# Ray Tracing II: Acceleration Techniques

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# Overview

- Various ray-object intersection details
- Ray-object intersection a substantial computational cost
  - 50-90% of run time, depending on shading complexity
- Spatial subdivision, bounding volume hierarchies

# Ray-object details

- Object transformations
  - Transform the ray origin and direction by the inverse transform
  - Transform the object if possible, though
- Normalize ray direction vector?
  - Can make intersection tests faster, but renormalizing after transform is slow
  - Comparing ray t values easier if not re-normalized after transform!

# Shape Intersection Interface

- Intersect(): general rays
- IntersectP(): shadow rays: no geom. info
- WorldBound(): world space bounding box
- ObjectBound(): object space bbox
- CanIntersect(): can we call Intersect()?
- Refine(): new shapes

# Local Differential Geometry

- Shape-independent method for representing intersection information
  - Point P
  - Normal N
  - Parametric (u,v)
  - Partial derivatives
  - (Tangents, change in normal, ...)

# Ray Intersection Acceleration

- Problem: naive algorithm scales linearly with scene complexity
- Solution: don't use the naive algorithm!
- Four main options
  - Faster ray-object intersections
  - Fewer ray-object intersections
  - Fewer rays
  - Generalized rays

# Faster Ray-Object Intersections

- Micro-optimization techniques
  - SSE/4 rays at once via SIMD (Wald et al)
- maxt to quickly cull objects
- Shadow rays don't need differential geometry

# Tracing Generalized Rays

- Beams, cones, pencils, ...
- Area sampling rather than point sampling
- Geometric computations are tricky
- Problems with refraction, ...

# Fewer Ray-Object Intersections

- Shadow rays are special: any intersection will do
  - Stop after first hit
  - Shadow cache
  - Light buffer
  - Shaft culling
- Backface culling
- Bounding volumes

# Basic Bounding Volumes

- Surround object with a simple volume
- Test ray against volume first
- Cost model: $n \times c_b + p_i \times n \times c_o$
- $n$ is given; minimize $c_b$ and $p_i$
- Spheres, boxes...
- Test object-space or world-space bound?

# Spatial Data Structures

- 3+D data structure
  - Two main approaches
    - Spatial Subdivision
    - Bounding Volume Hierarchies
  - Does the hierarchy drive the subdivision of space, or do the bounds of the objects drive it?

# Uniform Grids: Creation

- Find bounding box
- Choose # of voxels: $k \times \sqrt[3]{n}$
- Engrid objects
  - Use bounds to find candidate voxels
  - Possibly do voxel-object overlap test

# Uniform Grids: Traversal

- Intersect ray with grid bounds
- Use DDA to step through voxels
  - Like Bresenham, but must visit all voxels the ray passes through!
- Compute intersections with objects in each voxel

# Objects that overlap multiple voxels

- Continue until intersection in current voxel
  - Early out for shadow rays, though
- Mailboxes to eliminate redundant intersection tests
  - Assign rays numbers, check against objects last-tested-ray number
  - Not so good for multi-threading...

# Hierarchical Grids

- Solves the lack-of-adaptivity problem
- Can re-use DDA setup computations
- Effective in practice

# Hierarchical Spatial Subdivision

- Recursive subdivision of space
  - Octree, kd-tree, bsp-tree
  - 1-1 Relationship between points in the scene and leaf nodes of the tree
- Example: point location by recursive search (log time)

# Creating Spatial Hierarchies

- Top down versus bottom up
- Top down:

```
Create(node, prims) {
  if (# prims < MAX_PRIMS ||
      depth > MAX_DEPTH)
    add(prims, node->prims);
  else {
    refine(node);
    foreach node->child
      Create(child, overlap(prims, child));
  }
}
```

# Traversing Spatial Hierarchies

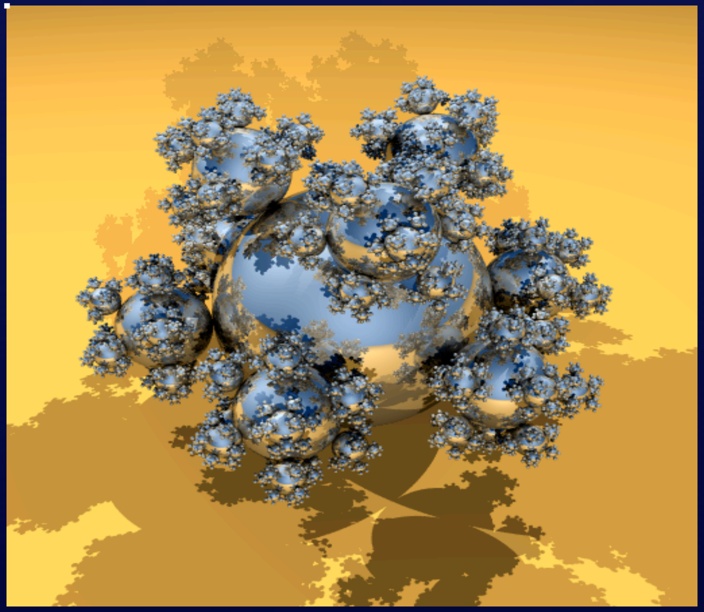
- Recursive traversal from top node
- Maintain front-to-back todo list
- Examples...

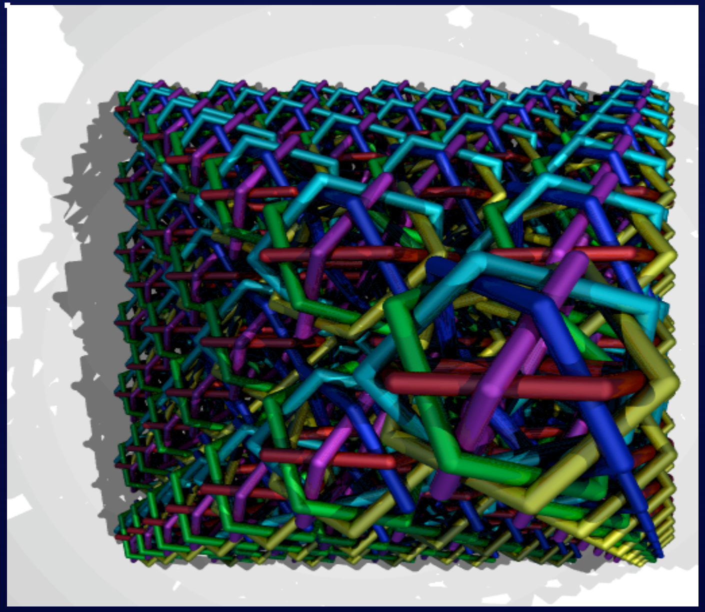
# Other Approaches

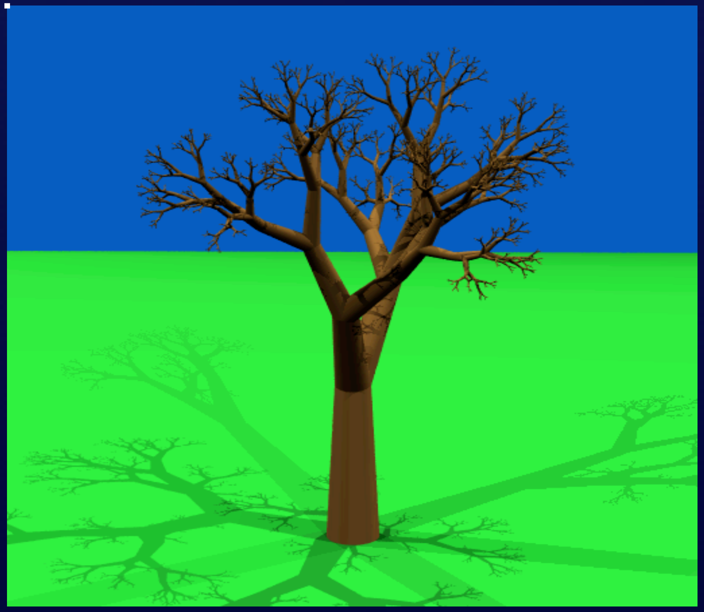
- Bounding volume hierarchies
  - Kay-Kajiya: heap based on t distance to bounding volume intersection
- 5D ray hierarchies
- Meta-hierarchies

# So What's Best?

- Every method has been conclusively proven to be better than all of the others.
- SPD scenes popular, though dated
- V. Havran, Best Efficiency Scheme Project `http://sgi.felk.cvut.cz/BES/`







# Really, What's Best?

- What kinds of scenes do you want to render?
  - "Teapot in a stadium" versus uniform distribution
  - Impact of tessellation of patches/subdivision surfaces on distribution?
- Constant factors are critically important
- Adaptivity generally key for robustness
- Cache effects becoming more important

# Asymptotic Running Time

- Triangles (Pellegrini)
  - Time: $O(\log n)$
  - Space: $O(n^{5+\epsilon})$
- Spheres (Guibas and Pellegrini)
  - Time: $O(\log^2 n)$
  - Space: $O(n^{5+\epsilon})$
- In practice, log-ish behavior generally seen