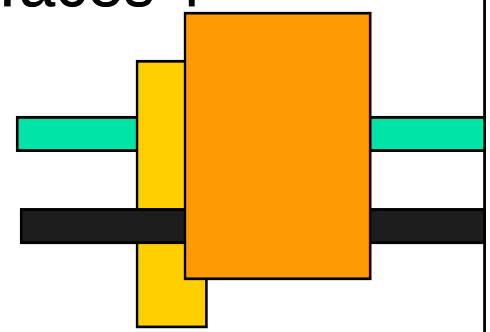
$$n \cdot v = n_x v_x + n_y v_y + n_z v_z = \|n\| \cdot \|v\| \cos\theta$$

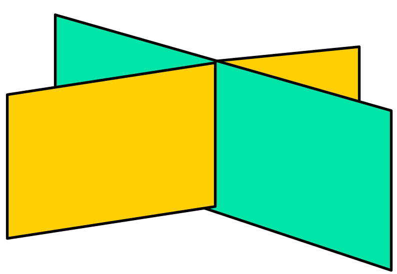
- In a convex object :
  - Invisible back faces
  - All front faces entirely visible $\Rightarrow$ solves hidden surfaces problem
- In non-convex object:
  - Invisible back faces
  - Front faces can be visible, invisible, or partially visible

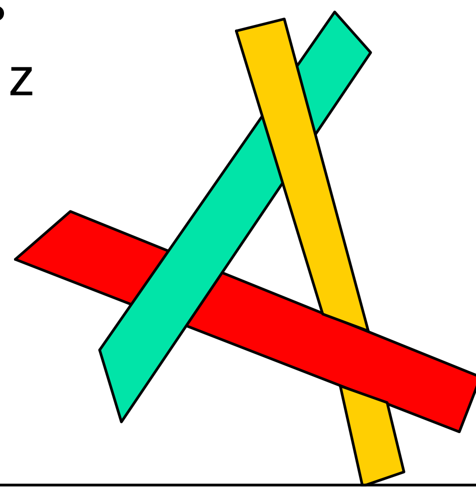
Demo 1 Demo 2

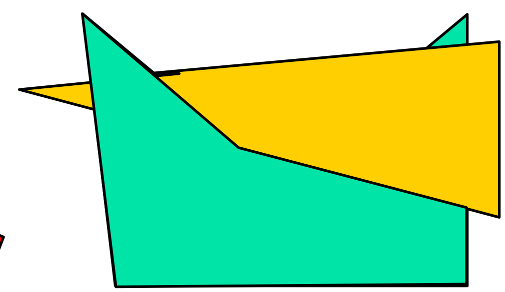
Depth Sort (object space)

- Question: Given a set of polygons, is it possible to:
  - sort them (by depth)
  - then paint them back to front (over each other) to remove the hidden surfaces ?
- Answer: No
- Works for special cases
  - E.g. polygons with constant z









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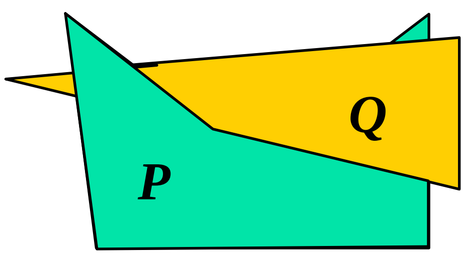
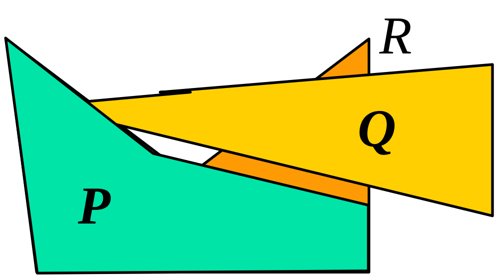
Depth Sort by Splitting

- Given two polygons, P and Q, can order in *z* if:
    1. P and Q do not overlap in their x extents
    2. Or P and Q do not overlap in their y extents
    3. Or P is totally on one side of Q's plane
    4. Or Q is totally on one side of P's plane
    5. Or P and Q do not intersect in projection plane
- If neither holds, split P along its intersection with Q (2D) into two smaller polygons
- How does this apply to examples on previous slide?





$P < Q < R$

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BSP Trees

- Different use of tests 3 & 4 in Depth Sort method
- Define:
  - S_P – set of polygons
  - $P \in S_P$
  - N_p normal to P
  - P in plane L_p
- Subdivide into 3 groups:
  - Polygons in front of L_p (N_p direction)
  - Polygons behind L_p
  - Polygons intersecting L_p
- Split polygons in class 3 along L_p place pieces in first 2 groups

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BSP Trees

- After subdivision
  - Polygons behind L_p can't obscure P $\Rightarrow$ draw first
  - P can't obscure polygons in front of L_p $\Rightarrow$ draw P
  - Draw polygons in front of L_p
- Recursively subdivide and draw front & back sets
- BSP – Binary Space Partition

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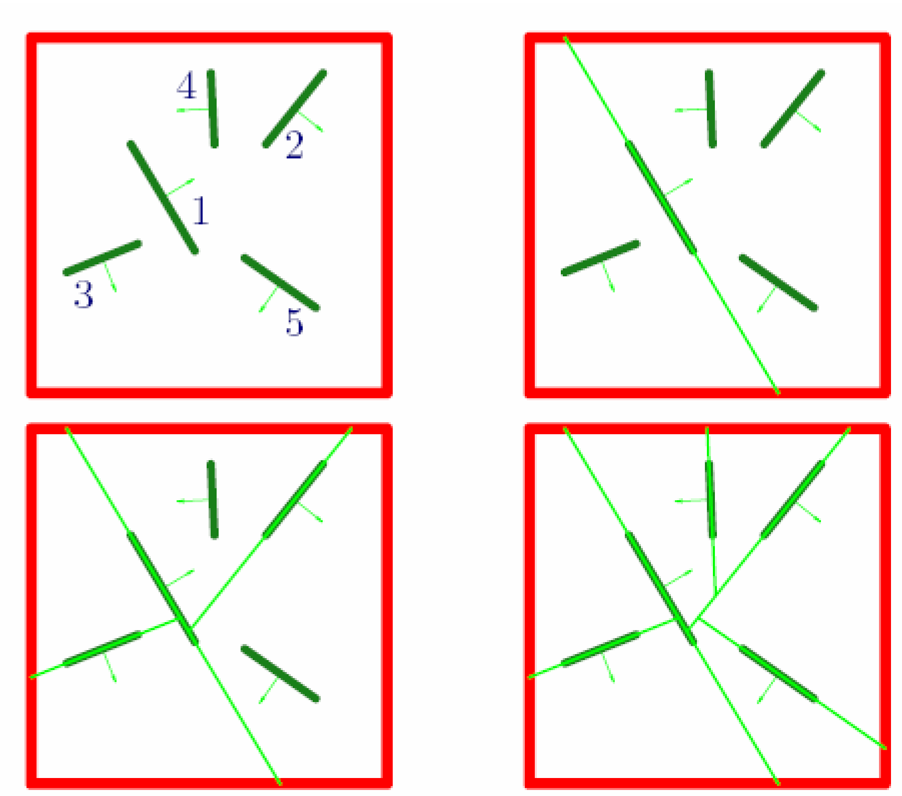
BSP Trees



- Convention: Right sibling in N_p direction
- BSP Tree is ***view independent***
- Constructed using only object geometry
- Can be used in hidden surface removal from multiple views
- How to choose what is visible for given view?

