Accelerating Ray-Scene Intersection Calculations

Jason Lawrence

CS 4810: Graphics

Acknowledgment: slides by Misha Kazhdan, Allison Klein, Tom Funkhouser, Adam Finkelstein and David Dobkin
Overview

• Acceleration techniques
  o Bounding volume hierarchies
  o Spatial partitions
    » Uniform grids
    » Octrees
    » BSP trees
Goal

• Find intersection with front-most primitive in group

Intersection FindIntersection(Ray ray, Scene scene)
{
    min_t = ∞
    min_shape = NULL
    For each primitive in scene
    {
        t = Intersect(ray, primitive);
        if (t > 0 and t < min_t) then
            min_shape = primitive
            min_t = t
    }
}
return Intersection(min_t, min_shape)
Acceleration Techniques

• A direct approach tests for an intersection of every ray with every primitive in the scene.

• Acceleration techniques:
  o Grouping:
    Group primitives together and test if the ray intersects the group. If it doesn’t, don’t test individual primitives.
  o Ordering:
    Test primitives/groups based on their distance along the ray. If you find a close hit, don’t test distant primitives/groups.
Bounding Volumes

- Check for intersection with the bounding volume:
  - Bounding cubes
  - Bounding boxes
  - Bounding spheres
  - Etc.

Stuff that’s easy to intersect
Bounding Volumes

• Check for intersection with the bounding volume
Bounding Volumes

• Check for intersection with the bounding volume
  • If ray doesn’t intersect bounding volume, then it doesn’t intersect its contents
Bounding Volumes

- Check for intersection with the bounding volume
  
  If ray doesn’t intersect bounding volume, then it doesn’t intersect its contents

Still need to check for intersections with shape.
Bounding Volume Hierarchies

- Build hierarchy of bounding volumes
  - Bounding volume of interior node contains all children
Bounding Volume Hierarchies

- Grouping acceleration

```c
FindIntersection(Ray ray, Node node) {
    min_t = ∞
    min_shape = NULL

    // Test if you intersect the bounding volume
    if( !intersect ( node.boundingVolume ) ) {
        return (min_t,min_shape);
    }

    // Test the children
    for each child {
        (t, shape) = FindIntersection(ray, child)
        if (t < min_t) {min_shape=shape}
    }
    return (min_t, min_shape);
}
```
Bounding Volume Hierarchies

• Use hierarchy to accelerate ray intersections
  - Intersect node contents only if hit bounding volume
Bounding Volume Hierarchies

- Use hierarchy to accelerate ray intersections
  - Intersect node contents only if hit bounding volume

- Don’t need to test shapes A or B
- Need to test groups 1, 2, and 3
- Need to test shapes C, D, E, and F
Bounding Volume Hierarchies

- Grouping + Ordering acceleration

```c
void FindIntersection(Ray ray, Node node) {
    // Find intersections with child node bounding volumes
    ...
    // Sort intersections front to back
    ...
    // Process intersections (checking for early termination)
    min_t = ∞
    min_shape = NULL
    for each intersected child {
        if (min_t < bv_t[child]) break;
        (t, shape) = FindIntersection(ray, child);
        if (t < min_t) {
            min_t = t
            min_shape = shape
        }
    }
    return (min_t, min_shape);
}
```
Bounding Volume Hierarchies

• Use hierarchy to accelerate ray intersections
  o Intersect nodes only if you haven’t hit anything closer
Bounding Volume Hierarchies

• Use hierarchy to accelerate ray intersections
  • Intersect nodes only if you haven’t hit anything closer

• Don’t need to test shapes A, B, D, E, or F
• Need to test groups 1, 2, and 3
• Need to test shape C
Overview

• Acceleration techniques
  o Bounding volume hierarchies
  o Spatial partitions
    » Uniform grids
    » Octrees
    » BSP trees
Uniform (Voxel) Grid

• Construct uniform grid over scene
  • Index primitives according to overlaps with grid cells

• A primitive may belong to multiple cells
• A cell may have multiple primitives
Uniform (Voxel) Grid

• Trace rays through grid cells
  - Fast
  - Incremental

Only check primitives in intersected grid cells
Uniform (Voxel) Grid

- Potential problem:
  - How choose suitable grid resolution?

