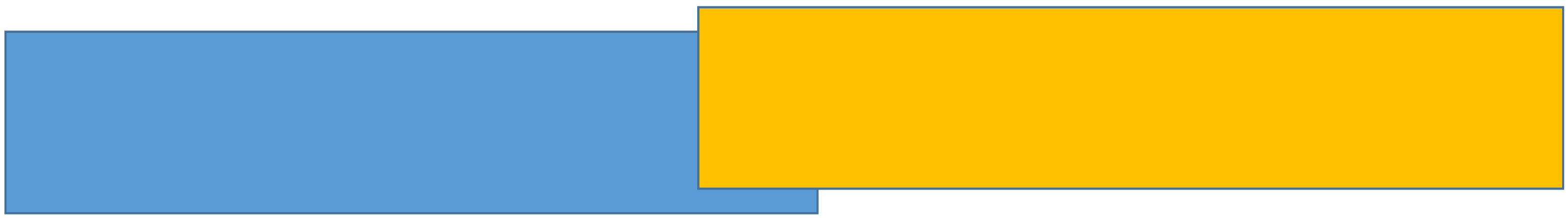
CPSC 314
21 – DEPTH TEST



Textbook: 11.1

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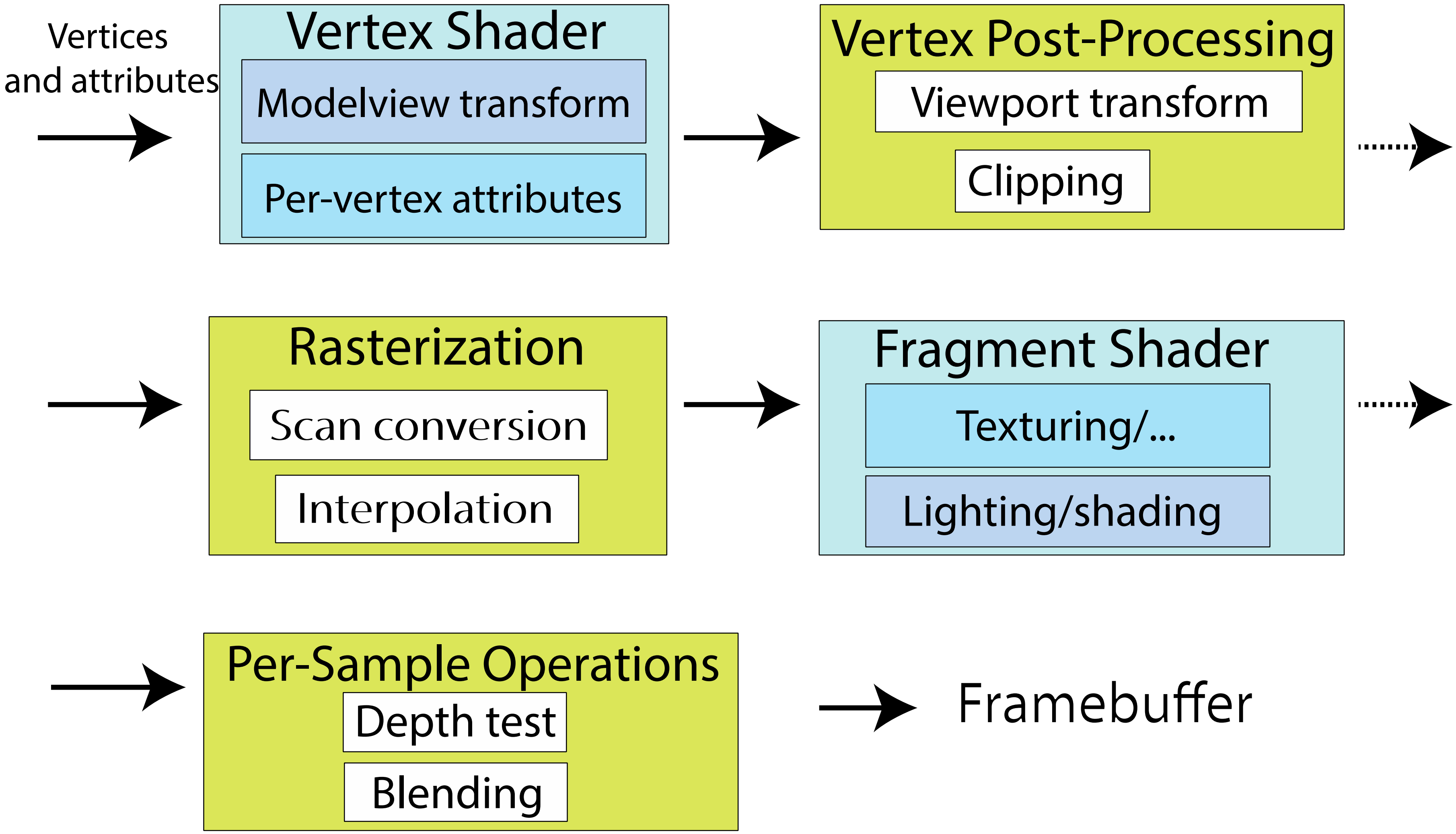
THE RENDERING PIPELINE

