9. Hidden Surface Algorithms

Introduction

In the previous lecture, we figured out how to transform the geometry so that the relative sizes will be correct if we drop the $z$ component.

But, how do we decide which geometry actually gets drawn to a pixel?

Known as the hidden surface elimination problem or the visible surface determination problem.

There are dozens of hidden surface algorithms.

They can be characterized in at least three ways:

- Object-precision vs. image-precision (a.k.a., object-space vs. image-space)
- Object order vs. image order
- Sort first vs. sort last

Object-precision algorithms

Basic idea:

- Operate on the geometric primitives themselves. (We'll use "object" and "primitive" interchangeably.)
- Objects typically intersected against each other
- Tests performed to high precision
- Finished list of visible objects can be drawn at any resolution

Complexity:

- For $n$ objects, can take $O(n^2)$ time to compute visibility.
- For an $m \times m$ display, have to fill in colors for $m^2$ pixels.
- Overall complexity can be $O(k_{obj}n^2 + k_{disp}m^2)$.

Implementation:

- Difficult to implement
- Can get numerical problems

Reading

Reading:

- Watt, 6.6 (esp. intro and subsections 1, 4, and 8–10), 12.1.4.

Optional reading:

- Foley, van Dam, Feiner, Hughes, Chapter 15
Image-precision algorithm

Basic idea:
- Find the closest point as seen through each pixel
- Calculations performed at display resolution
- Does not require high precision

Complexity:
- Naive approach checks all n objects at every pixel. Then, \( O(n \, m^2) \).
- Better approaches check only the objects that could be visible at each pixel. Let’s say, on average, \( d \) objects are visible at each pixel (a.k.a., depth complexity). Then, \( O(d \, m^2) \).

Implementation:
- Very simple to implement.
  - Used a lot in practice.

Object order vs. image order

Object order:
- Consider each object only once, draw its pixels, and move on to the next object.
- Might draw the same pixel multiple times.

Image order:
- Consider each pixel only once, find nearest object, and move on to the next pixel.
- Might compute relationships between objects multiple times.

Sort first vs. sort last

Sort first:
- Find some depth-based ordering of the objects relative to the camera, then draw back to front.
- Build an ordered data structure to avoid duplicating work.

Sort last:
- Sort implicitly as more information becomes available.

Outline of Lecture

- Z-buffer
- Ray casting
- Binary space partitioning (BSP) trees
Z-buffer

The Z-buffer or depth buffer algorithm [Catmull, 1974] is probably the simplest and most widely used.

Here is pseudocode for the Z-buffer hidden surface algorithm:

\begin{verbatim}
for each pixel (i,j) do
    Z-buffer[i,j] ← FAR
    Framebuffer[i,j] ← <background color>
end for
for each polygon A do
    for each pixel in A do
        Compute depth z and shade s of A at (i,j)
        if z > Z-buffer[i,j] then
            Z-buffer[i,j] ← z
            Framebuffer[i,j] ← s
        end if
    end for
end for
\end{verbatim}

Q: What should FAR be set to?

Z-buffer, cont'd

The process of filling in the pixels inside of a polygon is called rasterization.

During rasterization, the z value and shade s can be computed incrementally (fast!).

Curious fact:
- Described as the “brute-force image space algorithm” by [SSS]
- Mentioned only in Appendix B of [SSS] as a point of comparison for huge memories, but written off as totally impractical.

Today, Z-buffers are commonly implemented in hardware.

Z-buffer: Analysis

- Classification?
- Easy to implement?
- Easy to implement in hardware?
- Incremental drawing calculations (uses coherence)?
- Pre-processing required?
- On-line (doesn’t need all objects before drawing begins)?
- If objects move, does it take extra work than normal to draw the frame?
- If the viewer moves, does it take extra work than normal to draw the frame?
- Typically polygon-based?
- Efficient shading (doesn’t compute colors of hidden surfaces)?
- Handles transparency?
- Handles refraction?

Ray casting

Idea: For each pixel center $P_{ij}$
- Send ray from eye point (COP), $C$, through $P_{ij}$ into scene.
- Intersect ray with each object.
- Select nearest intersection.
Ray casting, cont.

Implementation:
- Might parameterize each ray:
  \[ r(t) = c + t(P - c) \]
- Each object \( O_k \) returns \( t_k > 1 \) such that first intersection with \( O_k \) occurs at \( r(t_k) \).

Q: Given the set \( \{t_k\} \) what is the first intersection point?

Note: these calculations generally happen in world coordinates.

Ray casting: Analysis

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Binary-space partitioning (BSP) trees

Idea:
- Do extra preprocessing to allow quick display from any viewpoint.

Key observation: A polygon \( A \) is painted in correct order if
- Polygons on far side of \( A \) are painted first
- \( P \) is painted next
- Polygons in front of \( A \) are painted last.

BSP tree creation
BSP tree creation (cont’d)

procedure MakeBSPTree:
takes PolygonList L
returns BSPTree

Choose polygon A from L to serve as root
Split all polygons in L according to A
node ← A
node.neg ← MakeBSPTree(Polygon on neg. side of A)
node.pos ← MakeBSPTree(Polygon on pos. side of A)
return node
end procedure

Note: Performance is improved when fewer polygons are split — in practice, best of ~ 5 random splitting polygons are chosen.

Note: BSP is created in world coordinates.

BSP tree display

procedure DisplayBSPTree:
Takes BSPTree T

if T is empty then return

if viewer is in front (on pos. side) of T.node
DisplayBSPTree(T._____)
Draw T.node
DisplayBSPTree(T._____)
else
DisplayBSPTree(T._____)
Draw T.node
DisplayBSPTree(T._____)
end if
end procedure

BSP trees: Analysis
• Classification?
• Easy to implement?
• Easy to implement in hardware?
• Incremental drawing calculations (uses coherence)?
• Pre-processing required?
• On-line (doesn’t need all objects before drawing begins)?
• If objects move, does it take extra work than normal to draw the frame?
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Visibility tricks for Z-buffers

Z-buffering is the algorithm of choice for hardware rendering, so let’s think about how to make it run as fast as possible…

What is the cost of the Z-buffer algorithm?

What can we do to decrease the constants?
Summary

What to take home from this lecture:

- Classification of hidden surface algorithms
- Understanding of Z-buffer, ray casting, and BSP tree hidden surface algorithms
- Familiarity with some Z-buffer acceleration strategies