CPSC 314
21 - DEPTH TEST

Textbook: 11.1

UGRAD.CS.UBC.CA/~CS314

Alla Sheffer
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THE RENDERING PIPELINE

Vertices and attributes

Vertex Shader
- Modelview transform
- Per-vertex attributes

Rasterization
- Scan conversion
- Interpolation

Vertex Post-Processing
- Viewport transform
- Clipping

Fragment Shader
- Texturing/...
- Lighting/shading

Per-Sample Operations
- Depth test
- Blending

Framebuffer
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
Augment color framebuffer with Z-buffer: Z per pixel
  • Also called depth buffer
  • First initialize all pixel depths to $\infty$ (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 \(i,j\) 
    
    \[
    \begin{align*}
    \text{Depth}[i,j] &= \text{MAX_DEPTH} \\
    \text{Image}[i,j] &= \text{BACKGROUND_COLOUR}
    \end{align*}
    \]

    for all polygons \(P\) 
    
    for all pixels in \(P\) 
    
    if \((Z_{\text{pixel}} < \text{Depth}[i,j])\) 
    
    \[
    \begin{align*}
    \text{Image}[i,j] &= \text{C}_{\text{pixel}} \\
    \text{Depth}[i,j] &= \text{Z}_{\text{pixel}}
    \end{align*}
    \]
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:

\[
T \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & a & b \\ 0 & 0 & -1 & 0 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}
\]

- Thus:

\[
z_{NDC} = \frac{az_{eye} + b}{-z_{eye}} = -a - \frac{b}{z_{eye}}
\]
DEPTH TEST PRECISION

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

- Issue with \textbf{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 a correct image, we 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: