# EECS 487: Interactive Computer Graphics

Lecture 7:
- Occlusion culling/hidden surface removal

## Hidden Surface Elimination

A scene composed of 3D objects may have some of them obscuring all or parts of the others

Draw only objects closest to the viewing position and eliminate those obscured

A.k.a. hidden surface removal or visible surface detection or occlusion culling

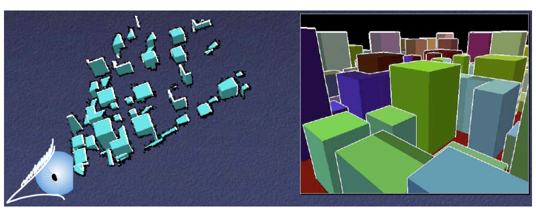
Changing viewpoint can change the obscuring relationship

Benefit?

## Hidden Surface Elimination

Algorithms are usually classified by whether they work on:

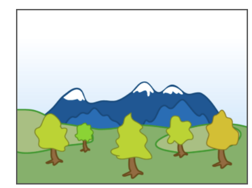
- object space:
  - painter's algorithm
    - BSP tree
- image space:
  - *z*-buffer
  - ray casting

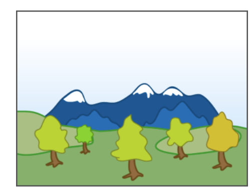


There are others, but *z*-buffer, BSP tree, and ray casting are most commonly used in practice

Funkhouser06

## Painter's Algorithm



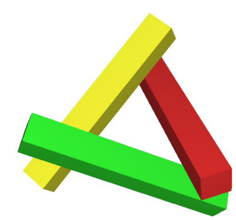


One of the earliest algorithms for image generation (1969-1972)

It solves the visible object problem by painting, or filling, with opaque paint, where closer objects are painted over farther ones

```
sort objects by z
for all objects {
  for all covered pixels(x,y)
    paint
}
```

Problem:
does not handle cyclic ordering



Akeley07

# Binary Space Partitioning

Very efficient visibility culling method for a static set of polygons

Trade off time-and-space intensive preprocessing
against linear display step

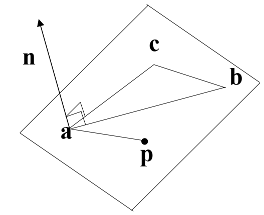
Well suited for applications where viewpoint changes,
but objects do not, e.g., 3D games such as *Doom*

Main idea: a polygon $A$ is painted in correct order if:
- polygons on the far side of $A$ are painted first
- $A$ is painted next
- polygons on near side of $A$ are painted last

Build a tree to recursively partition the space and group polygons

Two types:
- Polygon-aligned BSP
- Axis-aligned BSP

# Implicit 3D Plane Eqn




Consider a plane through points **a**, **b**, and **c**

The normal of the plane is: $\mathbf{n} = (\mathbf{b} - \mathbf{a}) \times (\mathbf{c} - \mathbf{a})$

A point **p** is on the plane if $\mathbf{n}\cdot(\mathbf{p} - \mathbf{a}) = 0$

Implicit plane equation, for **a** on plane, is thus: $f(\mathbf{p}) = \mathbf{n}\cdot(\mathbf{p} - \mathbf{a}) = 0$

Think of $(\mathbf{p} - \mathbf{a}) \cdot \mathbf{n}$ as projecting $(\mathbf{p} - \mathbf{a})$ onto $\mathbf{n}$:
- $f(\mathbf{p}) > 0$ if **p** is on the same side as **n**
- $f(\mathbf{p}) < 0$ if **p** is on the other side of **n**

Let $\mathbf{p} = (x, y, z)$, $\mathbf{n} = (A, B, C)$,
the implicit plane equation can also be expressed as:

$$f(\mathbf{p}) = \mathbf{n}\cdot(\mathbf{p}-\mathbf{a}) = \mathbf{n}\cdot\mathbf{p} - \mathbf{n}\cdot\mathbf{a} = \begin{bmatrix} A & B & C \end{bmatrix}\begin{bmatrix} x \\ y \\ z \end{bmatrix} - \begin{bmatrix} A & B & C \end{bmatrix}\begin{bmatrix} x_a \\ y_a \\ z_a \end{bmatrix}$$

$f(x,y,z) = Ax + By + Cz + D = 0$, where $D = -Ax_a - By_a - Cz_a = -\mathbf{n}\cdot\mathbf{a}$

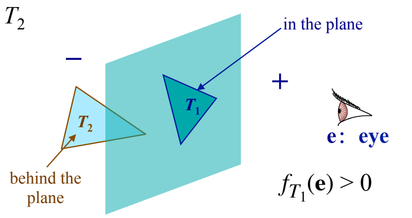
# Polygon-aligned BSP

Use plane that is coplanar with each triangle as scene separator

First assume no triangle crosses such planes

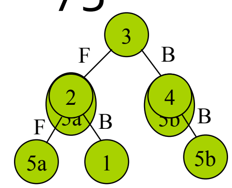
BSP idea is simply:

- let **e** be the eye-point and $f_{T_1}(\mathbf{p}) = 0$ be the implicit plane equation for the plane coplanar with $T_1$
- if $(f_{T_1}(\mathbf{e}) > 0)$ {
  // eye is closer to $T_1$ than to $T_2$
  draw $T_2$
  draw $T_1$
  } else {
  draw $T_1$
  draw $T_2$
  }

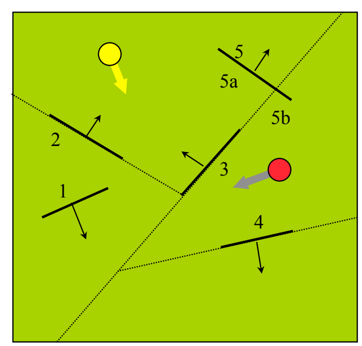





# Polygon-aligned BSP Tree




Using the BSP:
recurse on the far side (from eye) child
draw parent
recurse on the near side (to eye) child




```
render(node, eye) {
  if(node==0) return;
  if(node.f(eye) > 0) { // in front
    render(node.child_back, eye);
    draw(node.T);
    render(node.child_front, eye);
  } else {
    render(node.child_front, eye);
    draw(node.T);
    render(node.child_back, eye);
  }
}
```

(3) (2) (1) 1 2 (5a) 5a 3 (4) 4 (5b) 5b    (•) means visit (call `render`)

# BSP Tree Construction

Add all the triangles in any order
Recursive algorithm:

```
struct node_t {
  triangle_t T;
  plane_eqn f(point p);
  node_t *child_back, *child_front;
  void add(triangle_t *new_T); // add a child recursively
}

node_t::add(triangle_t *new_T) {
  if (self.f(new_T[0])>0 && self.f(new_T[1])>0 && self.f(new_T[2])>0)
    if (self.child_front == 0) // no children in front
      self.child_front = node_t(new_T);
    else
      self.child_front→add(new_T);
  else if (all negative)
    …
  else
   split_and_add_triangle(new_T);
}
```

# Polygon-aligned BSP

Use plane coplanar with each triangle as scene separator

First assume no triangle crosses such planes

What if a triangle does cross the plane defined by another triangle?

# BSP Tree Construction

Split triangle $T_2$:

- one of $T_2$'s vertices will be on the opposite side of $T_1$'s plane to the others
- find the intersections where the plane cuts the triangle (how?)

$\mathbf{p}(t) = \mathbf{k} + t(\mathbf{m} - \mathbf{k})$

If $\mathbf{p}(t)$ is on $T_1$'s plane,

for $\mathbf{a}$ any vertex of $T_1$,

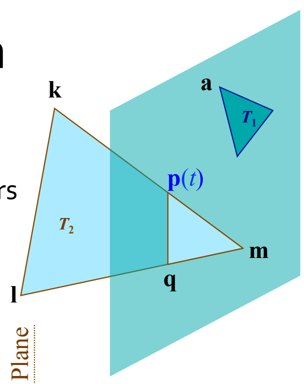
$\mathbf{n}$ the plane's normal:

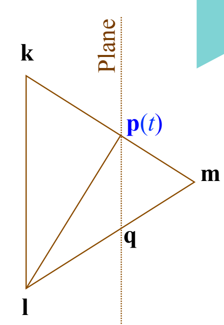
$f(\mathbf{p}(t)) = \mathbf{n} \cdot \mathbf{p}(t) - \mathbf{n} \cdot \mathbf{a} = 0$

$\mathbf{n} \cdot (\mathbf{k} + t(\mathbf{m} - \mathbf{k})) - \mathbf{n} \cdot \mathbf{a} = 0$

$t = \dfrac{\mathbf{n} \cdot \mathbf{a} - \mathbf{n} \cdot \mathbf{k}}{\mathbf{n} \cdot (\mathbf{m} - \mathbf{k})}$

Similarly for $\mathbf{q} = \mathbf{l} + t_2(\mathbf{m} - \mathbf{l})$



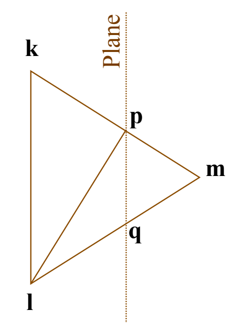

- then tessellate $T_2$ into 3 triangles

Merrello8

# BSP Tree Construction

Caveats when splitting triangle $T$:

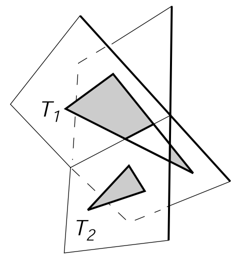
- use implicit equation of plane to check which one of $T$'s vertices is on the opposite side to the others
- must maintain vertex ordering to preserve normal!
- be careful not to create a sliver of a triangle: if distance of $\mathbf{m}$ from plane is $< \varepsilon$, treat $\mathbf{m}$ as if it is in the plane
- if one or more vertices are in the plane, no need to cut triangle



# BSP Tree Performance

Add triangles to the BSP tree in any order

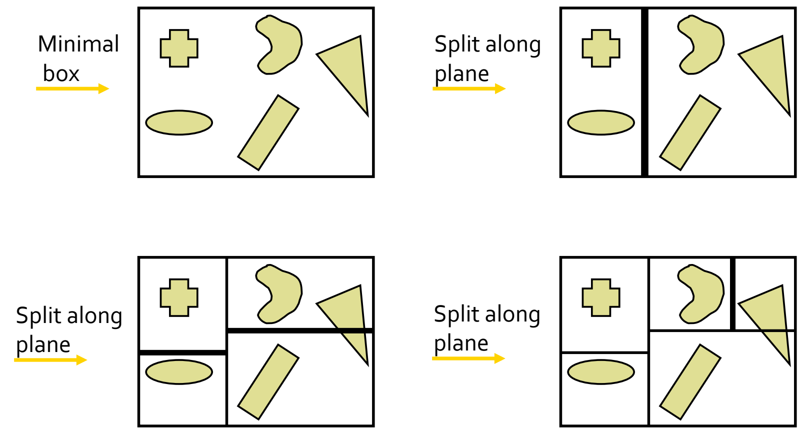
- tree shape doesn't effect performance for hidden surface elimination (why?)
  - but it is useful to keep BSP balanced for other uses, e.g., collision detection
- different ordering of triangle additions to the tree result in more (or less) tree nodes
  - one heuristics: in each round, pick 5 triangles at random, choose the plane with minimal triangle crossings as the separator




Shirley02

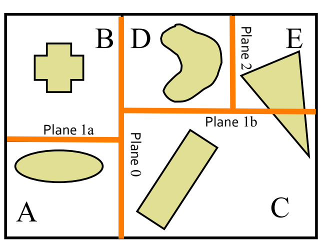
# Axis-Aligned BSP Tree: Idea

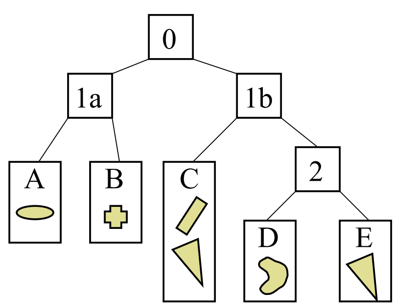
Splitting plane aligned to x, $y$, or $z$ axis






# Axis-Aligned BSP Tree: Build




Each internal node holds a divider plane
Leaves hold geometry

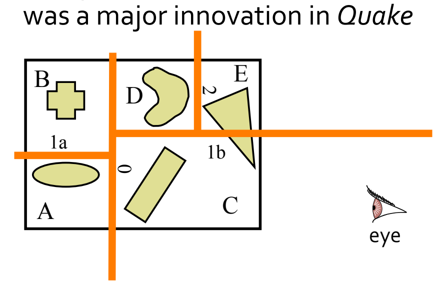
A.k.a., *k*d-tree

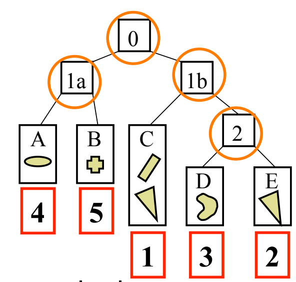


# Axis-aligned BSP-Tree: Usage

Test the planes against the point of view
Test recursively from root
To sort front to back, visit near side first

- being able to do so and not display invisible back polygons was a major innovation in *Quake*




- does not give exact sorting when there are multiple objects per node, or when an object spans multiple nodes

# Hidden Surface Elimination

Algorithms are usually classified by whether they work on:

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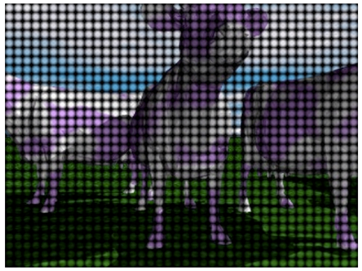
  - $z$-buffer
  - ray casting



There are others, but $z$-buffer, BSP tree, and ray casting are most commonly used in practice

Lozano&Popovic01

# $z$-Buffer or Depth Buffer

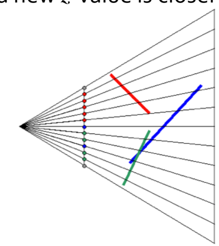
One of the simplest of all image-based hidden-surface elemination algorithms (Ed Catmull, 1974)

- originally considered too expensive
- now commonly implemented in hardware using fast memory (cheap now) and fast GPU
- geometry independent: hidden surface removal one fragment at a time!

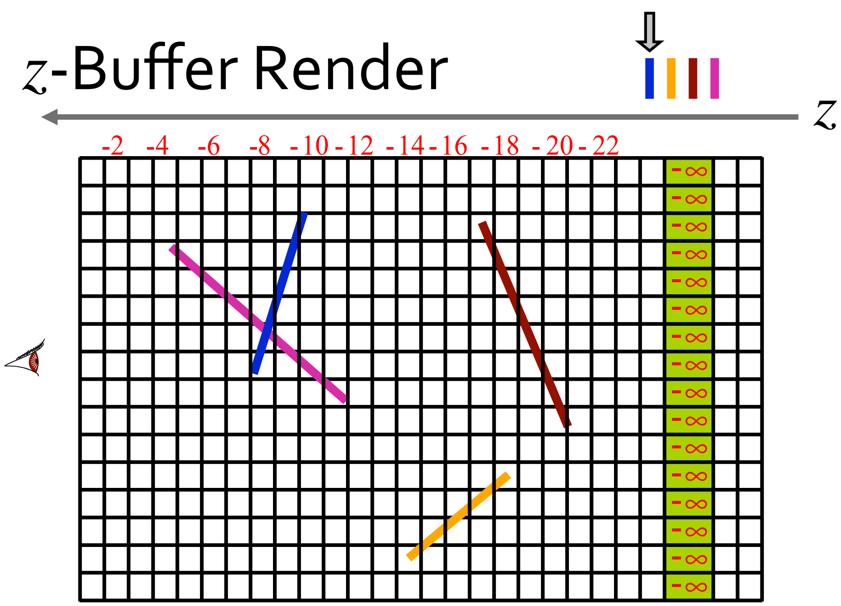
Algorithm:

- at each pixel, store the $z$-value of the closest triangle rasterized so far
- change the pixel's color (and depth value) only if a new $z$-value is closer to the viewer than the stored value

```
setpixel(int i, j, RGB c, real z) {
  if (z < z_buffer(i,j)){
    screen(i,j) = c;
    z_buffer(i,j) = z;
  }
}
```

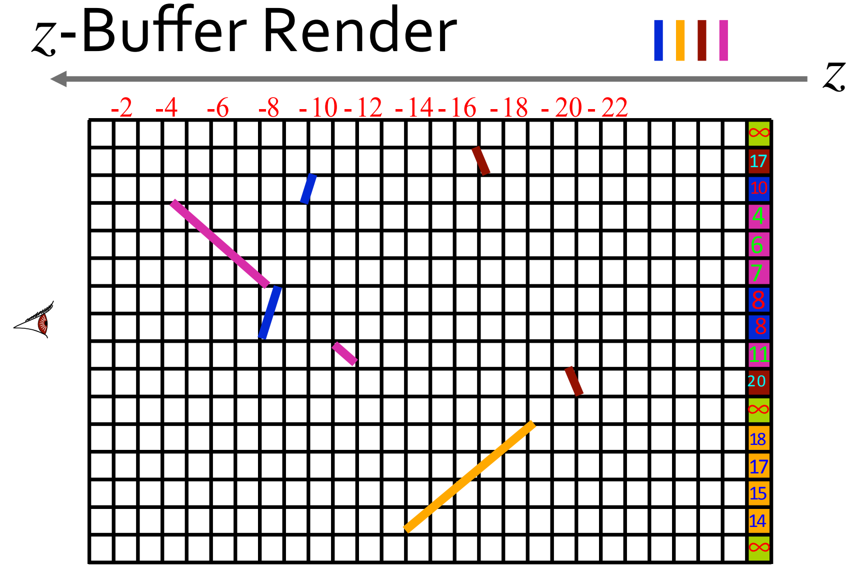


# $z$-Buffer Render




Riesenfeld

# $z$-Buffer Render

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# $z$-Values

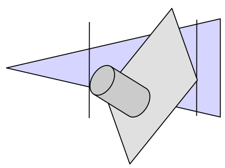
Computation:

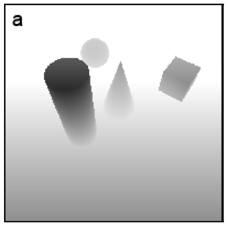
- use barycentric coordinates to interpolate depth value of each pixel from those of the vertices

Depth-value storage:

- as non-negative integers
- integers are represented in $b$ (=16 or 32) bits, giving a limited range of $B$ (= $2^b$) values $\{0, 1, 2, \ldots, B\text{-}1\}$

$z$-Buffer visualization:






# $z$-Buffer in OpenGL

```
glutInitDisplayMode(GLUT_DEPTH | . . . );
glClear(GL_DEPTH_BUFFER_BIT | . . . );
glEnable(GL_DEPTH_TEST);
// get viewing position and draw objects
. . .
```

Recall that OpenGL is a state machine

Boolean state settings can be turned on and off with `glEnable()` and `glDisable()`

Anything that can be set can be queried using `glGet()`