Object Representation

3D Object Representation

- So far we have used the notion of expressing 3D data as points(or vertices) in a Cartesian or Homogeneous coordinate system.
- We have simplified the representation of objects as a series of line segments representing the edges between vertices on a polygon object.
- Differing render engines use differing types of methods of representing 3D objects in CG applications:
- Fundamentally, most render engines reduce surfaces to polygon meshes.
- Some surface shading algorithms require geometry in the execution.
- The resolution of these meshes depends on the renderer and the implementation of the surface in the renderer.

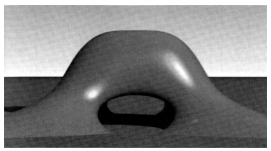
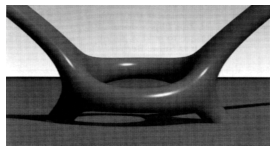
Types of Surface

- Computer graphics applications deal with the notion of approximating the surface.
- We have already covered Polygonal surfaces in some depth.

CSG

- Constructive Solid Geometry popular in CAD packages to obtain a "solid" representation.
  - CSG system uses a succession of Boolean operations on
  - primitive objects to gradually build up geometry
  - not as tangible to the user.
- Some applications allow the use of CSG.
- Current systems adopt less than solid approaches
  - only object surfaces are represented.

Mathematical Representation

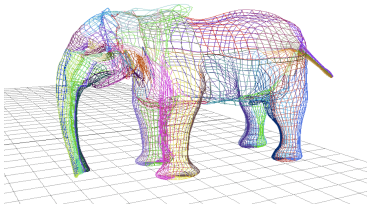



- Mathematical equations can be used directly to create object surfaces.
- The above examples are the visualisation of different polynomial equations.
- It would be hard though to explicitly describe objects in this manner to incorporate all of the detail required that everyday objects have.
- Some applications allow these to be used in conjunction with CSG

Parametric Representation

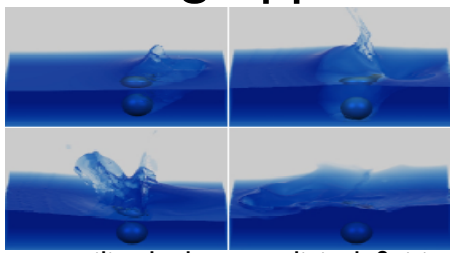
- Parametric representation is an approximation of a surface using curves to generate patches.
- By manipulating the curves and therefore the patches, explicit objects can be formed.
- By separating the representation of an object into many different patches, a surface can be described parametrically.

Parametric Representation



- Although patches present an alternate method for surface representation most computer graphics applications convert patch based objects to polygons prior to rendering.

Rendering Approaches



- Implicit surfaces are utilised where explicit definitions cannot be practically used.
- E.g. in gaseous elements, Clouds and fluids.
- Methods such as Eulerian grids, voxels, blobbies, particles, volumetric renderers etc.

Illumination Models

- Most CG algorithms are optimised for polygon data (ideally planar triangles).
- Geometric shapes can be manipulated using the notion that 2 vertices form a line segment – e.g. line clipping algorithms.
- The approximation of meshes varies:
  - screen resolution is important
- If the polygon samples(micro polygons) are smaller or the same size as the pixel area on the viewing plane, then the surface is described in a manner such that appears as a perfect representation at that given resolution.
- The user usually has some control over surface approximation, more in cases where the surface is not a primitive supported by the renderer.
- The usage of the mesh is important and the approximation may vary over distance from the camera: e.g. a surface used to describe an ocean.

Visualising Objects

Before we tackle the issue of ***image generation***, we must concern ourselves with the information required for such processes.

