

Spatial data structures

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Lecture Overview

Spatial data structures

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Spatial data structures

Bounding volumes

Hierarchical bounding volumes

Spatial subdivision

- 1 Spatial data structures
 - Bounding volumes
 - Hierarchical bounding volumes
 - Spatial subdivision

Ray tracing acceleration

Spatial data structures

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Bounding volumes

Hierarchical bounding volumes

Spatial subdivision

- ▶ **faster intersections**
 - ▶ faster ray-object intersections e.g. object bounding volume, efficient computation of intersections
- ▶ **fewer ray-object intersections**
 - ▶ hierarchical bounding volumes (boxes, spheres)
 - ▶ spatial data structures
 - ▶ directional techniques
- ▶ **fewer rays**
 - ▶ adaptive tree-depth control
 - ▶ stochastic sampling
- ▶ **generalized rays** (beams, cones)

Spatial data structures

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Spatial subdivision

Data structures to store geometric information

Sample applications

- ▶ collision detections
- ▶ location queries
- ▶ simulations
- ▶ rendering

Spatial data structures for ray tracing

- ▶ object-centric data structures (bounding volumes)
- ▶ space subdivision (grids, octrees, BSP trees)

→ speed-up of 10x, 100x, or more

Bounding volumes

Wrap complex objects in simple ones

Does ray intersect bounding box?

- ▶ no: does not intersect enclosed objects
- ▶ yes: calculate intersection with closest objects

Common types:



Sphere



Axis-aligned
Bounding
Box (AABB)



Oriented
Bounding
Box (OBB)



6-dop



Convex Hull

Selection of bounding volumes

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bounding volumes

Spatial subdivision

Effectiveness depends on:

- ▶ probability that ray hits bounding volume, but not enclosed objects (tight fit is better)
- ▶ cost of calculating intersections with bounding volume and enclosed objects

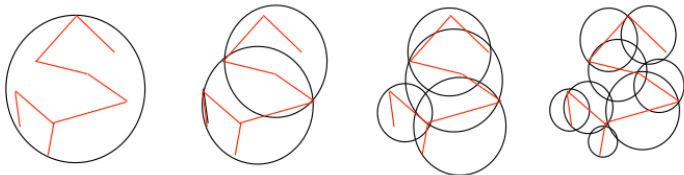
Use heuristics

Hierarchical bounding volumes

With simple bounding volumes, ray casting still requires $O(n)$ intersection tests

Idea: use tree data structure

- ▶ larger bounding volumes contain smaller ones etc
- ▶ sometimes naturally available (e.g. human figure)
- ▶ sometimes difficult to compute
- ▶ often reduces complexity to $O(\log(n))$



Ray intersection algorithm

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Spatial subdivision

Recursively descend down the tree

- ▶ if ray misses bounding volume, no intersection
- ▶ if ray intersects bounding volume, recurse with the enclosed volumes and objects

Maintain near and far bounds to prune further

Overall effectiveness depends on model and constructed hierarchy

Spatial subdivision

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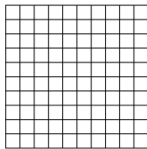
Bounding volumes

Hierarchical bounding volumes

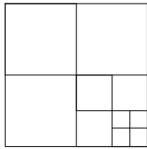
Spatial subdivision

Bounding volumes enclose objects, recursively i.e. object-centric

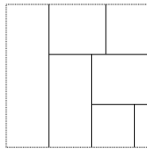
Alternatively, divide space (as opposed to objects) → for each segment of space, keep a list of intersecting surfaces or objects
Basic techniques:



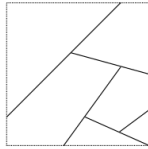
Uniform
Spatial Sub



Quadtree/Octree



kd-tree



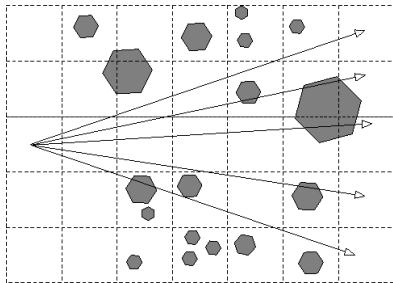
BSP-tree

Grids

3D array of cells (voxels) that tile space

Each cell keeps a list of all intersecting surfaces

Intersection algorithm steps from cell to cell

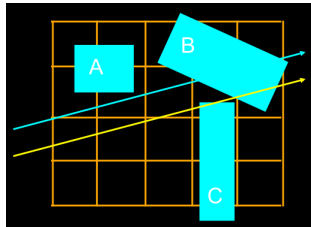


Caching intersection points

Objects can span multiple cells

For A need to test intersection only once

For B need to cache intersection and check next cell for any closer intersection with other objects. If not, C could be missed (yellow ray)



Assessment of grids

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Poor choice when world is non-homogeneous

Grid resolution:

- ▶ too large: too many surfaces per cell
- ▶ too small: too many empty cells to traverse

Can use algorithms like Bresenham's for efficient traversal

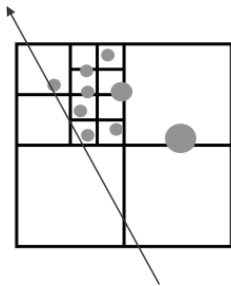
Non-uniform spatial subdivision more flexible. Can adjust to objects that are present

Quadtrees

Generalization of binary trees in 2D

- ▶ node (cell) is a square
- ▶ recursively split into 4 equal sub-squares
- ▶ stop subdivision based on number of objects

Ray intersection has to traverse quadtree. More difficult to step to next cell.



Octrees

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Spatial subdivision

Generalization of quadtree in 3D

Each cell may be split into 8 equal sub-cells

Internal nodes store pointers to children

Leaf nodes store list of surfaces

Adapts well to non-homogeneous scenes

Assessment for ray tracing

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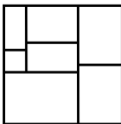
Spatial subdivision

- ▶ Grids
 - ▶ easy to implement
 - ▶ require a lot of memory
 - ▶ poor results for non-homogeneous scenes
- ▶ Octrees
 - ▶ better on most scenes (more adaptive)
- ▶ Alternative: nested grids
- ▶ Spatial subdivision expensive for animations
- ▶ Hierarchical bounding volumes
 - ▶ natural for hierarchical objects
 - ▶ better for dynamic scenes

Other spatial subdivision techniques

Relax rules for quadtrees and octrees

- ▶ k-dimensional tree (k-d tree)
 - ▶ split at arbitrary interior point
 - ▶ split one dimension at a time
- ▶ binary space partitioning tree (BSP tree)
 - ▶ in 2 dimensions, split with any line
 - ▶ in k dims. split with k-1 dimensional hyperplane
 - ▶ particularly useful for painter's algorithm
 - ▶ can also be used for ray tracing



BSP trees

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Spatial subdivision

Split space with any line (2D) or plane (3D)