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BSP Trees

- Given view direction *V* perform recursive tree traversal
  - Visit back side tree(from this view)
  - Draw current node's polygon
  - Visit from side tree

- To decide which side is back/front for given view check sign of VN_p

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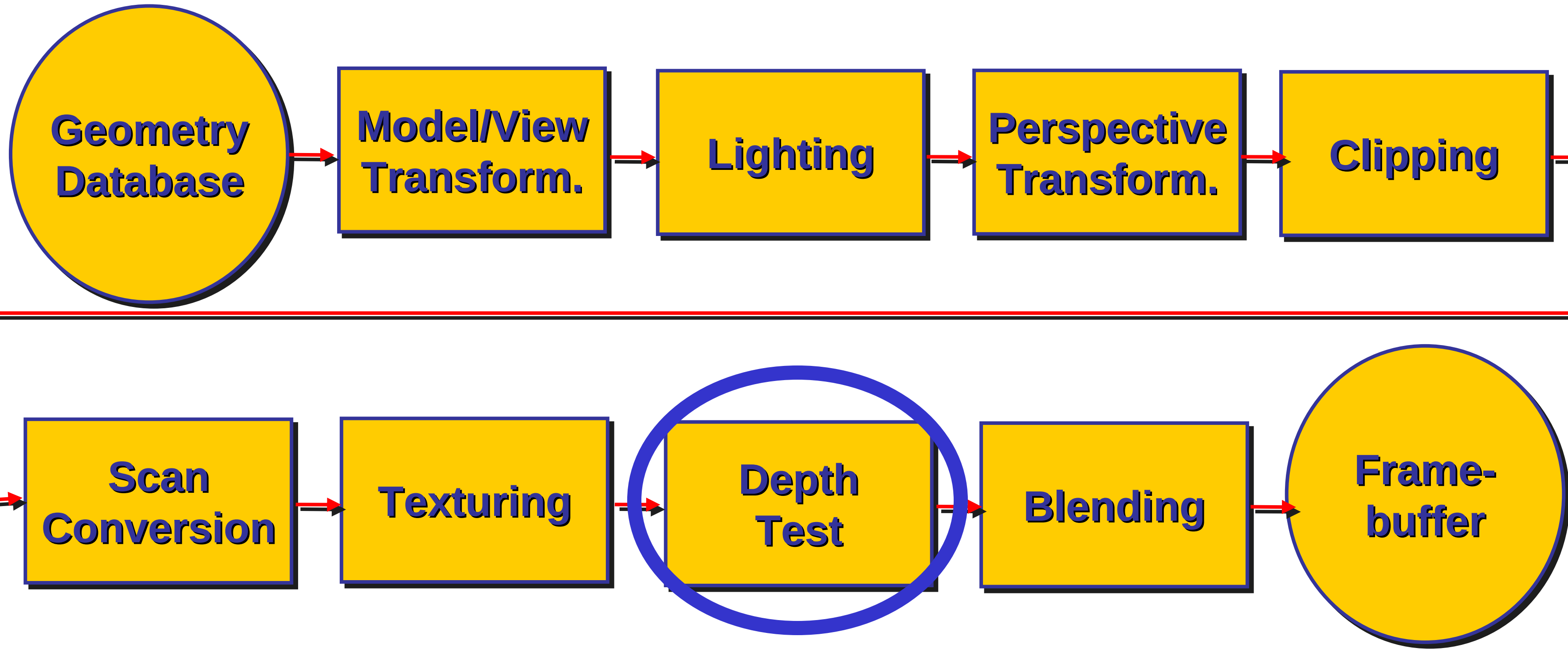
The Rendering Pipeline



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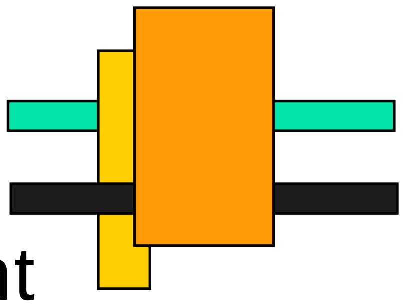
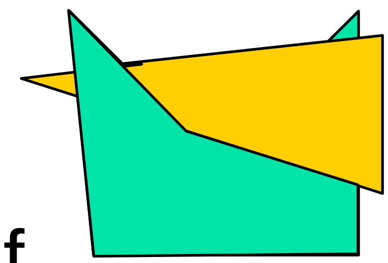
Z-Buffer Algorithm (image space)

- Idea: Instead of always painting over pixel while scan-converting a polygon, do that only if polygon's depth is less than current depth at that pixel



- In each pixel save color and current depth *z*



- New color will replace current only if closer in *z*

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Z-Buffer

```
ZBuffer(Scene)
For every pixel (x,y) do PutZ(x,y,MaxZ);
For each polygon P in Scene do
   Q := Project(P);
   For each pixel (x,y) in Q do
      z1 := Depth(Q,x,y);
      if (z1<GetZ(x,y)) then
         PutZ(x,y,z1);
         PutColor(x,y,Col(P));
      end;
   end;
end;
```

- Questions: How to compute Project(P) & Depth(Q,x,y)?

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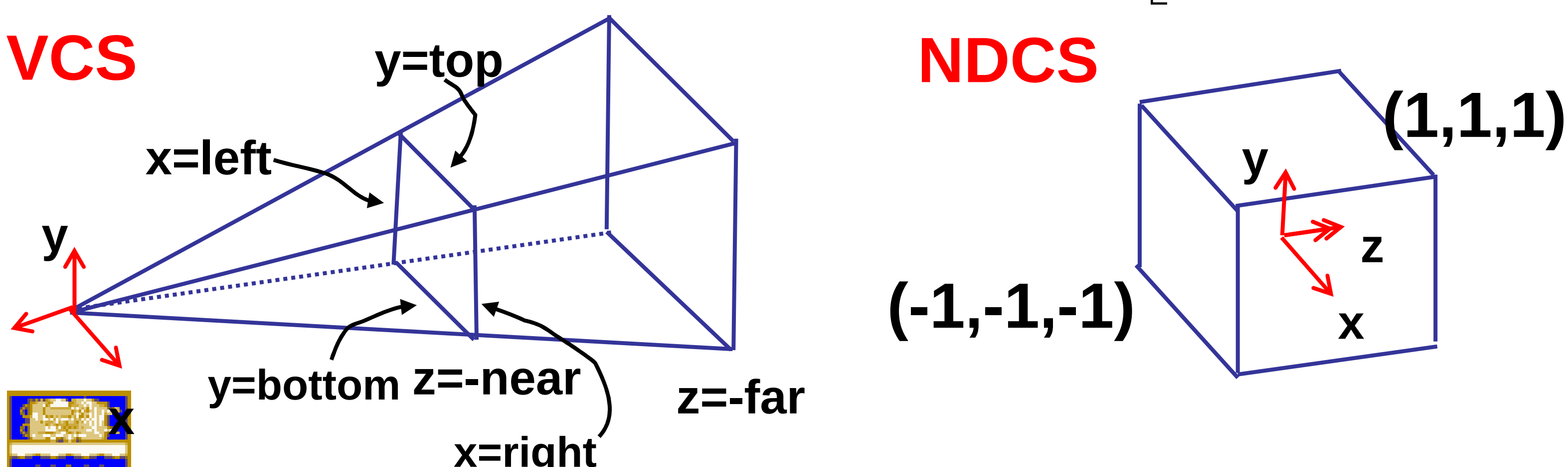
Z-Buffer - Project(P)

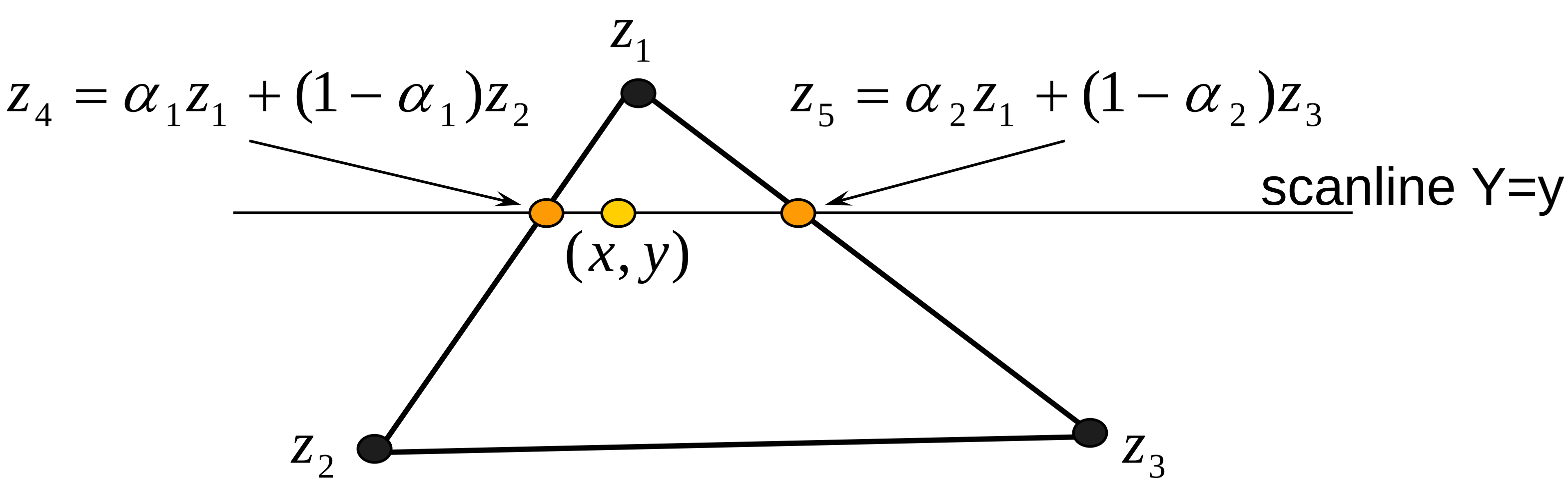
- Rasterize polygon (use x,y coords)
- To preserve depth
  - Store Z separately
  - Or use perspective warp (OpenGL rendering pipeline)

$$\begin{bmatrix} \frac{2n}{r-l} & 0 & \frac{r+l}{r-l} & 0 \\ 0 & \frac{2n}{t-b} & \frac{t+b}{t-b} & 0 \\ 0 & 0 & \frac{-(f+n)}{f-n} & \frac{-2fn}{f-n} \\ 0 & 0 & -1 & 0 \end{bmatrix}$$



- z_p monotonic in z – use as depth to set order

Z-Buffer – Depth(Q,x,y)



$$\text{Depth}(Q, x, y) = \alpha_3 z_4 + (1-\alpha_3) z_5$$

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Z-Buffer Algorithm Properties

- Image space algorithm


zbuffer

- Data structure: Array of depth values
- Common in hardware due to simplicity
- Depth resolution of 32 bits is common
- ***Scene may be updated on the fly adding new polygons***

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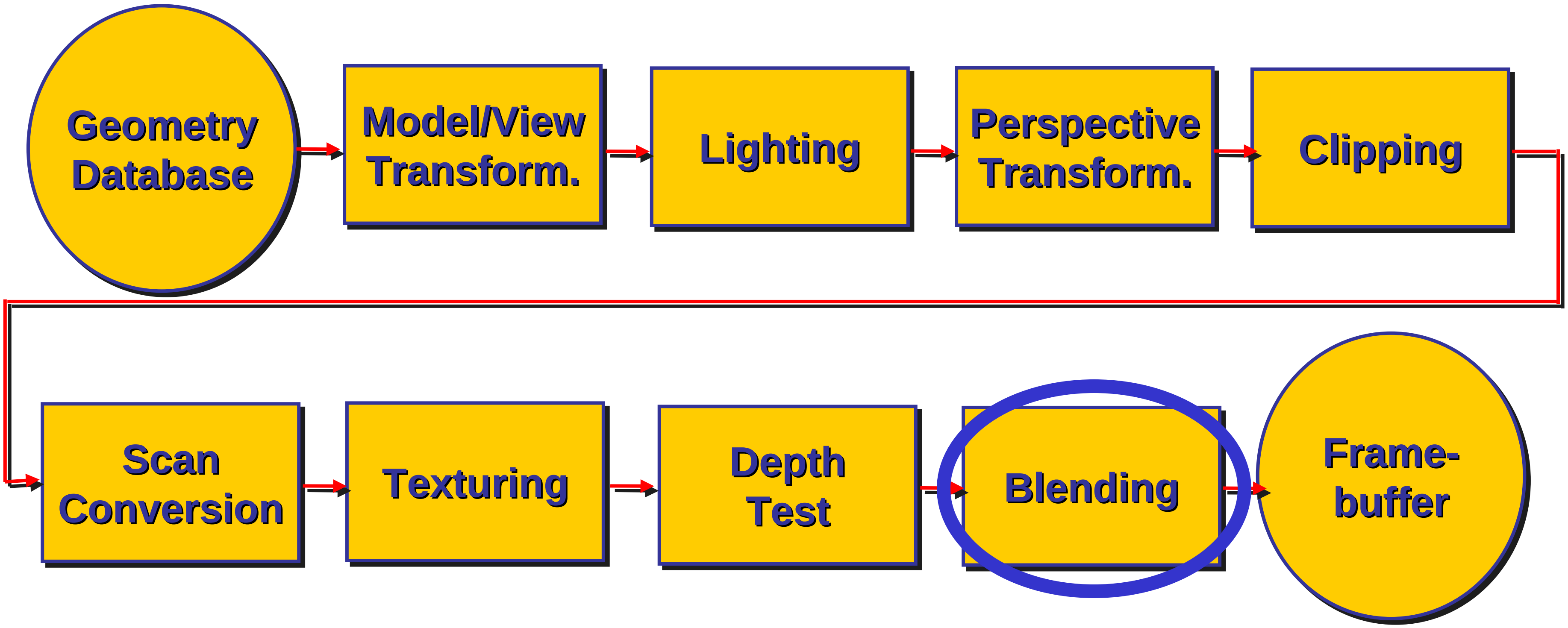
The Rendering Pipeline