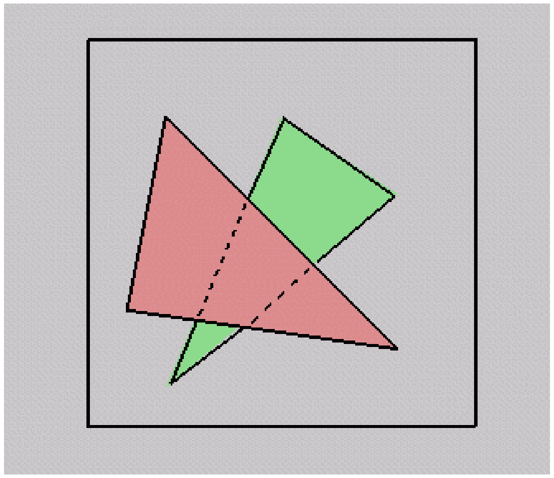


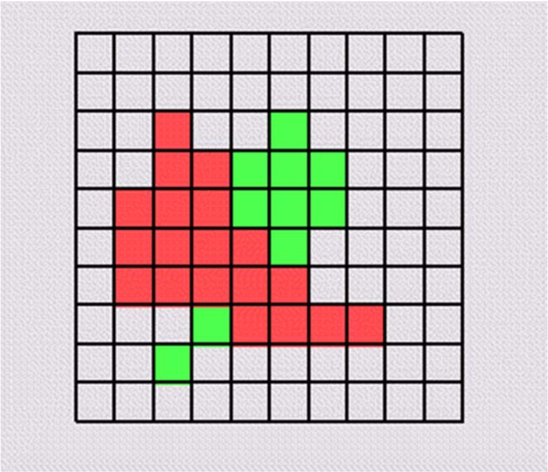
HIDDEN SURFACE REMOVAL

- Object Space Methods:
  - Perform in 3D before scan conversion
    - E.g. Painter's algorithm
  - Usually independent of resolution
    - Independent of output device (screen/printer etc.)
- Image Space Methods:
  - Work on per-pixel/per fragment basis after scan conversion
  - Z-Buffer/Depth Buffer
  - Much faster, but resolution dependent

THE Z-BUFFER ALGORITHM

- What happens if multiple primitives occupy the same pixel on the screen?
- Which is allowed to paint the pixel?





THE Z-BUFFER ALGORITHM

- Idea: retain depth after projection transform
  - Each vertex maintains z coordinate
    - Relative to eye point
    - To compute z per pixel use barycentric coordinates
      - Don’t forget about perspective correction
- Or maybe fragment shader modifies z

THE Z-BUFFER ALGORITHM

- Augment color framebuffer with Z-buffer: Z per pixel
    - Also called depth buffer
    - First initialize all pixel depths to ∞ (depth = far)
- When scan converting: interpolate depth (z) across polygon
- Check z-buffer before storing pixel color in framebuffer and storing depth in z-buffer
    - don't write pixel if its z value is more distant than the z value already stored there