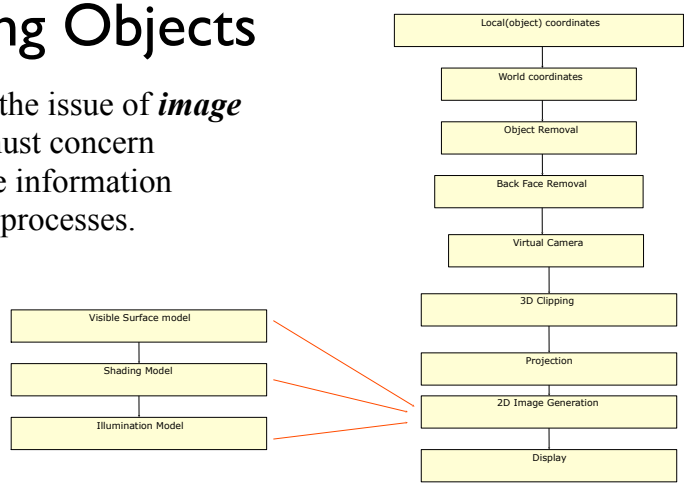


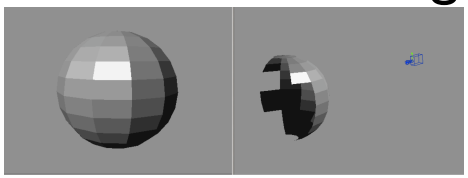
Image Synthesis

- The process of image synthesis is the part of the pipe line that finally turns our object information into actual imagery.
- There are 3 main aspects of this process:
  1. Rasterisation : mapping the polygons onto the pixels of the image.
  2. Hidden Surface Removal:the elimination of polygons not seen and polygons that are occluded in the output view.
  3. Shading the polygons be it from flat shading to full blown illumination modelling.

Visible Surface Algorithms

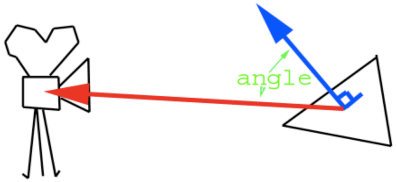
- Visible surface algorithms (or hidden surface elimination algorithms) basically do one thing:
- They calculate what is visible to the viewer and what is not.
- This process is very computationally expensive.
- The process has the potential to be called for every single pixel in an image.
- For example, for a standard PAL sized raster image, there are 720 x 576 pixels.
- This results in a staggering 414,720 pixels.
- Efficiency is paramount – especially in real-time applications.

Back Face Culling



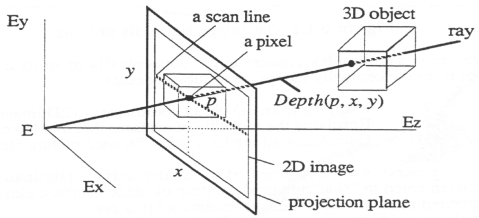
- One of the simplest visible surface determination algorithms is culling, or disregarding all polygons that face away from the camera.
- Most software packages make the option of rendering back faces available to the user.
- Note : By Default this option is usually on

Back Face Culling



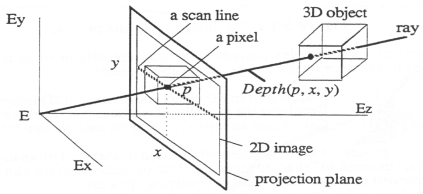
- The dot product is used to eliminate polygons, the normal of a polygon and a ray vector from the polygon to the camera
- From this, we can use simple rules to cull the polygon:
- If the viewing angle of the polygon is greater than 90 degree, cull it.
- Otherwise proceed with using polygon.

Visible Surface Calculations



- The basic system for calculating the surfaces visible deals with the depth of the objects in the viewing volume
- remember we retained the depth value of point data in our projection systems.
- If multiple surfaces intersect the ray, then all the surfaces need analysing.
- The surface which is nearest to the Eye is accepted as the viewable surface hence the depth requirement.

