

Ray Tracing II

CS 465 Lecture 18

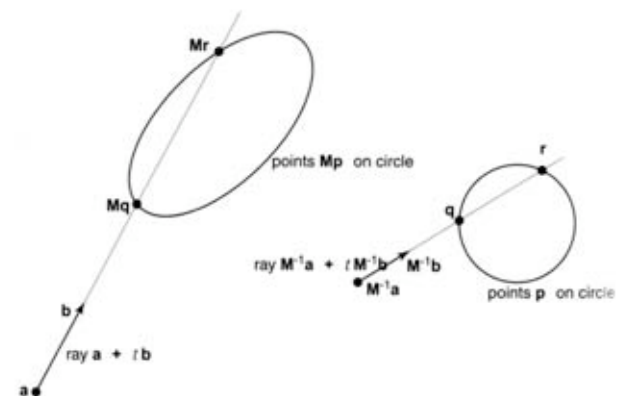
Topics

- Transformations in ray tracing
 - Transforming objects
 - Transformation hierarchies
- Ray tracing acceleration structures
 - Bounding volumes
 - Bounding volume hierarchies
 - Uniform spatial subdivision
 - Adaptive spatial subdivision

Transforming objects

- In modeling, we've seen the usefulness of transformations
 - How to do the same in RT?
- Take spheres as an example: want to support transformed spheres
 - Need a new Surface subclass
- Option 1: transform sphere into world coordinates
 - Write code to intersect arbitrary ellipsoids
- Option 2: transform ray into sphere's coordinates
 - Then just use existing sphere intersection routine

Intersecting transformed objects



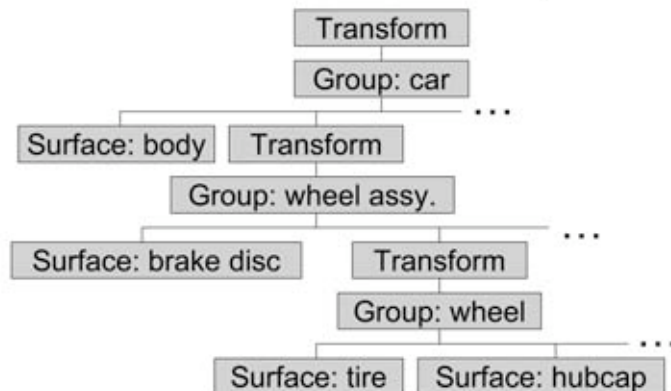
Implementing RT transforms

- Create wrapper object “TransformedSurface”
 - Has a transform T and a reference to a surface S
 - To intersect:
 - Transform ray to local coords (by inverse of T)
 - Call `surface.intersect`
 - Transform hit data back to global coords (by T)
 - Intersection point
 - Surface normal
 - Any other relevant data (maybe none)

Groups, transforms, hierarchies

- Often it's useful to transform several objects at once
 - Add “SurfaceGroup” as a subclass of Surface
 - Has a list of surfaces
 - Returns closest intersection
 - Opportunity to move ray intersection code here to avoid duplication
- With `TransformedSurface` and `SurfaceGroup` you can put transforms below transforms
 - Voilà! A transformation hierarchy.

A transformation hierarchy

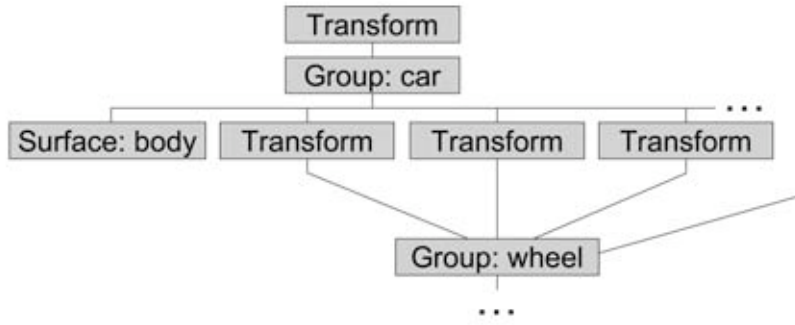


- Common optimization: merge transforms with groups
 - This is how we did it in the modeler assignment

Instancing

- Anything worth doing is worth doing n times
- If we can transform objects, why not transform them several ways?
 - Many models have repeated subassemblies
 - Mechanical parts (wheels of car)
 - Multiple objects (chairs in classroom, ...)
 - Nothing stops you from creating two `TransformedSurface` objects that reference the same Surface
 - Allowing this makes the transformation tree into a DAG
 - (directed acyclic graph)
 - Mostly this is transparent to the renderer

Hierarchy with instancing



Hierarchies and performance

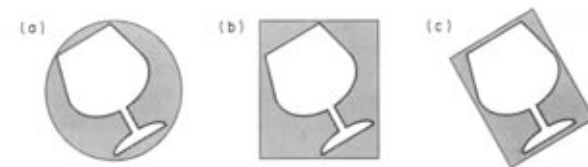
- Transforming rays is expensive
 - minimize tree depth: flatten on input
 - push all transformations toward leaves
 - triangle meshes may do best to stay as group
 - transform ray once, intersect with mesh
 - internal group nodes still required for instancing
 - can't push two transforms down to same child!

Ray tracing acceleration

- Ray tracing is slow. This is bad!
 - Ray tracers spend most of their time in ray-surface intersection methods
- Ways to improve speed
 - Make intersection methods more efficient
 - Yes, good idea. But only gets you so far
 - Call intersection methods fewer times
 - Intersecting every ray with every object is wasteful
 - Basic strategy: efficiently find big chunks of geometry that definitely do not intersect a ray

Bounding volumes

- Quick way to avoid intersections: bound object with a simple volume
 - Object is fully contained in the volume
 - If it doesn't hit the volume, it doesn't hit the object
 - So test bvol first, then test object if it hits



Bounding volumes

- Cost: more for hits and near misses, less for far misses
- Worth doing? It depends:
 - Cost of bvol intersection test should be small
 - Therefore use simple shapes (spheres, boxes, ...)
 - Cost of object intersect test should be large
 - Bvols most useful for complex objects
 - Tightness of fit should be good
 - Loose fit leads to extra object intersections
 - Tradeoff between tightness and bvol intersection cost

Implementing bounding volume

- Just add new Surface subclass, “BoundedSurface”
 - Contains a bounding volume and a reference to a surface
 - Intersection method:
 - Intersect with bvol, return false for miss
 - Return `surface.intersect(ray)`
 - Like transformations, common to merge with group
 - This change is transparent to the renderer (only it might run faster)
- Note that all Surfaces will need to be able to supply bounding volumes for themselves

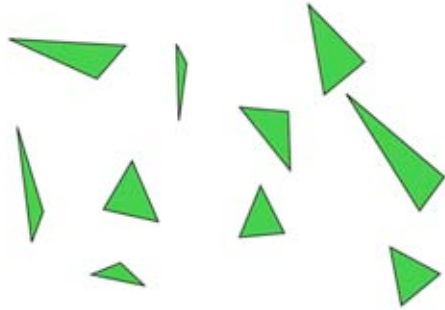
If it's worth doing, it's worth doing hierarchically!

- Bvols around objects may help
- Bvols around groups of objects will help
- Bvols around parts of complex objects will help
- Leads to the idea of using bounding volumes all the way from the whole scene down to groups of a few objects

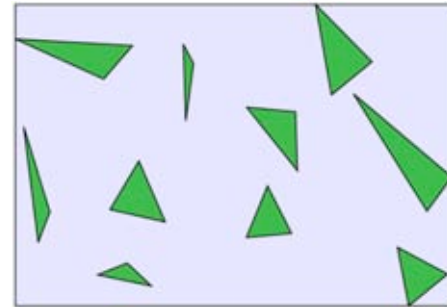
Implementing a bvol hierarchy

- A BoundedSurface can contain a list of Surfaces
- Some of those Surfaces might be more BoundedSurfaces
- Voilà! A bounding volume hierarchy
 - And it's all still transparent to the renderer

