Accelerated Ray Tracing

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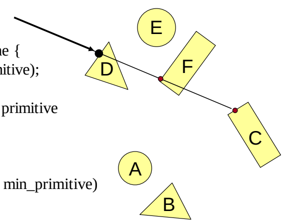
Ray-Scene Intersection

- Find intersection with front-most primitive in scene

```
Intersection FindIntersection(Ray ray, Scene scene)
{
    min_t = infinity
    min_primitive = NULL
    For each primitive in scene {
        t = Intersect(ray, primitive);
        if (t < min_t) then
            min_primitive = primitive
            min_t = t
        }
    }
    return Intersection(min_t, min_primitive)
}
```



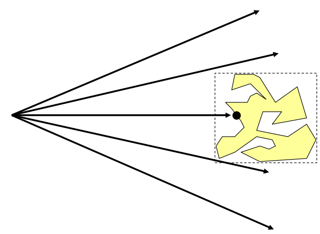
Ray-Scene Intersection

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

Beyond rays
- Beam tracing
- etc.

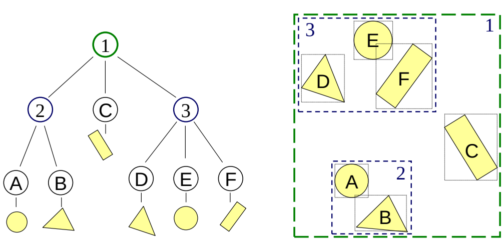
Bounding Volumes

- Check for intersection with simple shape first
  - If ray doesn't intersect bounding volume, then it doesn't intersect its contents



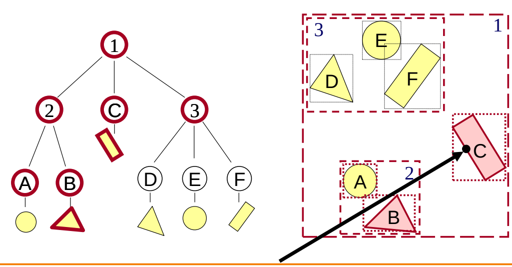
Bounding Volume Hierarchies I

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



Bounding Volume Hierarchies

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



Bounding Volume Hierarchies III

- Sort hits & detect early termination

```
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 = infinity;
    for each intersected child i {
        if (min_t < bv_t[i]) break;
        shape_t = FindIntersection(ray, child);
        if (shape_t < min_t) { min_t = shape_t;}
    }
    return min_t;
}
```

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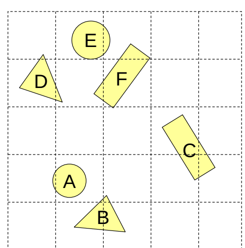
Uniform Grid

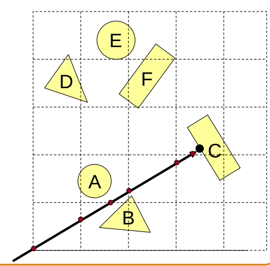
- Construct uniform grid over scene
  - Index primitives according to overlaps with grid cells



Uniform Grid

- Trace rays through grid cells
  - Fast
  - Incremental

Only check primitives in intersected grid cells

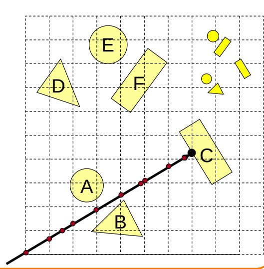


Uniform Grid

- Potential problem:
  - How choose suitable grid resolution?