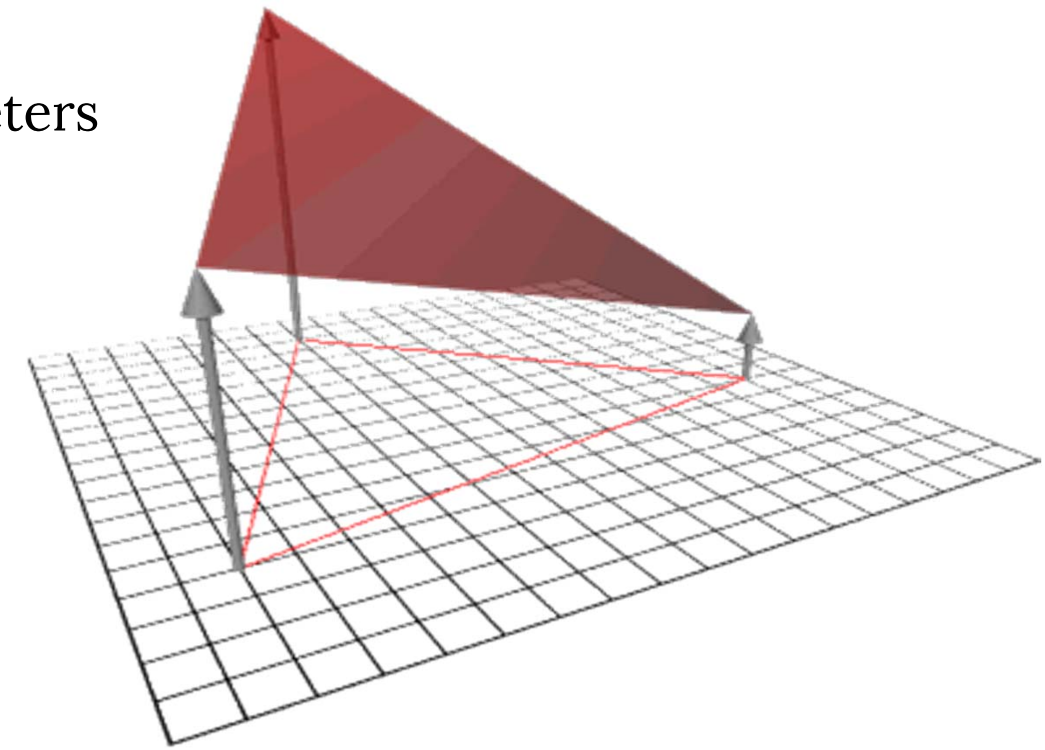
Z-BUFFER

- Store (r,g,b,z) for each pixel
  - typically 8+8+8+24 bits, can be more

```
for all i,j {
 Depth[i,j] = MAX_DEPTH
 Image[i,j] = BACKGROUND_COLOUR
}
for all polygons P {
  for all pixels in P {
    if (Z_pixel < Depth[i,j]) {
      Image[i,j] = C_pixel
      Depth[i,j] = Z_pixel
    }
  }
}
```

INTERPOLATING Z

- Use barycentric coordinates
  - Interpolate z like other parameters
    - E.g. color
    - Use one of three formulas
      - Plane/edge walk/barycentric



THE Z-BUFFER ALGORITHM (MID-70'S)

- History:
  - Object space algorithms were proposed when memory was expensive
  - First 512x512 framebuffer was >$50,000!

- Radical new approach at the time
  - The big idea:
    - Resolve visibility independently at each pixel

DEPTH TEST PRECISION

- Reminder: projective transformation maps eye-space z to generic z-range (NDC)
- Simple example:

$$T\left(\begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}\right) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & a & b \\ 0 & 0 & -1 & 0 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

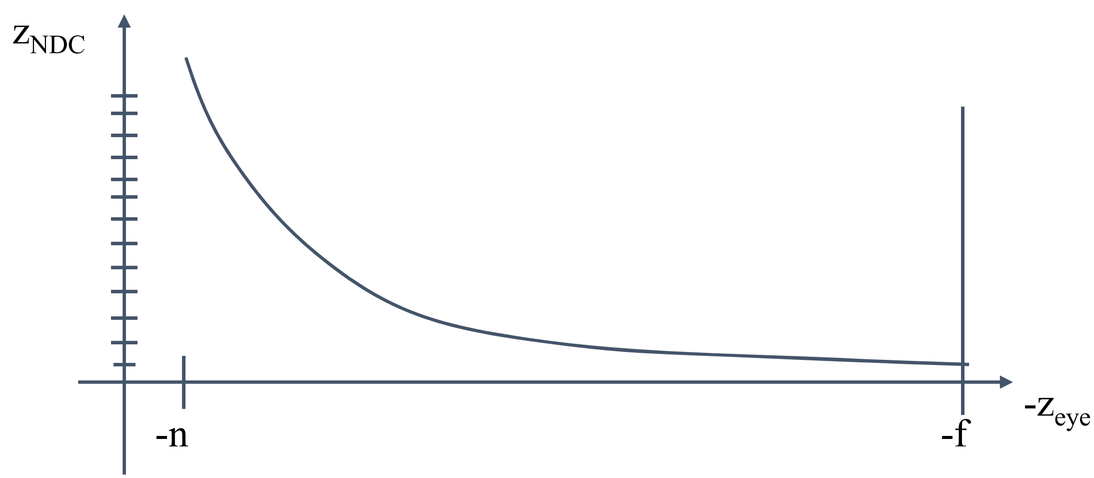
- Thus:

$$z_{NDC} = \frac{a z_{eye} + b}{-z_{eye}} = -a - \frac{b}{z_{eye}}$$

DEPTH TEST PRECISION

Therefore, depth-buffer essentially stores -1/z, rather than z!

- Issue with **integer** depth buffers
  - High precision for near objects
  - Low precision for far objects



DEPTH TEST PRECISION

- Low precision can lead to **depth fighting** for far objects
  - Two different depths in eye space get mapped to same depth in framebuffer
  - Which object "wins" depends on drawing order and scan-conversion

- Gets worse for larger ratios *f:n*
  - Rule of thumb: $f{:}n < 1000$ for 24 bit depth buffer

- With 16 bits cannot discern cm differences in objects at 1 km distance

HOW NEAR AND FAR PLANES AFFECT PRECISION

$$z_{NDC} = \frac{az_{eye} + b}{-z_{eye}} = -a - \frac{b}{z_{eye}}$$

$$z_{NDC} = \frac{f + n}{f - n} + \frac{2fn}{(f - n)z_{eye}}$$

$$\frac{dz_{NDC}}{dz_{eye}} = \frac{-2fn}{(f - n)z_{eye}^2} = -\frac{2f}{\left(\frac{f}{n} - 1\right) z_{eye}^2}$$

Z-BUFFER ALGORITHM QUESTIONS

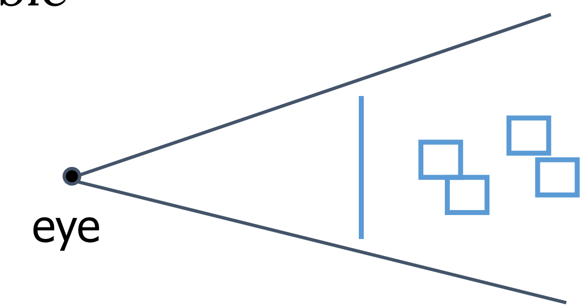
- How much memory does the Z-buffer use?
- Does the image rendered depend on the drawing order?
- Does the time to render the image depend on the drawing order?
- How does Z-buffer load scale with visible polygons? with framebuffer resolution?

Z-BUFFER PROS

- Simple!
- Easy to implement in hardware
  - Hardware support in all graphics cards today
- Polygons can be processed in arbitrary order
- Easily handles polygon interpenetration

Z-BUFFER CONS

- Poor for scenes with high depth complexity
  - Need to render all polygons, even if most are invisible