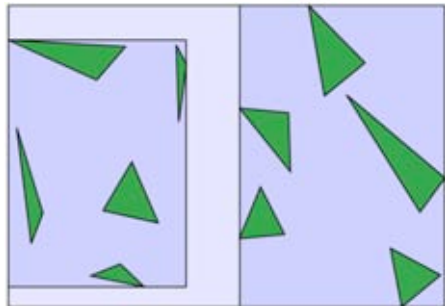
BVH construction example



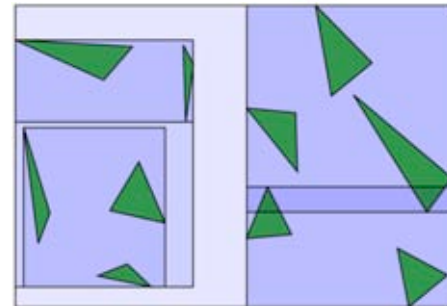
BVH construction example



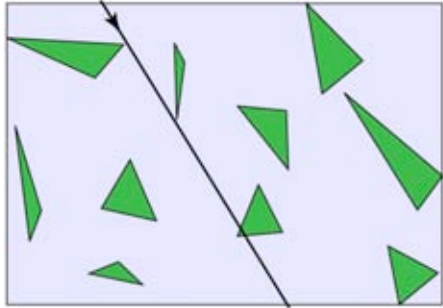
BVH construction example



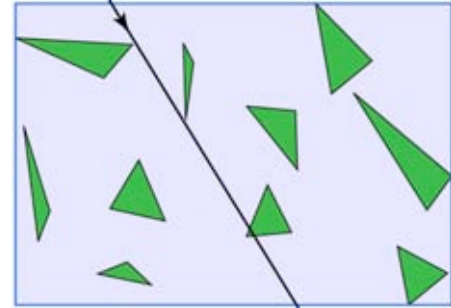
BVH construction example



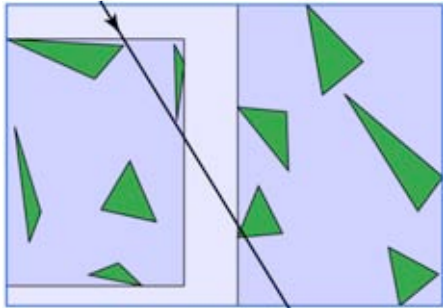
BVH ray-tracing example



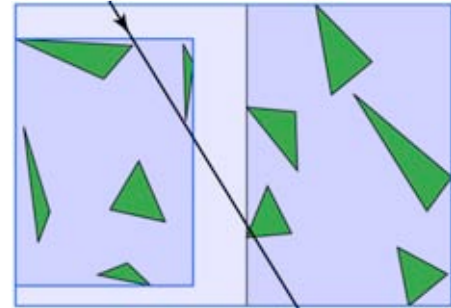
BVH ray-tracing example



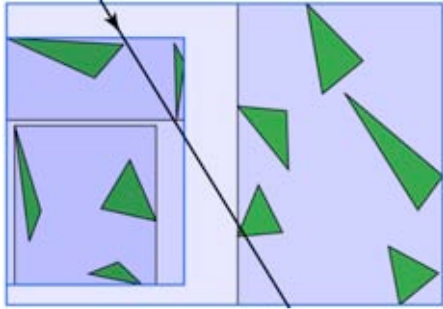
BVH ray-tracing example



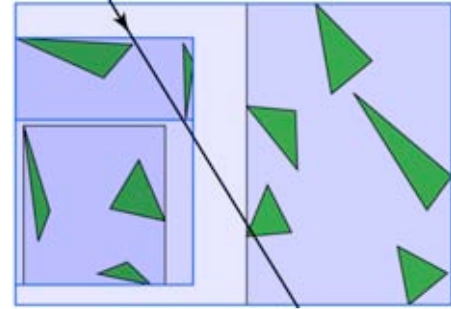
BVH ray-tracing example



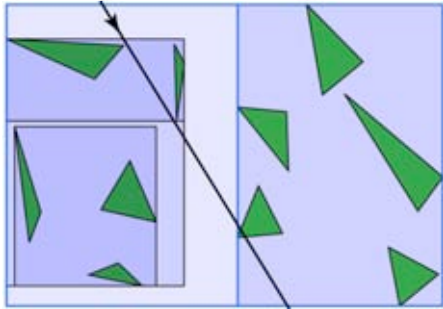
BVH ray-tracing example



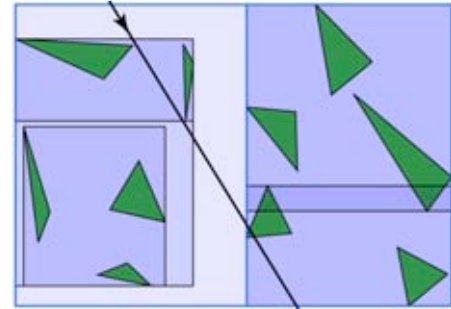
BVH ray-tracing example



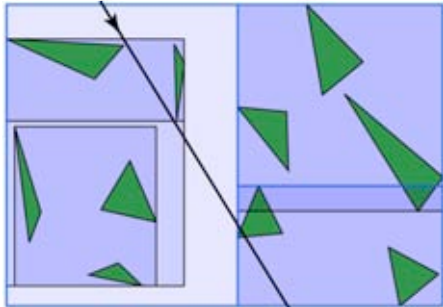
BVH ray-tracing example



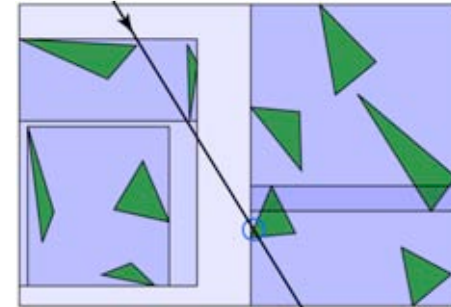
BVH ray-tracing example



BVH ray-tracing example



BVH ray-tracing example