  Too little benefit if grid is too coarse
  - Too much cost if grid is too fine
“Teapot in a Stadium” Problem
Ray-Scene Intersection

» Acceleration techniques
  o Bounding volume hierarchies
  o Spatial partitions
    » Uniform grids
    » Octrees
    » BSP trees
Octrees

- We can think of a voxel grid as a tree.
  - The root node is the entire region
  - Each node has eight children obtained by subdividing the parent into eight equal regions
Octrees

• We can think of a voxel grid as a tree.
  o The root node is the entire region
  o Each node has eight children obtained by subdividing the parent into eight equal regions
Octrees

- We can think of a voxel grid as a tree.
  - The root node is the entire region
  - Each node has eight children obtained by subdividing the parent into eight equal regions
Octrees

- We can think of a voxel grid as a tree.
  - The root node is the entire region
  - Each node has eight children obtained by subdividing the parent into eight equal regions
Octrees

• In an octree, we only subdivide regions that contain more than one shape.
Octrees

• In an octree, we only subdivide regions that contain more than one shape.
Octrees

- In an octree, we only subdivide regions that contain more than one shape.
Octrees

- In an octree, we only subdivide regions that contain more than one shape.
Octrees

• In an octree, we only subdivide regions that contain more than one shape.
Octrees

• In an octree, we only subdivide regions that contain more than one shape.

• Adaptively determines grid resolution.
Ray-Scene Intersection

- Intersections with geometric primitives
  - Sphere
  - Triangle

- Acceleration techniques
  - Bounding volume hierarchies
  - Spatial partitions
    - Uniform (Voxel) grids
    - Octrees
    - BSP trees
Binary Space Partition (BSP) Tree

- Recursively partition space by planes
Binary Space Partition (BSP) Tree

- Recursively partition space by planes
  - Generate a tree structure where the leaves store the shapes.
Binary Space Partition (BSP) Tree

- Recursively partition space by planes
  - Generate a tree structure where the leaves store the shapes.
Binary Space Partition (BSP) Tree

- Recursively partition space by planes
  - Generate a tree structure where the leaves store the shapes.
Binary Space Partition (BSP) Tree

- Recursively partition space by planes
  - Generate a tree structure where the leaves store the shapes.
Binary Space Partition (BSP) Tree

- Recursively partition space by planes
  - Generate a tree structure where the leaves store the shapes.
Binary Space Partition (BSP) Tree

- Recursively partition space by planes
  - Every cell is a convex polyhedron
Binary Space Partition (BSP) Tree

• Example: Point Intersection
Binary Space Partition (BSP) Tree

- Example: Point Intersection
  - Recursively test what side we are on
Binary Space Partition (BSP) Tree

• Example: Point Intersection
  o Recursively test what side we are on
    » Left of 1 (root) → 2
Binary Space Partition (BSP) Tree

- Example: Point Intersection
  - Recursively test what side we are on
    » Left of 2 → 4
Binary Space Partition (BSP) Tree

- Example: Point Intersection
  - Recursively test what side we are on
    » Right of 4 → Test B
Binary Space Partition (BSP) Tree

- Example: Point Intersection
  - Recursively test what side we are on
    » Missed B. No intersection!
Binary Space Partition (BSP) Tree

- Example: Ray Intersection 1
  - Recursively split the ray and test nearer and farther halves, nearest first. Stop once you hit something:
Binary Space Partition (BSP) Tree

• Example: Ray Intersection 1
  o Recursively split the ray and test nearer and farther halves, nearest first. Stop once you hit something:
    » Test half to the left of 1
Binary Space Partition (BSP) Tree

• Example: Ray Intersection 1
  • Recursively split the ray and test nearer and farther halves, nearest first. Stop once you hit something:
  » Test half to the right of 2
Binary Space Partition (BSP) Tree

- Example: Ray Intersection 1
  - Recursively split the ray and test nearer and farther halves, nearest first. Stop once you hit something:
    » Intersection with C. Done!
Binary Space Partition (BSP) Tree

- Example: Ray Intersection 2
  - Recursively split the ray and test nearer and farther halves, nearest first. Stop once you hit something:
    » Test half to the left of 1
Binary Space Partition (BSP) Tree

- Example: Ray Intersection 2
  - Recursively split the ray and test nearer and farther halves, nearest first. Stop once you hit something:
  - Test half to the right of 2
Binary Space Partition (BSP) Tree

- Example: Ray Intersection 2
  - Recursively split the ray and test nearer and farther halves, nearest first. Stop once you hit something:
    » Missed C. Recurse!

Monday, September 19, 11
Binary Space Partition (BSP) Tree

- Example: Ray Intersection 2

  - Recursively split the ray and test nearer and farther halves, nearest first. Stop once you hit something:
    - Test half to left of 2
Binary Space Partition (BSP) Tree

- Example: Ray Intersection 2
  - Recursively split the ray and test nearer and farther halves, nearest first. Stop once you hit something:
    » Test half to left of 4
Binary Space Partition (BSP) Tree

• Example: Ray Intersection 2
  • Recursively split the ray and test nearer and farther halves, nearest first. Stop once you hit something:
    » Missed A. Recurse!
Binary Space Partition (BSP) Tree

- Example: Ray Intersection 2
  - Recursively split the ray and test nearer and farther halves, nearest first. Stop once you hit something:
    » No half to right of 4.
Binary Space Partition (BSP) Tree

- Example: Ray Intersection 2
  - Recursively split the ray and test nearer and farther halves, nearest first. Stop once you hit something:
    - Test half to right of 1
Binary Space Partition (BSP) Tree

- Example: Ray Intersection 2
  - Recursively split the ray and test nearer and farther halves, nearest first. Stop once you hit something:
    » Test half to left of 3
Binary Space Partition (BSP) Tree

- Example: Ray Intersection 2
  - Recursively split the ray and test nearer and farther halves, nearest first. Stop once you hit something:
    » Intersection with D. Done!
Binary Space Partition (BSP) Tree

RayTreeIntersect(Ray ray, Node node, double min, double max) {
  if (Node is a leaf)
    return intersection of closest primitive in cell, or NULL if none
  else
    // Find splitting point
    dist = distance along the ray point to split plane of node

    // Find near and far children
    near_child = child of node that contains the origin of Ray
    far_child = other child of node

    // Recurse down near child first
    if the interval to look is on near side {
      isect = RayTreeIntersect(ray, near_child, min, max)
      if( isect ) return isect  // If there’s a hit, we are done
    }

    // If there’s no hit, test the far child
    if the interval to look is on far side
      return RayTreeIntersect(ray, far_child, min, max)
}
Acceleration

- Intersection acceleration techniques are important
  - Bounding volume hierarchies
  - Spatial partitions

- General concepts
  - Sort objects spatially
  - Make trivial rejections quick

Expected time is sub-linear in number of primitives
Summary

• Writing a simple ray casting renderer is easy
  - Generate rays
  - Intersection tests
  - Lighting calculations

```java
Image RayCast(Camera camera, Scene scene, int width, int height) {
    Image image = new Image(width, height);
    for (int i = 0; i < width; i++) {
        for (int j = 0; j < height; j++) {
            Ray ray = ConstructRayThroughPixel(camera, i, j);
            Intersection hit = FindIntersection(ray, scene);
            image[i][j] = GetColor(hit);
        }
    }
    return image;
}
```
Next Time is Illumination!

Without Illumination

With Illumination