- Shared edges/overlaps handled inconsistently
  - *Ordering dependent*

Z-BUFFER CONS

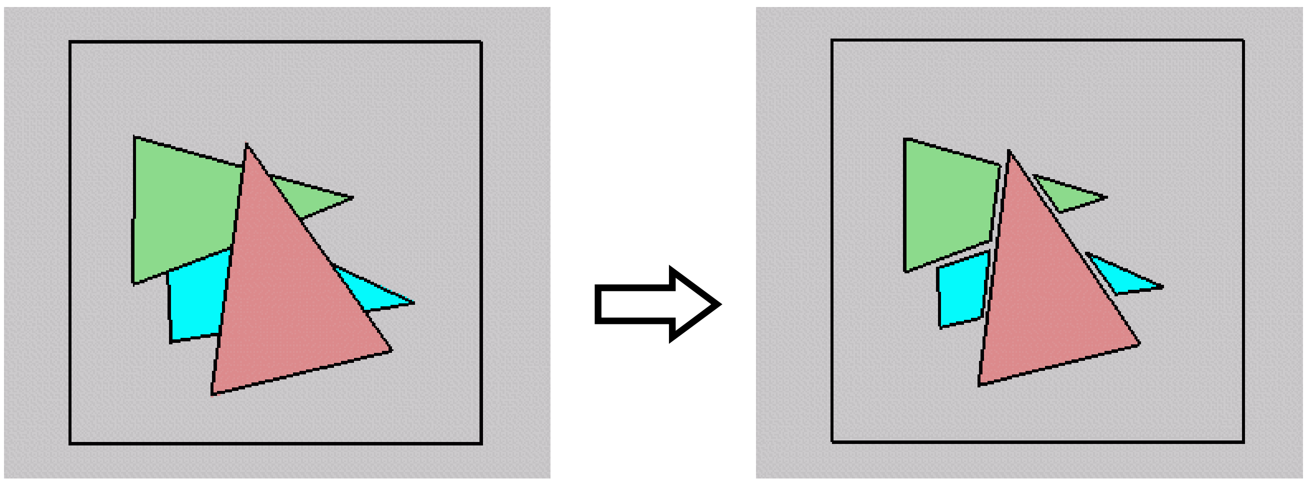
- Requires more memory
  - (e.g. 1280x1024x32 bits, depends on the implementation)
- Requires fast memory
  - Read-Modify-Write in inner loop
- Hard to simulate transparent polygons
  - We throw away color of polygons behind closest one
  - Works if polygons ordered back-to-front
    - Extra work throws away much of the speed advantage

OBJECT SPACE ALGORITHMS

- Determine visibility on object or polygon level
  - Using camera coordinates
- Resolution independent
  - Explicitly compute visible portions of polygons
- Early in pipeline
  - After clipping
- Requires depth-sorting
  - Painter's algorithm
  - BSP trees

OCCLUSION

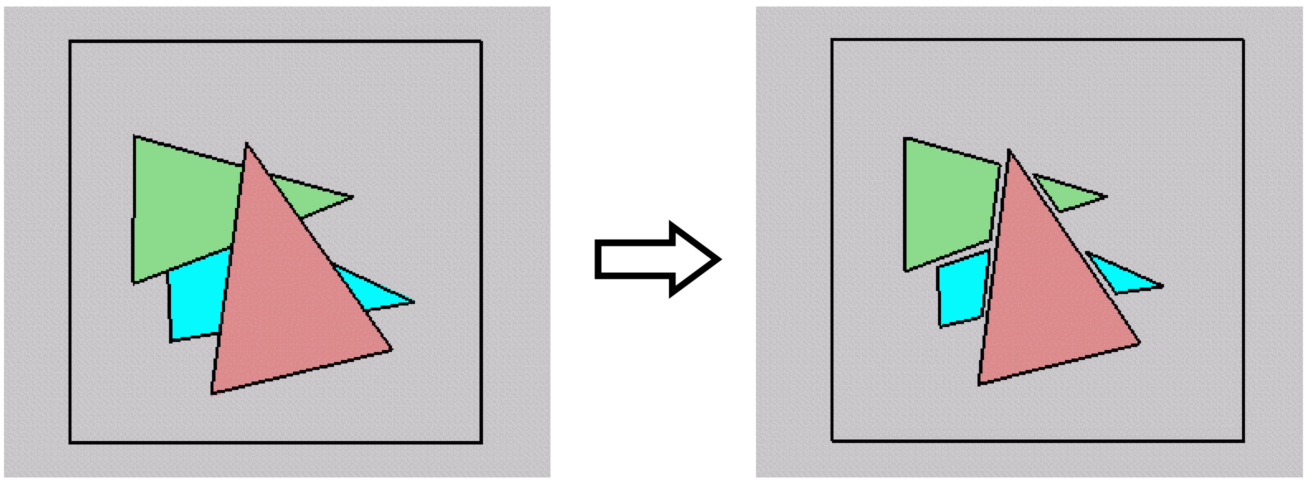
- For most interesting scenes, some polygons overlap



- To render correct image need to determine which polygons occlude which

PAINTER'S ALGORITHM

- Order & render the polygons from back to front, "painting over" previous polygons



- Draw cyan, then green, then red
- Will this work in general?

PAINTER'S ALGORITHM: PROBLEMS

- Intersecting polygons present a problem
- Even non-intersecting polygons can form a cycle with no valid visibility order: