University of British Columbia

CPSC 414 Computer Graphics

Visibility: Z Buffering

Week 10, Mon 3 Nov 2003

Poll

- how far are people on project 2?
- preferences for
  - Plan A: status quo
    - P2 stays due Tue Nov 4, stays 10% of total grade
    - P3 is "the big one" stays 15%, due Fri Nov 28
  - Plan B: P2 is "the big one"
    - P2 extension to Mon Nov 10, upgrade weight to 15%
    - P3 smaller, downgrade weight to 10%, due Fri Dec 5

Demo

- sample program
  - remember, download all 3 textures to run this!
  - you should also use the checkerboard image
- questions?

Readings

- Chapter 8.8: hidden surface removal

News

- yet more extra office hours TBD
  - check newsgroup

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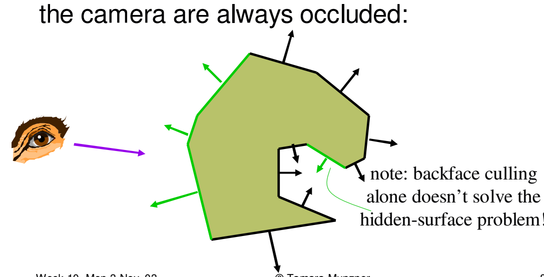
Visibility recap

Invisible Primitives

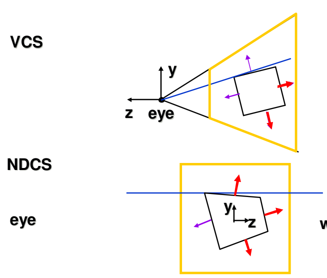
- why might a polygon be invisible?
  - polygon outside the *field of view / frustum*
    - clipping
  - polygon is *backfacing*
    - backface culling
  - polygon is *occluded* by object(s) nearer the viewpoint
    - hidden surface removal

Back-Face Culling

- on the surface of a closed manifold, polygons whose normals point away from the camera are always occluded:



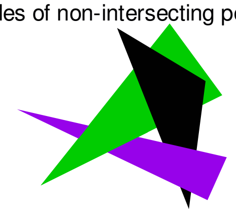
Back-face Culling: NDCS



works to cull if $N_Z > 0$

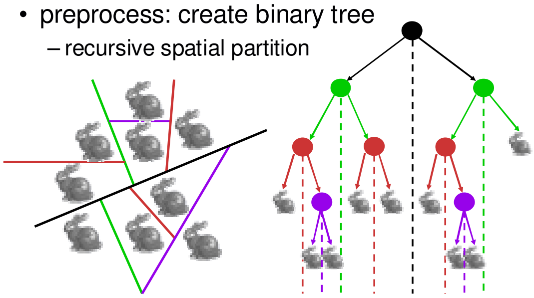
Painter's Algorithm

- draw objects from back to front
- problems: no valid visibility order for
  - intersecting polygons
  - cycles of non-intersecting polygons possible



BSP Trees

- preprocess: create binary tree
  - recursive spatial partition



BSP Trees

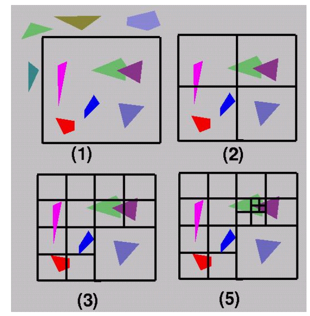
- runtime: correctly traversing this tree enumerates objects from back to front
  - check which side of plane viewpoint is on
  - draw far, draw object in question, draw near

Summary: BSP Trees

- pros:
  - simple, elegant scheme
  - only writes to framebuffer (no reads to see if current polygon is in front of previously rendered polygon, i.e., painters algorithm)
    - thus very popular for video games (but getting less so)
- cons:
  - computationally intense preprocess stage restricts algorithm to static scenes
  - slow time to construct tree: O(n log n) to

Warnock's Algorithm

- recursive viewport subdivision, stop if
  - 0 polygons
    - background color
  - 1 polygon
    - object color
  - down to single pixel
    - explicitly find depths of all objects in viewport



Warnock's Algorithm

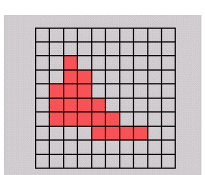
- pros:
  - very elegant scheme
  - extends to any primitive type
- cons:
  - hard to embed hierarchical schemes in hardware
  - complex scenes usually have small polygons and high depth complexity
    - thus most screen regions come down to the single-pixel case

The Z-Buffer Algorithm

- both BSP trees and Warnock's algorithm were proposed when memory was expensive
  - example: first 512x512 framebuffer > $50,000!
- Ed Catmull (mid-70s) proposed a radical new approach called z-buffering.
- the big idea: resolve visibility independently at each pixel

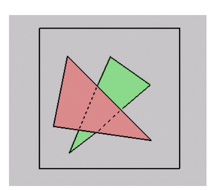
The Z-Buffer Algorithm

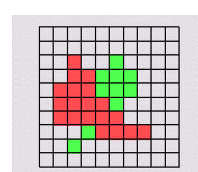
- we know how to rasterize polygons into an image discretized into pixels:



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

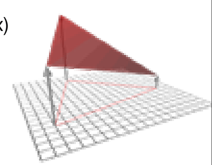
- idea: retain depth (Z in eye coordinates) through projection transform
  - use canonical viewing volumes
  - each vertex has z coordinate (relative to eye point) intact

The Z-Buffer Algorithm

- augment color framebuffer with Z-buffer or *depth buffer* which stores Z value at each pixel
  - at frame beginning, initialize all pixel depths to ∞
  - when rasterizing, interpolate depth (Z) across polygon and store in pixel of Z-buffer
  - suppress writing to a pixel if its Z value is more distant than the Z value already stored there

Interpolating Z

- edge equations: Z just another planar parameter:
  - z = (-D - Ax – By) / C
  - if walking across scanline by (Dx) znew = zold – (A/C)(Dx)
  - total cost:
    - 1 more parameter to increment in inner loop
    - 3x3 matrix multiply for setup



- edge walking: just interpolate Z along edges and across spans

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
    }
  }
}
```


Depth Test Precision

- reminder: projective transformation maps eye-space *z* to generic *z*-range (NDC)
- simple example:

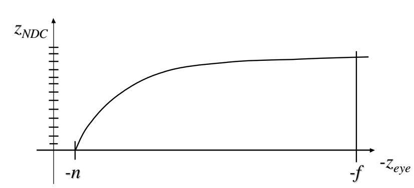
$$T\left(\begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}\right) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & a & b \\ 0 & 0 & -1 & 0 \end{bmatrix} \cdot \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

- thus:

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

Depth Test Precision

- therefore, depth-buffer essentially stores $1/z$, rather than z!
- this yields precision problems with integer depth buffers:

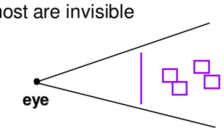


Depth Test Precision

– precision of depth buffer is bad for far objects
– depth fighting: 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*

Z-buffer

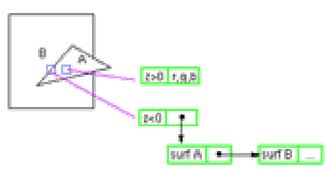
– hardware support in graphics cards
– poor for high-depth-complexity scenes
  • need to render all polygons, even if most are invisible



– "jaggies": pixel staircase along edges

The A-Buffer

– antialiased, area-averaged accumulation buffer
  • z-buffer: one visible surface per pixel
  • A-buffer: linked list of surfaces



• data for each surface includes
  • *RGB, Z, area-coverage percentage, ...*

The Z-Buffer Algorithm

• 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?

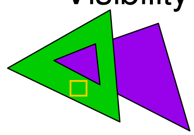
Z-Buffer Pros

• simple!!!
• easy to implement in hardware
• polygons can be processed in arbitrary order
• easily handles polygon interpenetration
• enables *deferred shading*
  – rasterize shading parameters (e.g., surface normal) and only shade final visible fragments

Z-Buffer Cons

• lots of memory (e.g. 1280x1024x32 bits)
  – with 16 bits cannot discern millimeter differences in objects at 1 km distance
• Read-Modify-Write in inner loop requires fast memory
• hard to do analytic antialiasing
  – we don't know which polygon to map pixel back to
• shared edges are handled inconsistently
  – ***ordering dependent***
• hard to simulate translucent polygons
  – we throw away color of polygons behind closest one

Visibility



– object space algorithms
  - explicitly compute visible portions of polygons
  - painter's algorithm: depth-sorting, BSP trees
– image space algorithms
  - operate on pixels or scan-lines
  - visibility resolved to the precision of the display
  - Z-buffer, Warnock's

Hidden Surface Removal

- 2 classes of methods
  – image-space algorithms
    - perform visibility test for every pixel independently
    - limited to resolution of display
    - performed late in rendering pipeline
  – object-space algorithms
    - determine visibility on a polygon level in camera coordinates
    - resolution independent
    - early in rendering pipeline (after clipping)
    - expensive

Pick up Homework 1