Too little benefit if grid is too coarse

Too much cost if grid is too fine



Ray-Scene Intersection

Acceleration techniques
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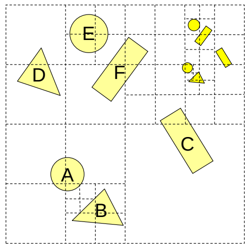
Octree

- Construct adaptive grid over scene
  - Recursively subdivide box-shaped cells into 8 octants
  - Index primitives by overlaps with cells

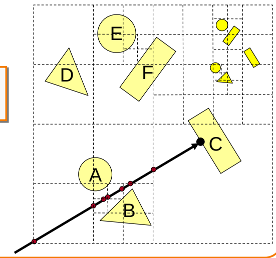
Generally fewer cells



Octree

- Trace rays through neighbor cells
  - Fewer cells
  - More complex neighbor finding

Trade-off fewer cells for more expensive traversal



Ray-Scene Intersection

Acceleration techniques
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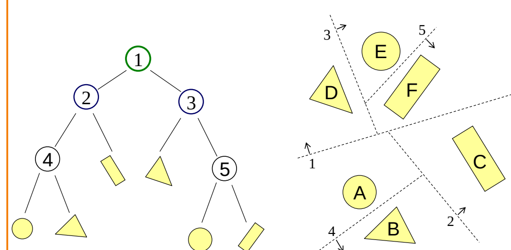
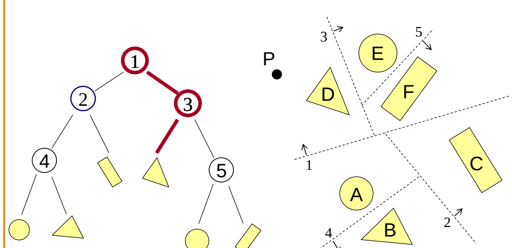
Binary Space Partition (BSP) Tree

- Recursively partition space by planes
  - Every cell is a convex polyhedron



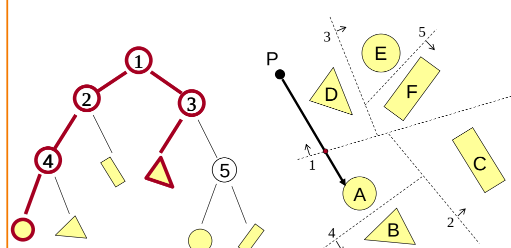
Binary Space Partition (BSP) Tree

- Simple recursive algorithms
  - Example: point finding



Binary Space Partition (BSP) Tree

- Trace rays by recursion on tree
  - BSP construction enables simple front-to-back traversal

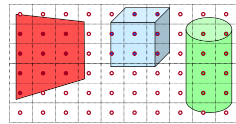


Binary Space Partition (BSP) Tree

```
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
        dist = distance of the ray point to split plane of node
        near_child = child of node that contains the origin of Ray
        far_child = other child of node
        if the interval to look is on near side
            return RayTreeIntersect(ray, near_child, min, max)
        else if the interval to look is on far side
            return RayTreeIntersect(ray, far_child, min, max)
        else if the interval to look is on both side
            if (RayTreeIntersect(ray, near_child, min, dist)) return …;
            else return RayTreeIntersect(ray, far_child, dist, max)
}
```

Other Accelerations

- Screen space coherence
  - Check last hit first
  - Beam tracing
  - Pencil tracing
  - Cone tracing
- Memory coherence
  - Large scenes
- Parallelism
  - Ray casting is “embarassingly parallelizable”
- etc.



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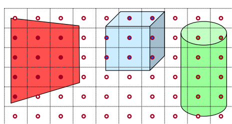
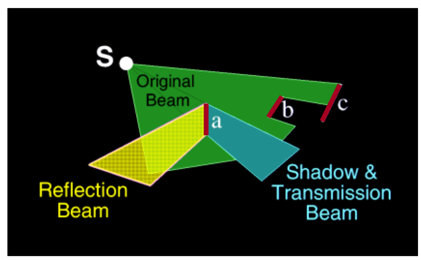


Beam Tracing

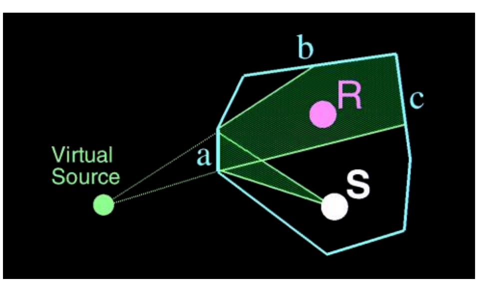
- Trace “bundle of rays” all at once



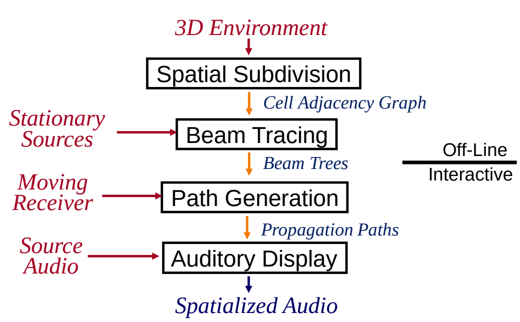
Trace beams (bundles of rays) from source

Beam Tracing

- Specular reflections

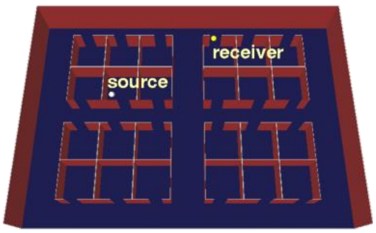


Beam Tracing Method



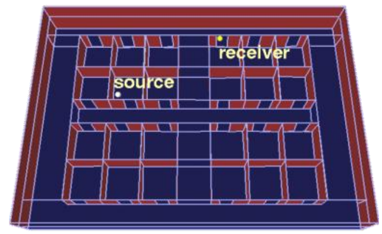
Beam Tracing Method

- Input is source, receiver, and 3D environment



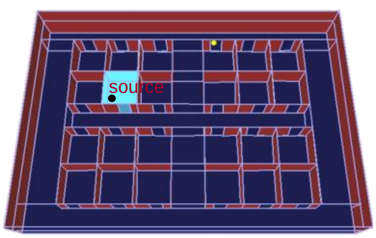
Step 1: Spatial Subdivision

- Partition space into convex polyhedral cells



Step 2: Beam Tracing

- Trace beams through cell adjacency graph



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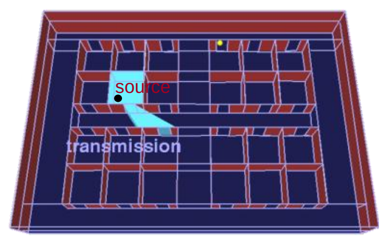

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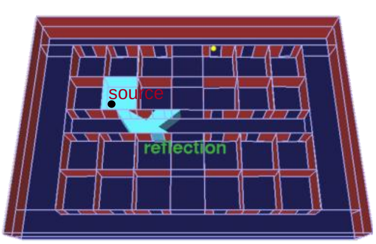

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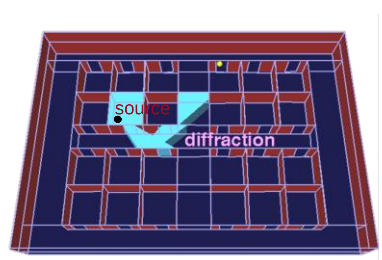

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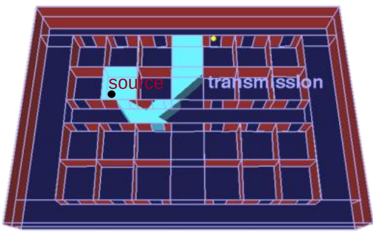

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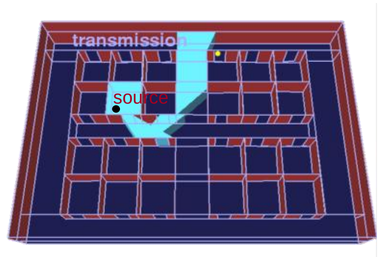

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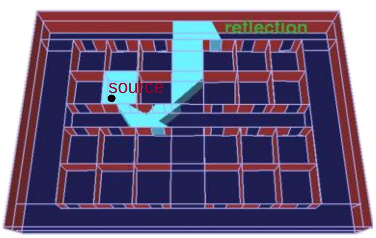
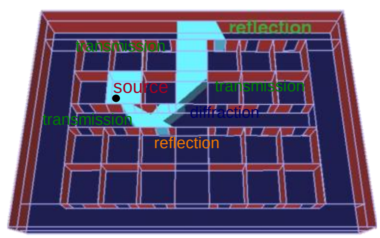


Step 2: Beam Tracing

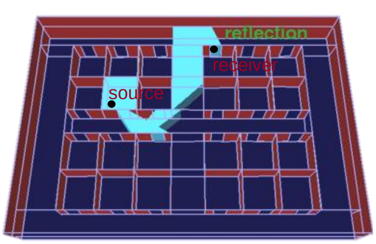
- Store all beams in a tree data structure



Beam tree encodes regions reached by different sequences of scattering from source

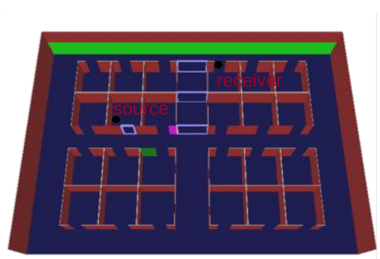
Step 3: Path Generation

- For each beam containing receiver ...



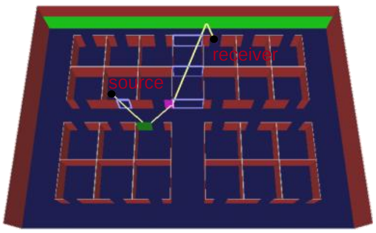
Step 3: Path Generation

- Lookup propagation sequence in beam tree



Step 3: Path Generation

- Construct shortest path along sequence

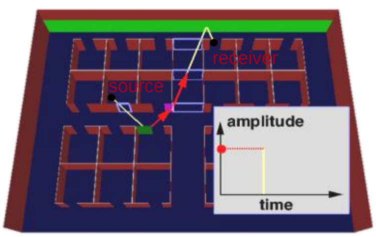


Step 3: Path Generation

- Solve equal angle constraints for diffractions

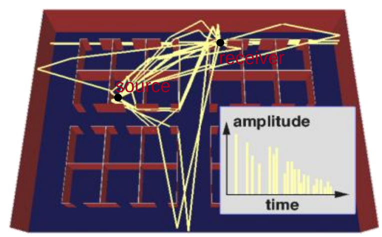
Step 4: Auralization

- Apply filter for each propagation path

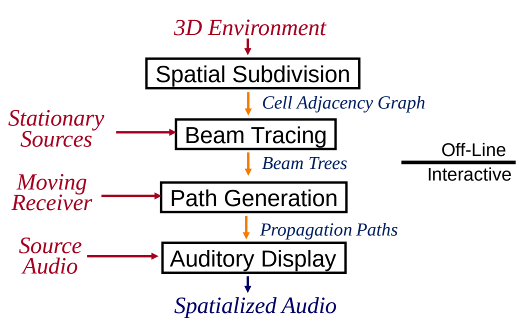


Step 4: Auralization

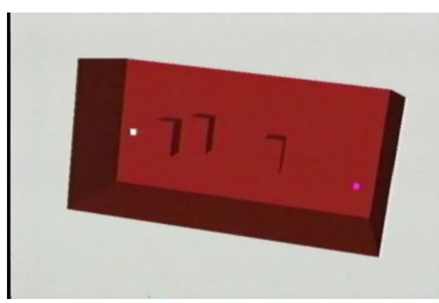
- Combine paths to model early response



Beam Tracing Method

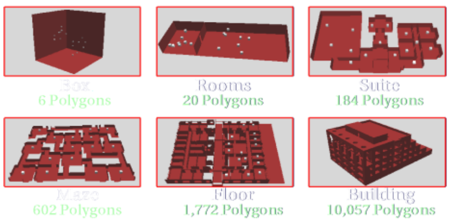


Beam Tracing Demo



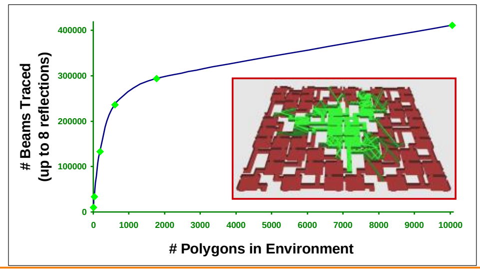
Experimental Results

- Test propagation path update rates in large environments with several reflections



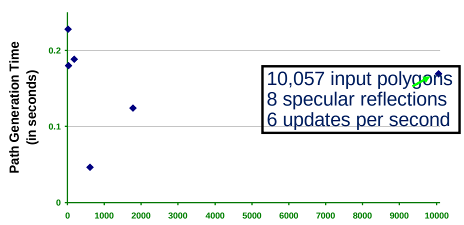
Beam Tracing Results

- Beam tree does not necessarily grow with global complexity of environment

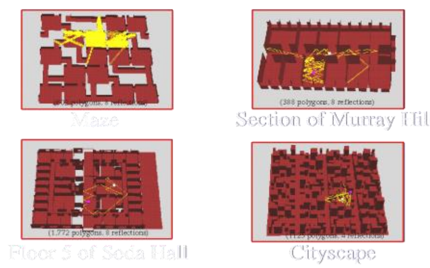


Path Generation Results

- Propagation paths updated interactively … even for large environments



Path Generation Video



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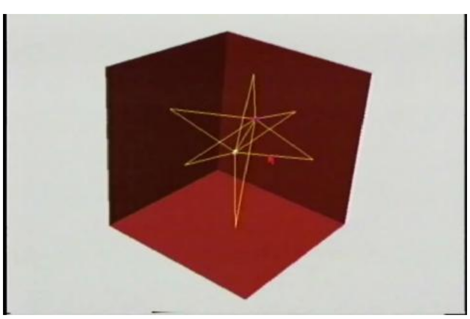
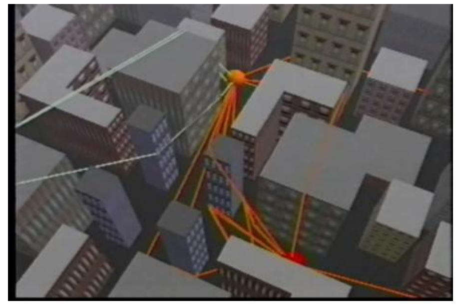


Auralization Video

Specular reflection only

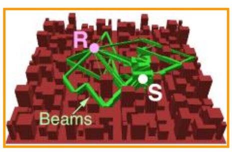
Auralization Video

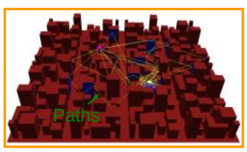
Auralization Video II



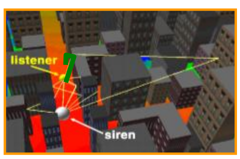
Diffraction and specular reflection

Diagnostic Results





Power



Power + Paths

Summary

- Intersection acceleration techniques are important
  - Bounding volume hierarchies
  - Spatial partitions
- General concepts
  - Sort objects spatially
  - Make trivial rejections quick
  - Utilize coherence when possible

Expected time is sub-linear in number of primitives

- Useful for sound propagation too!