Visible-Surface Detection Methods

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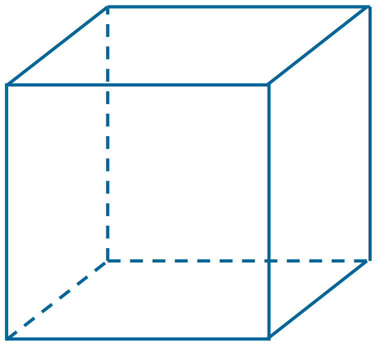
<Computer Graphics>

2001/08/03

Contents

Abstract

- Hidden-surface elimination methods
- Identifying visible parts of a scene from a viewpoint
- Numerous algorithms
  - More memory - storage
  - More processing time – execution time
  - Only for special types of objects - constraints
- Deciding a method for a particular application
  - Complexity of the scene
  - Type of objects
  - Available equipment
  - Static or animated scene



<Ex. Wireframe Displays>

Introduction

Classification of Visible-Surface Detection Algorithms

- *Object-space methods* vs. *Image-space methods*
  - Object definition directly vs. their projected images
  - Most visible-surface algorithms use image-space methods
  - Object-space can be used effectively in some cases
    - Ex) Line-display algorithms
- Object-space methods
  - Compares objects and parts of objects to each other
- Image-space methods
  - Point by point at each pixel position on the projection plane

Sorting and Coherence Methods

- To improve performance
- *Sorting*
  - Facilitate depth comparisons
    - Ordering the surfaces according to their distance from the viewplane
- *Coherence*
  - Take advantage of regularity
    - Epipolar geometry
    - Topological coherence

Back-Face Detection

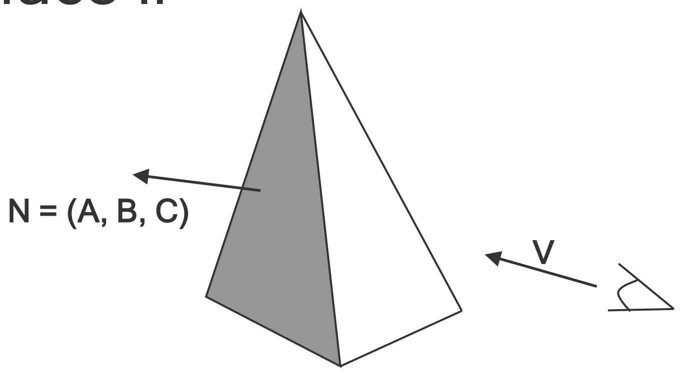
Inside-outside test

- A point (x, y, z) is "inside" a surface with plane parameters A, B, C, and D if

$$Ax + By + Cz + D < 0$$

- The polygon is a back face if

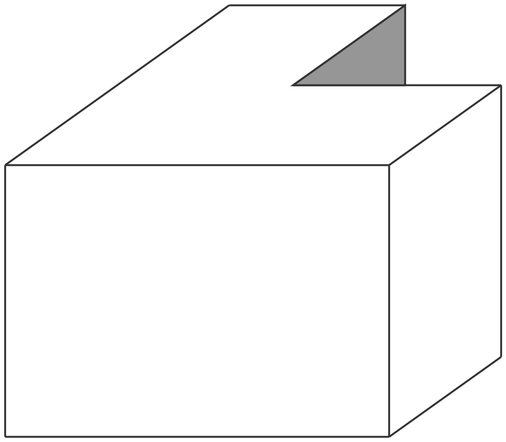
$$V \cdot N > 0$$



  - V is a vector in the viewing direction from the eye(camera)
  - N is the normal vector to a polygon surface

Advanced Configuration

- In the case of *concave polyhedron*
  - Need more tests
    - Determine faces totally or partly obscured by other faces
  - In general, back-face removal can be expected to eliminate *about half of the surfaces* from further visibility tests

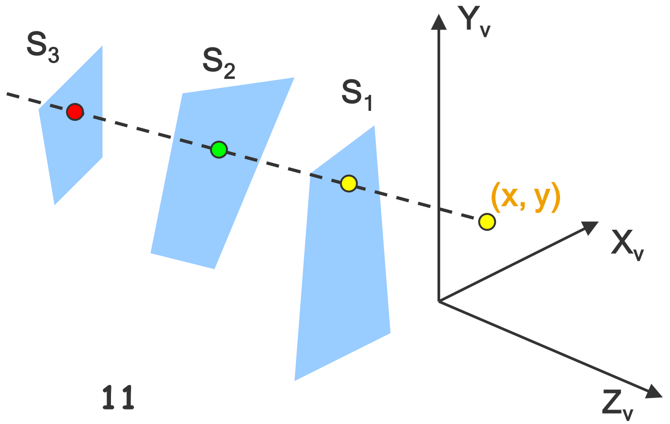


<View of a concave polyhedron with one face partially hidden by other surfaces>

Depth-Buffer Method

Characteristics

- Commonly used image-space approach
- Compares depths of each pixel on the projection plane
  - Referred to as the *z-buffer* method
- Usually applied to scenes of polygonal surfaces
  - Depth values can be computed very quickly
  - Easy to implement



Depth Buffer & Refresh Buffer

- Two buffer areas are required
  - Depth buffer
    - Store depth values for each (x, y) position
    - All positions are initialized to minimum depth
      - Usually 0 – most distant depth from the viewplane
  - Refresh buffer
    - Stores the intensity values for each position
    - All positions are initialized to the background intensity

Algorithm

- Initialize the depth buffer and refresh buffer

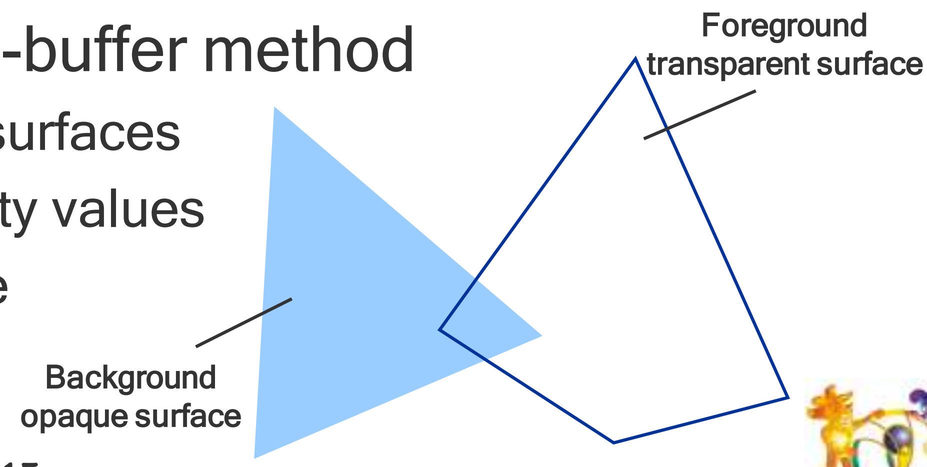
  depth(x, y) = 0, refresh(x, y) = $I_{backgnd}$
- For each position on each polygon surface
  - Calculate the depth for each (x, y) position on the polygon
  - If z > depth(x, y), then set

    depth(x, y) = z, refresh(x, y) = $I_{surf}(x, y)$
- Advanced
  - With resolution of 1024 by 1024
    - Over a million positions in the depth buffer
  - Process one section of the scene at a time
    - Need a smaller depth buffer
    - The buffer is reused for the next section

A-Buffer Method

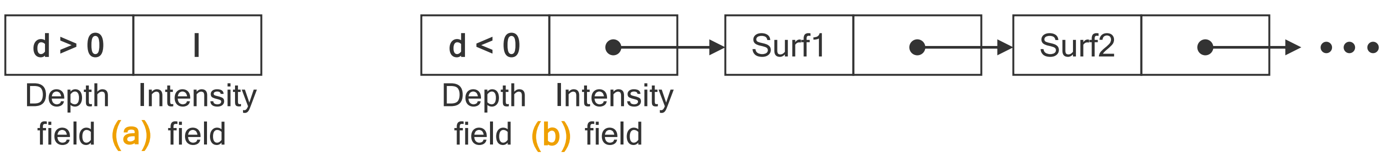
Characteristics

- An extension of the ideas in the depth-buffer method
- The origin of this name
  - At the other end of the alphabet from “z-buffer”
  - Antialiased, area-averaged, accumulation-buffer
  - Surface-rendering system developed by ‘Lucasfilm’
    - REYES(Renders Everything You Ever Saw)
- A drawback of the depth-buffer method
  - Deals only with opaque surfaces
  - Can’t accumulate intensity values for more than one surface



Algorithm(1 / 2)

- Each position in the buffer can reference a linked list of surfaces
  - Several intensities can be considered at each pixel position
  - Object edges can be antialiased
- Each position in the A-buffer has two fields
  - Depth field
    - Stores a positive or negative real number
  - Intensity field
    - Stores surface-intensity information or a pointer value



<Organization of an A-buffer pixel position : (a) single-surface overlap (b) multiple-surface overlap>

Algorithm(2 / 2)

- If the depth field is positive
  - The number at that position is the depth
  - The intensity field stores the RGB
- If the depth field is negative
  - Multiple-surface contributions to the pixel
  - The intensity field stores a pointer to a linked list of surfaces
  - Data for each surface in the linked list
    - RGB intensity components
    - Opacity parameters(percent of transparency)
    - Depth
    - Percent of area coverage
    - Surface identifier
    - Pointers to next surface

Scan-Line Method

Characteristics

- Extension of the scan-line algorithm for filling polygon interiors
  - For all polygons intersecting each scan line
    - Processed from left to right
    - Depth calculations for each overlapping surface
    - The intensity of the nearest position is entered into the refresh buffer

Tables for The Various Surfaces

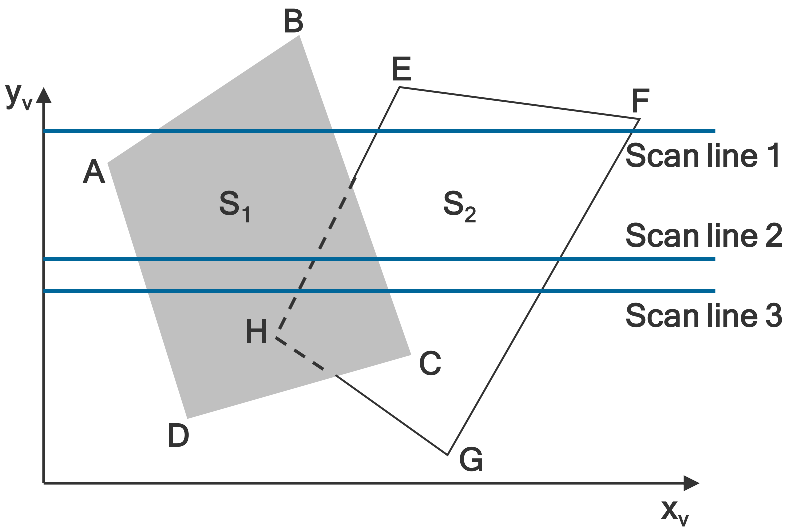
- Edge table
  - Coordinate endpoints for each line
  - Slope of each line
  - Pointers into the polygon table
    - Identify the surfaces bounded by each line
- Polygon table
  - Coefficients of the plane equation for each surface
  - Intensity information for the surfaces
  - Pointers into the edge table

Active List & Flag

- Active list
  - Contain only edges across the current scan line
  - Sorted in order of increasing x
- Flag for each surface
  - Indicate whether inside or outside of the surface
  - At the leftmost boundary of a surface
    - The surface flag is turned on
  - At the rightmost boundary of a surface
    - The surface flag is turned off

Example

- Active list for scan line 1
  - Edge table
    - AB, BC, EH, and FG
    - Between AB and BC, only the flag for surface S_1 is on
      - No depth calculations are necessary
      - Intensity for surface S_1 is entered into the refresh buffer
    - Similarly, between EH and FG, only the flag for S_2 is on

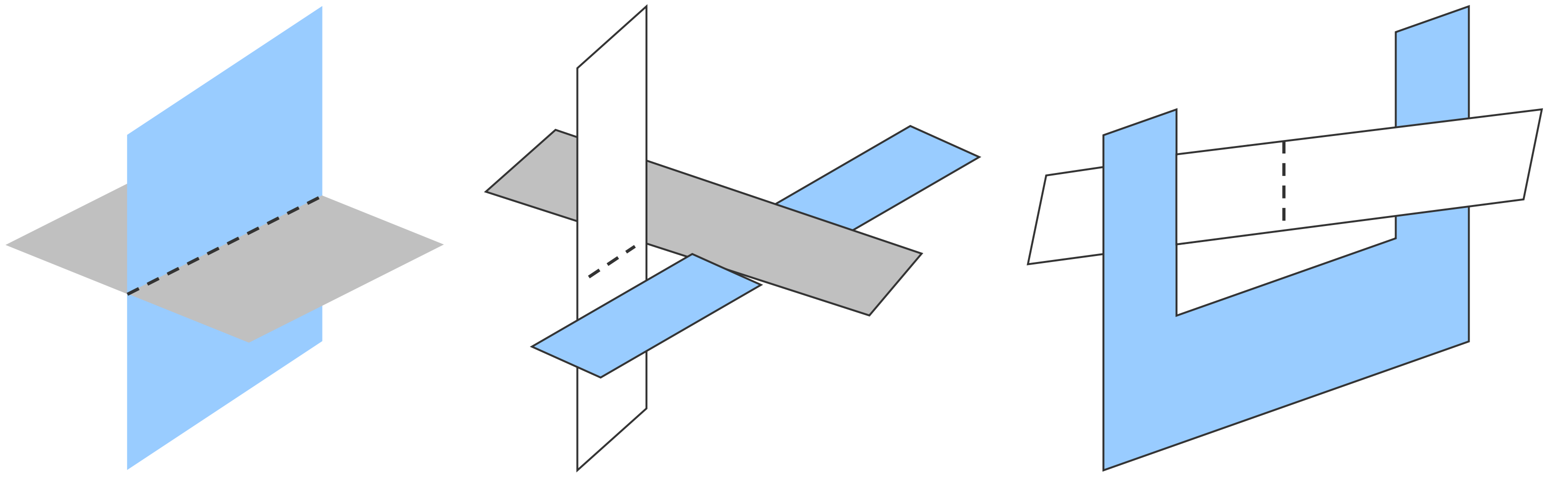


Example(cont.)

- For scan line 2, 3
  - AD, EH, BC, and FG
    - Between AD and EH, only the flag for S_1 is on
    - Between EH and BC, the flags for both surfaces are on
      - Depth calculation is needed
      - Intensities for S_1 are loaded into the refresh buffer until BC
  - Take advantage of coherence
    - Pass from one scan line to next
    - Scan line 3 has the same active list as scan line 2
    - Unnecessary to make depth calculations between EH and BC

Drawback

- Only if surfaces don't cut through or otherwise cyclically overlap each other
  - If any kind of cyclic overlap is present
    - Divide the surfaces



Depth-Sorting Method

Operations

- Image-space and object-space operations
  - Sorting operations in both image and object-space
  - The scan conversion of polygon surfaces in image-space
- Basic functions
  - Surfaces are sorted in order of decreasing depth
  - Surfaces are scan-converted in order, starting with the surface of greatest depth

Algorithm

- Referred to as the *painter's algorithm*
  - In creating an oil painting
    - First paints the background colors
    - The most distant objects are added
    - Then the nearer objects, and so forth
    - Finally, the foregrounds are painted over all objects
  - Each layer of paint covers up the previous layer
- Process
  - Sort surfaces according to their distance from the viewplane
  - The intensities for the farthest surface are then entered into the refresh buffer
  - Taking each succeeding surface in decreasing depth order

Overlapping Tests

- Tests for each surface that overlaps with S

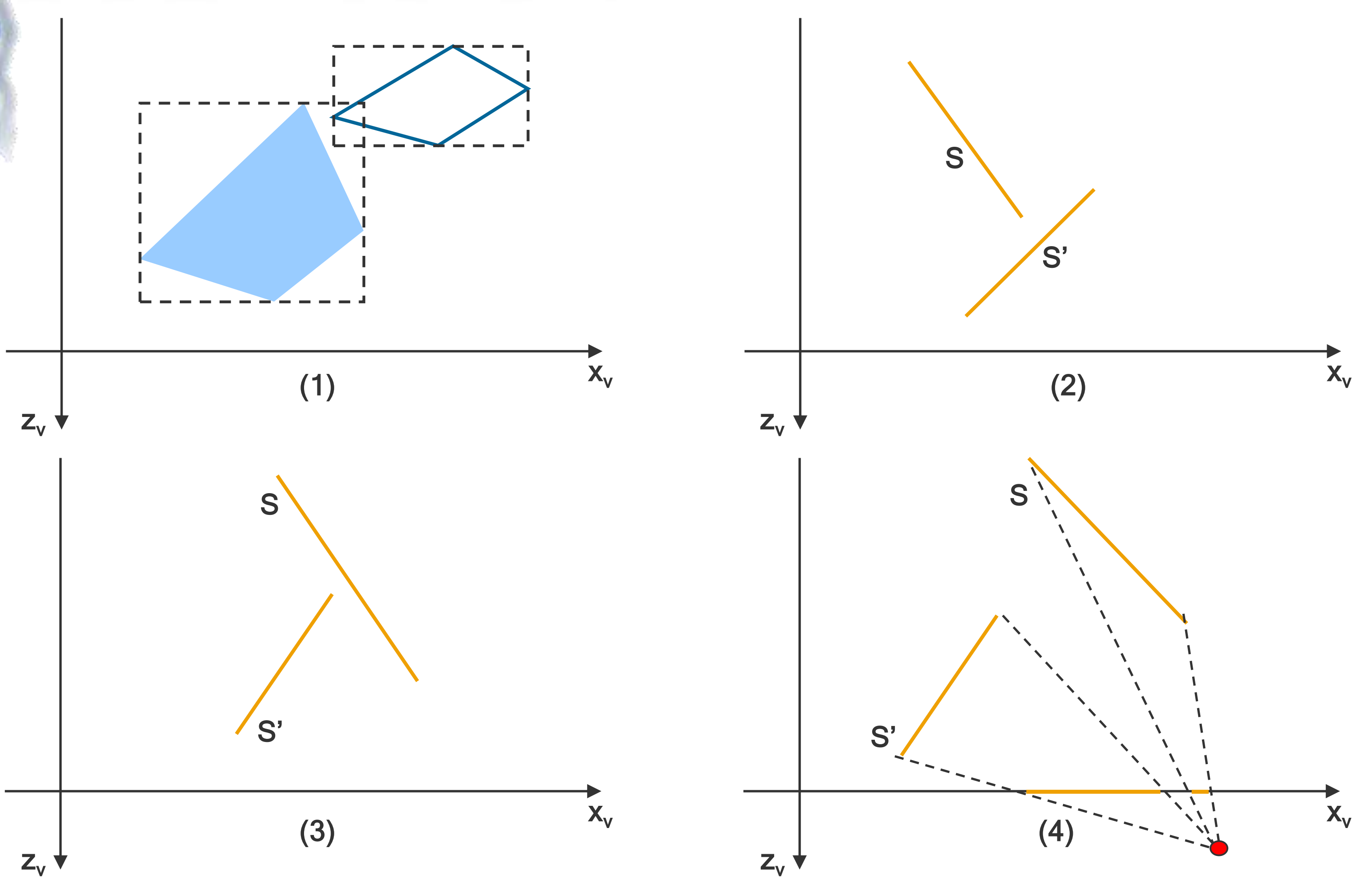
Easy ↑

  - The bounding rectangle in the xy plane for the two surfaces do not overlap (1)
  - Surface S is completely behind the overlapping surface relative to the viewing position (2)
  - The overlapping surface is completely in front of S relative to the viewing position (3)
  - The projections of the two surfaces onto the viewplane do not overlap (4)

↓ Difficult

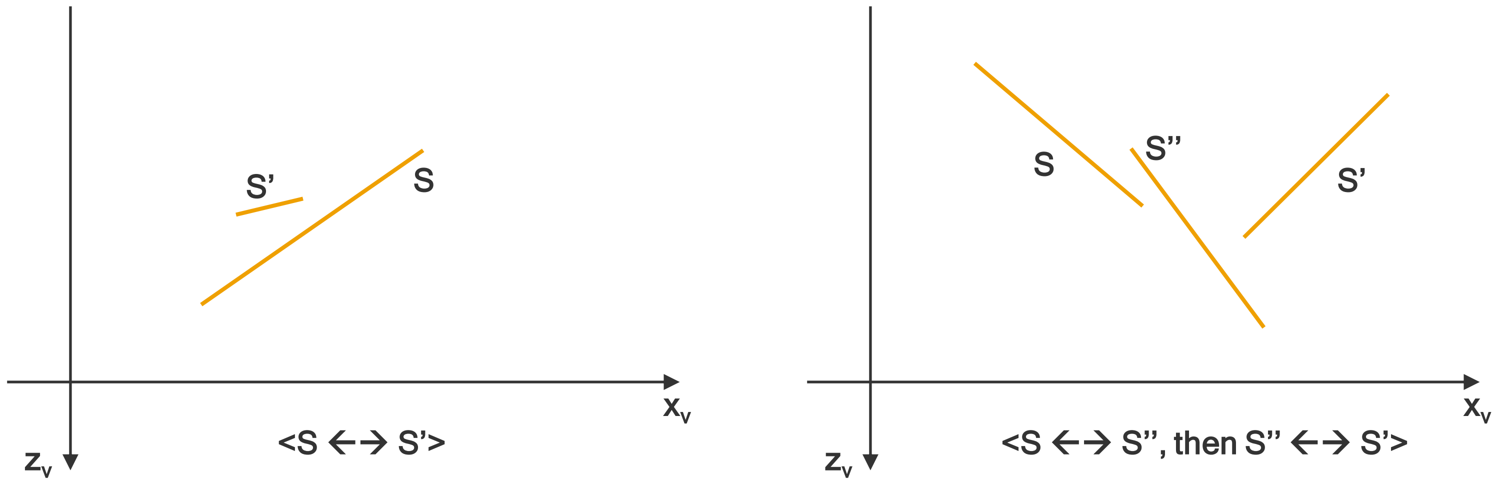
- If all the surfaces pass at least one of the tests, and none of them is behind S
  - No reordering is then necessary and S is scan converted

Overlapping Test Examples



Surface Reordering

- If all four tests fail with S'
  - Interchange surfaces S and S' in the sorted list
  - Repeat the tests for each surface that is reordered in the list



Drawback

- If two or more surfaces alternately obscure each other
  - Infinite loop
  - Flag any surface that has been reordered to a farther depth
    - It can't be moved again
  - If an attempt to switch the surface a second time
    - Divide it into two parts to eliminate the cyclic loop
    - The original surface is then replaced by the two new surfaces

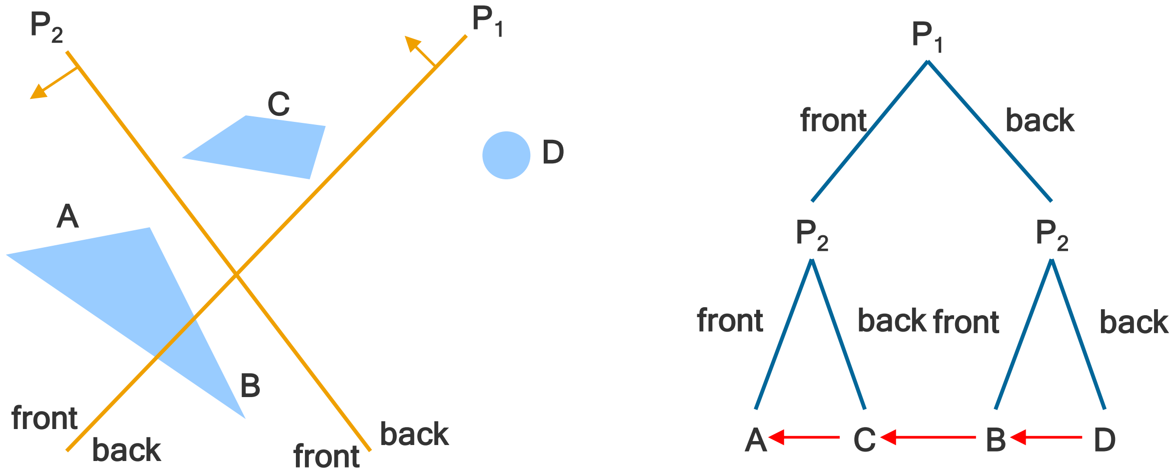
BSP-Tree Method

Characteristics

- Binary Space-Partitioning(BSP) Tree
- Determining object visibility by painting surfaces onto the screen from back to front
  - Like the painter's algorithm
- Particularly useful
  - The view reference point changes
  - The objects in a scene are at fixed positions

Process

- Identifying surfaces
  - “inside” and “outside” the partitioning plane
- Intersected object
  - Divide the object into two separate objects(A, B)



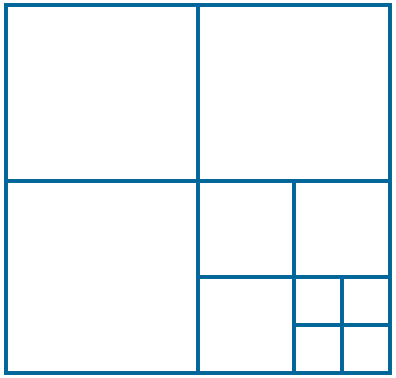
Area-Subdivision Method

Characteristics

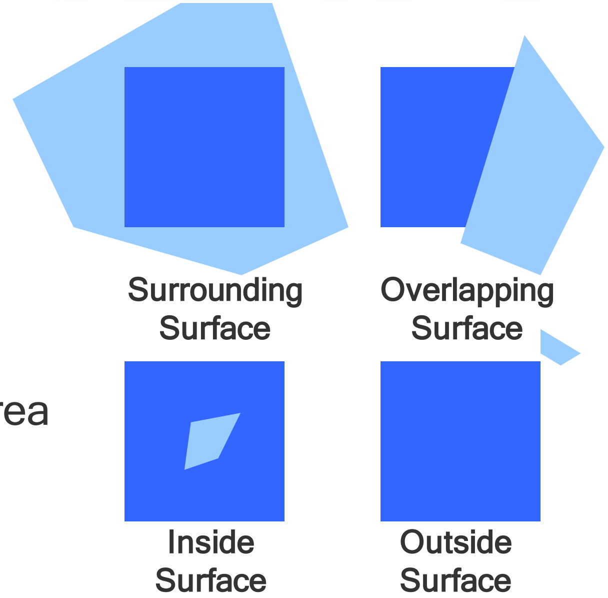
- Takes advantage of area coherence
  - Locating view areas that represent part of a single surface
  - Successively dividing the total viewing area into smaller rectangles
    - Until each small area is the projection of part of a single visible surface or no surface
  - Require tests
    - Identify the area as part of a single surface
    - Tell us that the area is too complex to analyze easily
- Similar to constructing a *quadtree*

Process

- Staring with the total view
  - Apply the identifying tests
  - If the tests indicate that the view is sufficiently complex
    - Subdivide
  - Apply the tests to each of the smaller areas
    - Until belonging to a single surface
    - Until the size of a single pixel
- Example
  - With a resolution 1024×1024
    - 10 times before reduced to a point



Identifying Tests

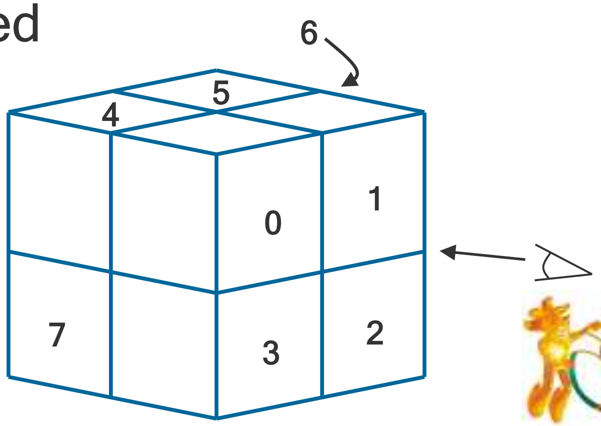


- Four possible relationships
  - Surrounding surface
    - Completely enclose the area
  - Overlapping surface
    - Partly inside and partly outside the area
  - Inside surface
  - Outside surface
- No further subdivisions are needed if one of the following conditions is true
  - All surface are outside surfaces with respect to the area
  - Only one inside, overlapping, or surrounding surface is in the area
  - A surrounding surface obscures all other surfaces within the area boundaries → from depth sorting, plane equation

Octree Method

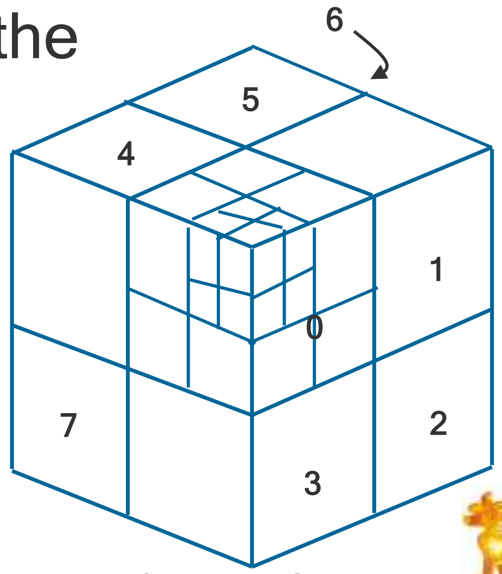
Characteristics

- Extension of *area-subdivision method*
- Projecting octree nodes onto the viewplane
  - Front-to-back order ←→ Depth-first traversal
    - The nodes for the front suboctants of octant 0 are visited before the nodes for the four back suboctants
    - The pixel in the framebuffer is assigned that color if no values have previously been stored
      - Only the front colors are loaded



Displaying An Octree

- Map the octree onto a quadtree of visible areas
  - Traversing octree nodes from front to back in a recursive procedure
  - The quadtree representation for the visible surfaces is loaded into the framebuffer



Octants in Space

Ray-Casting Method

Characteristics

- Based on geometric optics methods
  - Trace the paths of light rays
    - Line of sight from a pixel position on the viewplane through a scene
    - Determine which objects intersect this line
    - Identify the visible surface whose intersection point is closest to the pixel
  - Infinite number of light rays
    - Consider only rays that pass through pixel positions
      - Trace the light-ray paths backward from the pixels
- Effective visibility-detection method
  - For scenes with curved surfaces

Image-Space Method vs. Object-Space Method

- Image-Space Method
  - Depth-Buffer Method
  - A-Buffer Method
  - Scan-Line Method
  - *Area-Subdivision Method*
- Object-Space Method
  - Back-Face Detection
  - BSP-Tree Method
  - *Area-Subdivision Method*
  - Octree Methods
  - Ray-Casting Method

Curved Surfaces

Abstract

- Effective methods for curved surfaces
  - Ray-casting
  - Octree methods
- Approximate a curved surface as a set of plane, polygon surfaces
  - Use one of the other hidden-surface methods
  - More efficient as well as more accurate than using ray casting and the curved-surface equation

Curved-Surface Representations

- Implicit equation of the form

$$f(x, y, z) = 0$$

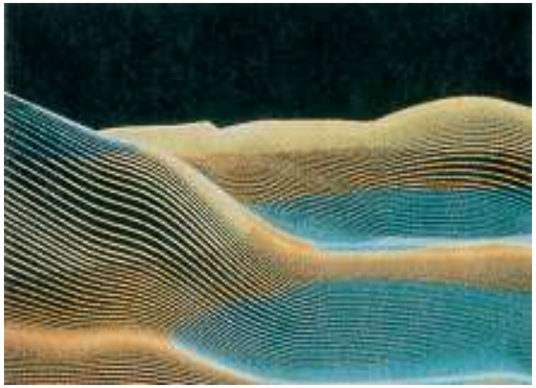
- Parametric representation
- Explicit surface equation

$$z = f(x, y)$$

  - Useful for some cases
    - A height function over an *xy* ground plane
- Scan-line and ray-casting algorithms
  - Involve numerical approximation techniques

Surface Contour Plots

- Display a surface function with a set of contour lines that show the surface shape
  - Useful in math, physics, engineering, ...
- With an explicit representation
  - Plot the visible-surface contour lines
  - To obtain an *xy* plot → $y = f(x, z)$
    - Plotted for values of *z*
    - Using a specified interval Δz


<Color-coded surface contour plot>

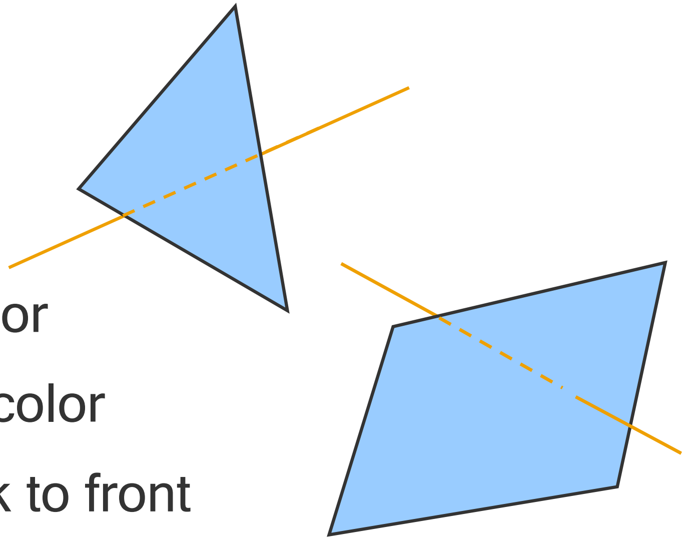
Wireframe Methods

Characteristics

- In wireframe display
  - Visibility tests are applied to surface edges
  - Visible edge sections are displayed
  - Hidden edge sections can be eliminated or displayed differently from the visible edges
- Procedures for determining visibility of edges
  - Wireframe-visibility(Visible-line detection, Hidden-line detection) methods

Wireframe Visibility Methods

- Compare each line to each surface
  - Direct approach to identifying the visible lines
  - Depth values are compared to the surfaces
  - Use coherence methods
    - No actual testing each coordinate
- With depth-sorting
  - Interiors are in the background color
  - Boundaries are in the foreground color
  - Processing the surfaces from back to front
    - Hidden lines are erased by the nearer surfaces



Summary

Comparison(1 / 2)

- Back-face detection methods
  - Fast and effective as an initial screening
    - Eliminate many polygons from further visibility tests
  - In general, this can't completely identify all hidden surfaces
- Depth-buffer(z-buffer) method
  - Fast and simple
  - Two buffers
    - Refresh buffer for the pixel intensities
    - Depth buffer for the depth of the visible surface

Comparison(2 / 2)

- A-buffer method
  - An improvement on the depth-buffer approach
  - Additional information
    - Antialiased and transparent surfaces
- Other visible-surface detection schemes
  - Scan-line method
  - Depth-sorting method(painter's algorithm)
  - BSP-tree method
  - Area subdivision method
  - Octree methods
  - Ray casting