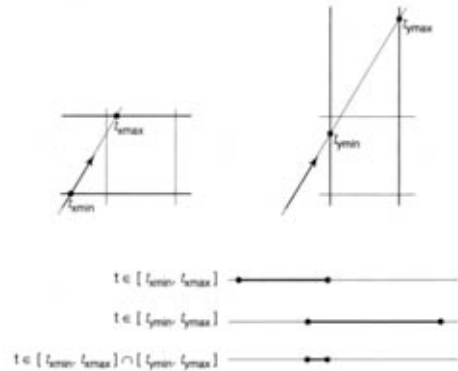
Choice of bounding volumes

- Spheres -- easy to intersect, not always so tight
- Axis-aligned bounding boxes (AABBs) -- easy to intersect, often tighter (esp. for axis-aligned models)
- Oriented bounding boxes (OBBs) -- easy to intersect (but cost of transformation), tighter for arbitrary objects
- Computing the bvols
 - For primitives -- generally pretty easy
 - For groups -- not so easy for OBBs (to do well)
 - For transformed surfaces -- not so easy for spheres

Axis aligned bounding boxes

- Probably easiest to implement
- Computing for primitives
 - Cube: duh!
 - Sphere, cylinder, etc.: pretty obvious
 - Groups or meshes: min/max of component parts
- AABBs for transformed surface
 - Easy to do conservatively: bbox of the 8 corners of the bbox of the untransformed surface
- How to intersect them
 - Treat them as an intersection of slabs (see Shirley)

Intersecting boxes



Building a hierarchy

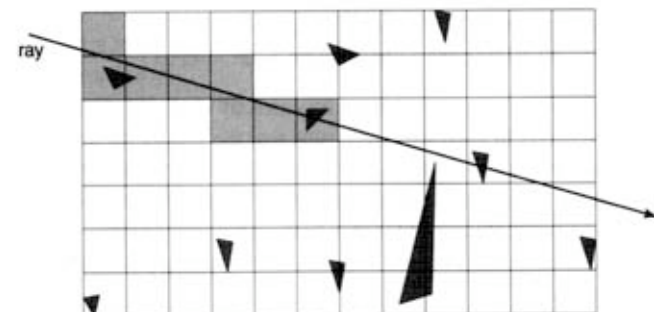
- Usually do it top-down
- Make bbox for whole scene, then split into (maybe 2) parts
 - Recurse on parts
 - Stop when there are just a few objects in your box

Building a hierarchy

- How to partition?
 - Ideal: clusters
 - Practical: partition along axis
 - Median partition
 - More expensive
 - More balanced tree
 - Center partition
 - Less expensive, simpler
 - Unbalanced tree, but that may actually be better

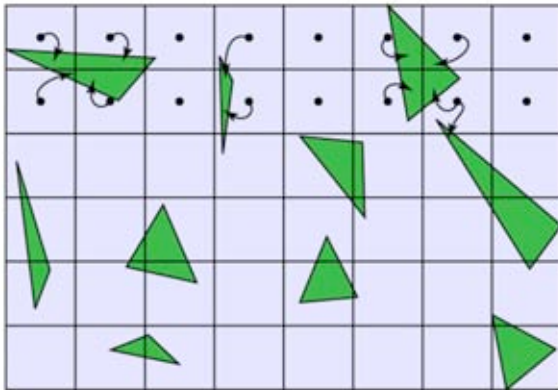
Regular space subdivision

- An entirely different approach: uniform grid of cells

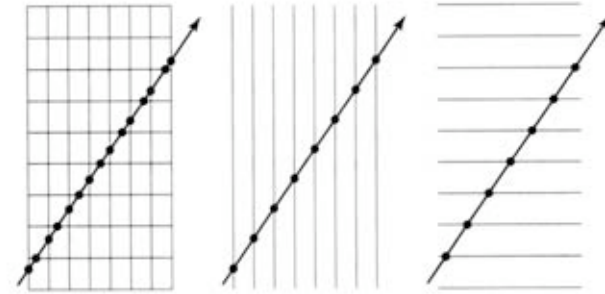


Regular grid example

- Grid divides space, not objects

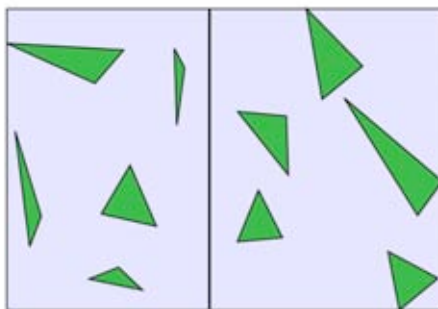


Traversing a regular grid



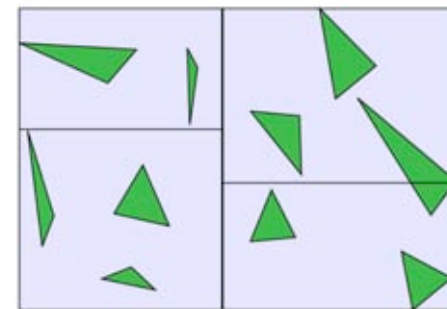
Non-regular space subdivision

- k-d Tree
 - subdivides space, like grid
 - adaptive, like BVH



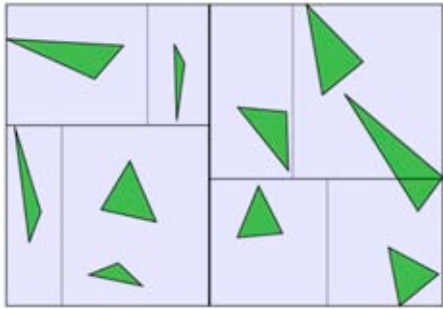
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Non-regular space subdivision

- *k*-d Tree
 - subdivides space, like grid
 - adaptive, like BVH



Implementing acceleration structures

- Conceptually simple to build acceleration structure into scene structure
- Better engineering decision to separate them