Applications

- ▶ Painter's algorithm for hidden surface removal
- ▶ Ray casting

Inherent spatial ordering given viewpoint

- ▶ left subtree: in front, right subtree: behind

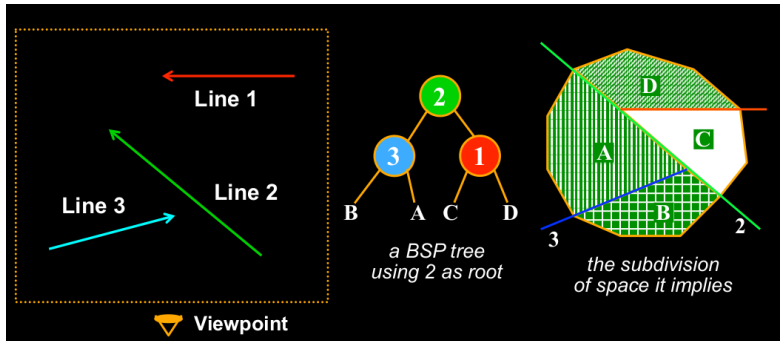
Problem: finding good space partitions

- ▶ proper ordering for any viewpoint
- ▶ how to balance the tree

Building a BSP tree

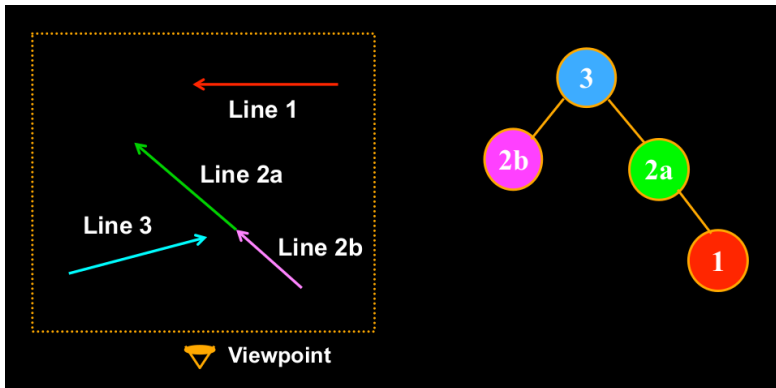
Use hidden surface removal as intuition

Using line 1 or line 2 as root is easy



Splitting of surfaces

Using line 3 as root requires splitting



Building a good tree

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Spatial subdivision

- ▶ naive partitioning of n polygons yields $O(n^3)$ polygons (in 3D)
- ▶ algorithms with $O(n^2)$ increase exist
 - ▶ try all, use polygon with fewest splits
 - ▶ do not need to split exactly along polygon planes
- ▶ should balance tree
 - ▶ more splits allow easier balancing
 - ▶ rebalancing?

Painter's algorithm with BSP trees

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Spatial subdivision

- ▶ building the tree
 - ▶ may need to split some polygons
 - ▶ slow, but done only once
- ▶ traverse back-to-front or front-to-back
 - ▶ order is viewer-direction dependent
 - ▶ what is front and what is back of each line changes
 - ▶ determine order on the fly

Details of Painter's algorithm

Each plane has form $Ax + By + Cz + D = 0$

Plug in coordinates and determine

- ▶ positive: front side
- ▶ zero: on plane
- ▶ negative: back side

Back-to-front: inorder traversal, farther child first

Front-to-back: inorder traversal, near child first

Do backface culling with same sign test

Clip against visible portion of space (portals)

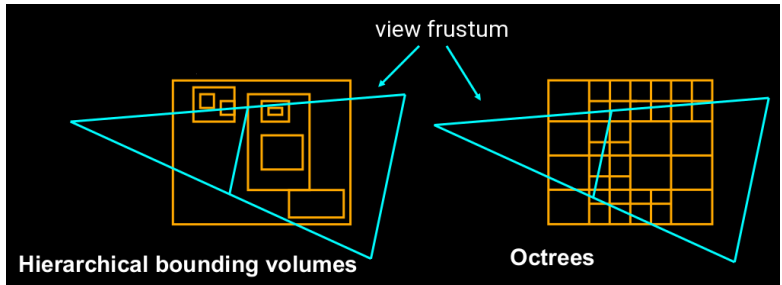
Culling with spatial data structures

Accelerate culling

- ▶ goal accept or reject whole sets of objects
- ▶ can use any spatial data structures

Scene should be mostly fixed

- ▶ terrain fly-through
- ▶ gaming



Data structures demos

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BSP Tree construction
KD Tree construction

Real-time and interactive ray tracing

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Interactive ray tracing via space subdivision State of the art in interactive ray tracing