Visible Surface Algorithms



- The first process determines which of n objects is visible at every pixel in the image:

```
For each pixel in the image
    for every object in the scene (n)
        calculate distance from the Eye to the intersection
        of the ray and the object.
    next
    return colour value of the nearest object
next
```

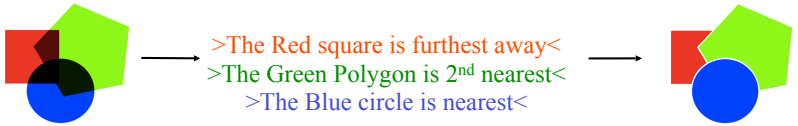
This process requires a loop through each pixel (p) and in that a loop through each object(n): np calculations.
For a PAL image with 20 objects in a scene, that's 8,294,400 object calls

Visible Surface Algorithms

- The second approach is more subtle:
- For every object in a scene (n), compare all the other objects in the scene and eliminates areas of the object that are occluded.
- In essence it's a clipping algorithm based on the current view:

```
For each object in the scene(n)
    for every object in the scene (n)
        calculate areas occluded by the 2nd loop object and clip
    next
    draw the current object
next
```

Example



In essence, this algorithm employs only n^2 calls.

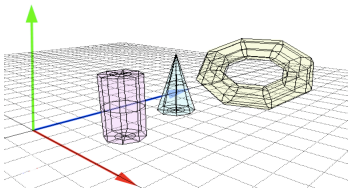
Types of basic algorithm

- In essence the 2 types of algorithm can be labelled:
- The first, dealing with pixel positions is called an image precision algorithm.
- The second, dealing with object relationships is called an object precision algorithm.
- Image precision algorithms are directly related to the raster size of the output image. (resolution dependant)
- Object precision algorithms are at first entirely based on objects relationships.

Types of Algorithms

- Image precision algorithm can be thought of as a sampling algorithm the objects are sampled to the desired output image resolution.
- The image cannot be scaled without the need to re-calculate the entire image precision algorithm again.
- Object precision algorithms are independent of the output resolution.
- We still have to address the image resolution in respect to drawing the pixels but it is a secondary function independent of the process.
- Object precision algorithms can be called prior to the image generation.
- The results are unaffected by any transformation on the actual output image itself.

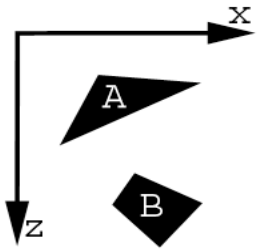
List Priority Algorithms



- This method of algorithm performs a series of evaluations on the objects to be viewed in order to ascertain a list of polygons sorted in bias of depth.
- Once a list is generated, the objects are rendered in descending depth order.
- As the pixel colours are calculated and stored in the colour buffer, pixels nearer the camera will be drawn last and thus overwrite data that is further away.

List Priority Algorithms

- Despite being simplistic in idea, the actual execution of the algorithm presents obstacles.



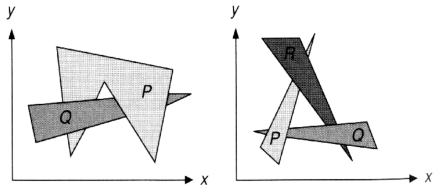
In the case to the left,
all of the faces of object A
are *nearer* than
all of the faces of object B.

Object B will drawn first,
then object A will be drawn.

Any faces of object A that occlude object B will automatically overwrite the colour buffer.

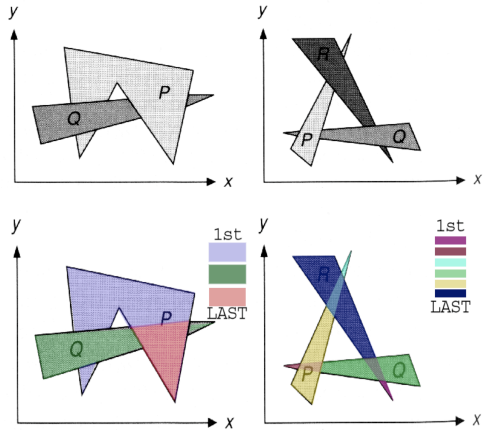
List Priority Algorithms

- Such a distinction between objects cannot be made in some cases.



In these cases, the algorithm splits the polygon faces down further so that a linear order can be generated.

List Priority Algorithms

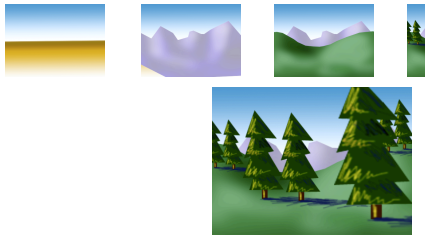


List Priority Algorithms

- List priority algorithms are a combination of image precision methods and object precision methods.
- Depth comparisons and object splitting is done in an object operation, whilst the actual image scan conversion relies on the display device for its operation.

The Depth Sort (Painters) Algorithm

- The Depth Sort Algorithm, by Newell, Newell and Sancha, it is affectionately termed as the painting algorithm
- (as an artist paints over parts of the image to put objects nearer to the viewed



Basic Depth Sort Algorithm

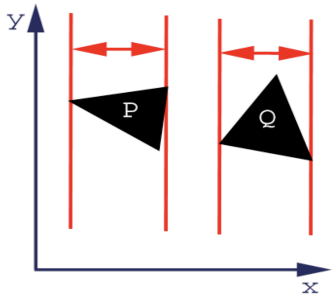
- The basic depth sort algorithm works on the following three steps:
  1. Sort all polygons to the farthest z coordinate of each.
  2. Resolve any ambiguous polygons where the z distances overlap – splitting polygons if necessary.
  3. Scan convert each polygon in ascending order of farthest z coordinate(i.e. back to front)

Basic Depth Sort

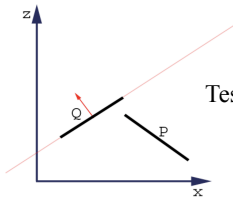
- For a polygon to successively be given a list priority, it must be tested against up to 5 operations levels of complexity.
- As soon as a single test is passed, the test polygon is deemed NOT to obscure the other polygon.
- If a polygon passes a test against all other polygons, then the polygon can be given a list priority.

Basic Depth Sort

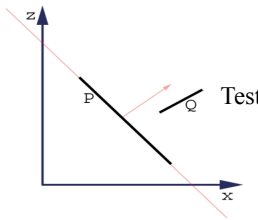
- For example, if we are testing polygon P against polygon Q
- Test 1 : Do the polygons' x extents not overlap
- And similarly …
- Test 2 : Do the polygons' y extents not overlap?



Basic Depth Sort



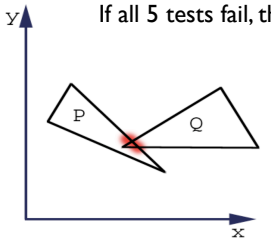
Test 3: Is P entirely on the opposite side of Q's plane from the viewport?



Test 4: Is Q entirely on the same side of P's plane from the viewport?

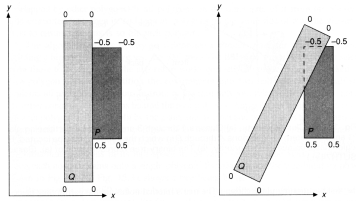
Basic Depth Sort

Test 5: Does the projections of the polygons onto the (x,y) plane not overlap?
This can be determined by comparing the edges of one face against another – similar in essence to 2D line clipping we explored earlier.



If all 5 tests fail, then we can assume that P actually obscures Q.

Example



The examples above are annotated only their depth value.
The image on the left passes test 1 – the x extent of each face do not overlap.

Consider the rotation of the left face to resemble the right picture.

Test1 fails – the x extent of each face overlap.
Test 2 fails – the y extent of each face overlap.
Test 3 and Test 4 fail – neither face is wholly in one half space of the other.
Test 5 fails – the face edges overlap.

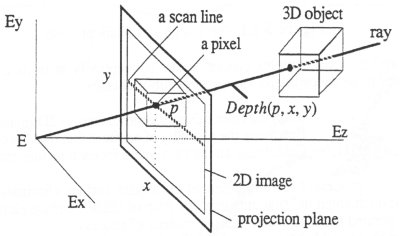
It is quite possible for a situation where all 5 tests fail on a polygon.

Does Depth Sorting Work?

- If the polygons are small the cyclic overlap errors are diminished
- Larger polygons generate larger visible errors
- Nobody uses depthsort:
- Its nasty to resolve cyclic overlaps!
- Many games use list priority sorting without fixing perspective overlap

1974 Catmull Z Buffer Algorithm

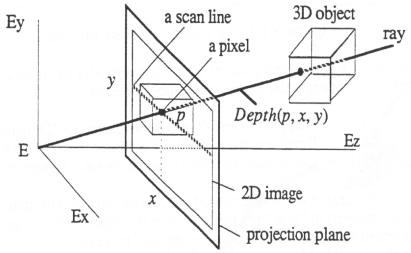
- This is the simplest image-precision algorithm.
- It generates not only a colour buffer for the colour of the pixels,
- but a z buffer as well, for the depth of each pixel.
- The colour buffer is initialised to the background colour defined.
- The z buffer is initialised to a very large distance.



Z Buffer

•Each polygon is scanned in turn against each pixel in the projection

•If pixel depth is no farther away than the current depth stored then the colour returned from the pixel polygon is placed in the colour buffer, and its respective depth in the depth buffer.

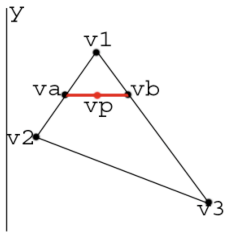


Catmull Algorithm

- As such, the Catmull algorithm does not require any object component sorting.
- The hardest problem with the Catmull algorithm is working out what pixels are covered by the faces.
- If the faces are all triangular then this becomes easier.

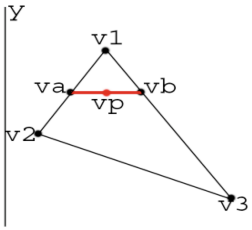
```
d(x,y) = very large
c(x,y) = bg colour
For each face
   For each pixel (x,y) covering the face
      depth = depth of face at x,y
      if depth<d(x,y) then
         c(x,y)=colour of face at x,y
         d(x,y)=depth
   next
next
```

Calculating the pixels in a triangle



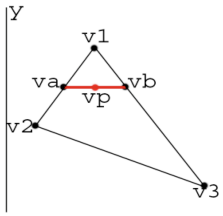
- We have a triangular face generated by 3 known points (v1,v2,v3).
- We can generate a scanline from the top of the triangle to the bottom, i.e. v_{1y} to v_{3y}.
- We explicitly describe the scanline y position – at v_{ay} in the example above.
- The horizontal pixels on the indicated scanline run from point v_{ax} to v_{bx} – unknown.

Calculating the pixels in a triangle



- To Calculate the unknown element we can use the following equation

$$va = v1 - \left[\frac{v1y - vay}{v1y - v2y} \times (v1 - v2) \right]$$



$$va = v1 - \left[\frac{v1y - vay}{v1y - v2y} \times (v1 - v2) \right]$$

start

scaling ratio

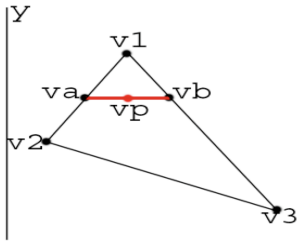
vector of distance

V_{ay} tends to V_{2y}

$$va = v1 - \left[\frac{v1y - v2y}{v1y - v2y} \times (v1 - v2) \right]$$
$$va = v1 - 1 \times (v1 - v2)$$
$$va = v1 - v1 + v2$$
$$va = v2$$

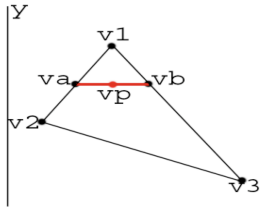
V_{ay} tends to V_{1y}

$$va = v1 - \left[\frac{v1y - v1y}{v1y - v2y} \times (v1 - v2) \right]$$
$$va = v1 - 0 \times (v1 - v2)$$
$$va = v1$$



We can also state that…

$$vb = v1 - \left[\frac{v1y - vay}{v1y - v3y} \times (v1 - v3) \right]$$



Hence for x components:

$$vax = v1\,x - \left[\frac{v1y - vay}{v1y - v2y} \times (v1x - v2x) \right]$$

$$vbx = v1\,x - \left[\frac{v1y - vay}{v1y - v3y} \times (v1x - v3x) \right]$$

Thus solving the start (v_{ax}) and end (v_{bx}) x positions for a given scanline vertical position.

Pros and Cons of the Z Buffer

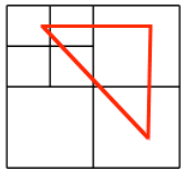
- Pros
  - No object sorting, comparison or splitting required – straight forward approach
- Cons
  - At least twice the memory overhead-
  - more memory for zdepth buffer to prevent depth aliasing
  - but we have so much these days or we could scan it in strips…
  - We need the z values! (We may require them anyway later for shaders etc)
  - We may perform more than one polygon draw per pixel

Z Buffer

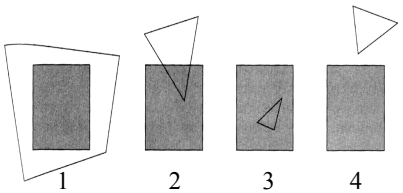
- The basic algorithm before gives us a colour buffer and a z-depth buffer
- The z buffer algorithm does not require only polygonal data : one of its strengths
- The z buffer algorithm is an image precision algorithm and as such can produce aliasing.
- More variations have been made :
  - Catmul '78
  - Carpenter in '84 A-Buffer

Screen Subdivision-Divide & Conquer

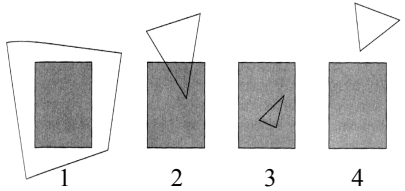
- An improvement to the basic algorithm is to subdivide the screen into "buckets" to aid efficiency.
- When studying the relationship between regions and polygons, we can come to 4 distinct cases:



1 A polygon completely surrounds the region.
2 A polygon and the region intersect.
3 The regions surrounds a polygon.
4 A polygon and the region are far apart.



Subdivision Methods



- This allows us to analyse the situation:
- In case 1, all of the pixels in the region can proceed visibility and testing.
- In case 4, none of the pixels in the region contribute to the visibility of the polygon and it is discarded.
- In cases 2 and 3, the region is subdivided to smaller regions and the process starts again.

Example Algorithm

```
Subdivide screen into X and Y regions

For y = Y to 1
For x = 1 to X          ... We loop thru each pixel in the region

  z_buffer(x,y)=Zmax                    ...Set the zbuffer to be very large
  For p = 1 to NOP      ...we loop thru all the polygons in the scene

  If case 4 then goto next polygon                ...the poly has no effect

  If case 2 or 3 then subdivide bucket and start again
   ...we need to subdivide the region more
  If case 1 then
    z = depth(p,x,y)        ... get the depth of the current polygon and store in z
    if z < z_buffer(x,y)    ... is the polygon nearer than the buffer data?
        z_buffer(x,y)=z     ...replace z_buffer data with current z
    polygon =               ... the current polygon for this pixel is p

proceed with shading current pixel with polygon polygon
```

Buckets

- Along the edges of polygons, the regions must be subdivided repeatedly until the region becomes a single pixel in size. For complex scenes, this algorithm is quite inefficient.
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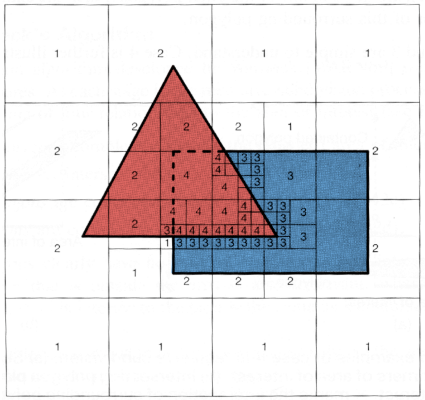

References

- Computer Graphics: Principles and Practice in C (2nd Edition) (Systems Programming Series) Foley, van Dam et Al