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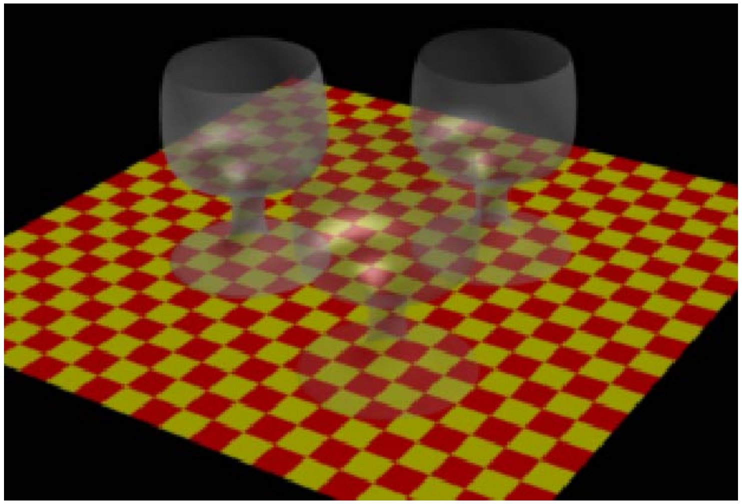
Transparency/Object Buffer

- A-buffer - extension to Z-buffer
- Save all pixel values
- At the end – have list of polygons & depths (order) for each pixel
- Simulate transparency by weighting different list elements



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Scan-Line Z-Buffer Algorithm

- In software implementations - amount of memory required for screen Z-buffer is prohibitive
- Scan-line Z-buffer algorithm:
  - Render image one line at a time
  - Take into account only polygons affecting this line
- Combination of polygon scan-conversion & Z-buffer algorithms
- Only Z-buffer the size of scan-line is required
- ***Scene must be available apriori***
- ***Image cannot be updated incrementally***

Scan-Line Z-Buffer Algorithm

```
ScanLineZBuffer(Scene)
Scene-2D := Project(Scene);
Sort Scene-2D into buckets of polygons P in
   increasing order of YMin(P);
A := EmptySet;
For y := YMin(Scene-2D) to YMax(Scene-2D) do
  For each pixel (x,y) in scanline Y=y do
    PutZ(x,MaxZ);
  A := A+{P in Scene : YMin(P)<=y};
  A := A-{P in A : YMax(P)<y};
  For each polygon P in A
    For each pixel (x,y) in P's spans on the scanline
      z1 := Depth(P,x,y);
      if (z1<GetZ(x)) then
         PutZ(x,z1);
         PutColor(x,y,Col(P));
      end;
    end;
end;
```