

Fall 2015

CSCI 420: **Computer Graphics**

10.1 Spatial Data Structures



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Ray Tracing Acceleration

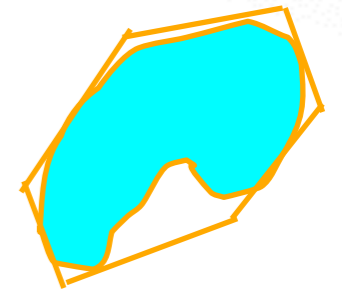
- Faster intersections
 - Faster ray-object intersections
 - Object bounding volume
 - Efficient intersectors
 - Fewer ray-object intersections
 - Hierarchical bounding volumes (boxes, spheres)
 - Spatial data structures
 - Directional techniques
- Fewer rays
 - Adaptive tree-depth control
 - Stochastic sampling
- Generalized rays (beams, cones)

Spatial Data Structures

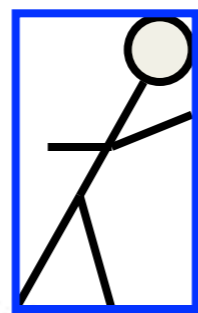
- Data structures to store geometric information
- Sample applications
 - Collision detection
 - Location queries
 - Chemical simulations
 - Rendering
- Spatial data structures for ray tracing
 - Object-centric data structures (bounding volumes)
 - Space subdivision (grids, octrees, BSP trees)
 - Speed-up of 10x, 100x, or more

Intersection of Rays and Implicit Surfaces

- Wrap complex objects in simple ones
- Does ray intersect bounding box?
 - No: does not intersect enclosed objects
 - Yes: calculate intersection with enclosed objects
- Common types:



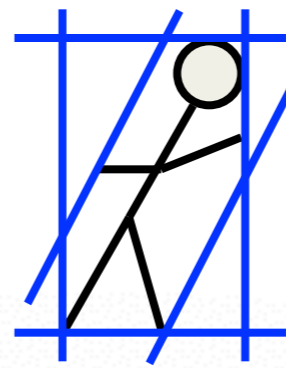
Sphere



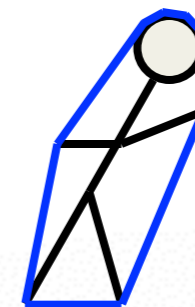
Axis-aligned
Bounding
Box (AABB)



Oriented
Bounding
Box (OBB)



6-dop



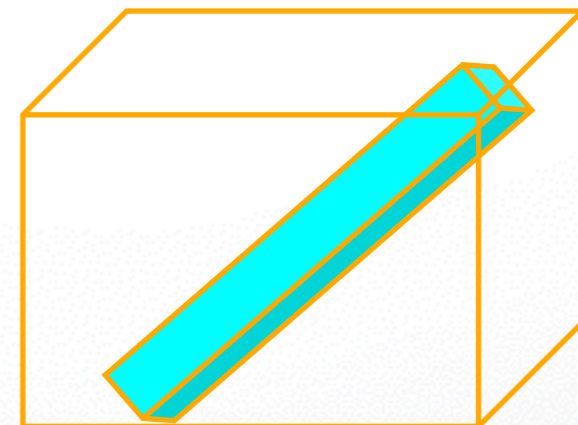
Convex Hull

Selection of Bounding Volumes

- Effectiveness depends on:
 - Probability that ray hits bounding volume, but not enclosed objects (tight fit is better)
 - Expense to calculate intersections with bounding volume and enclosed objects
- Amortize calculation of bounding volumes
- Use heuristics



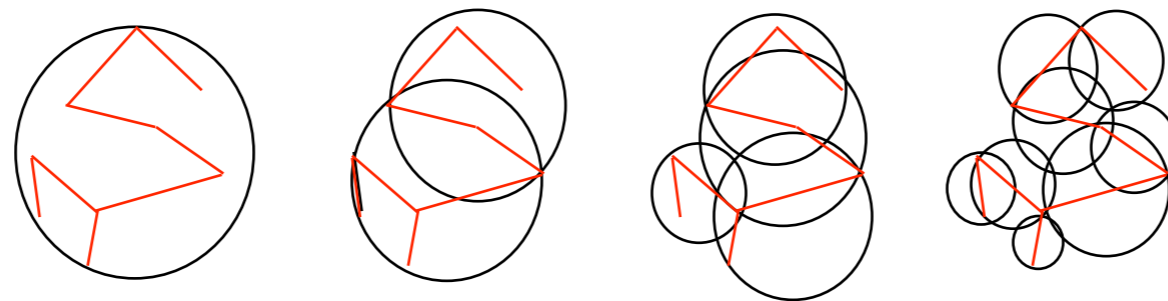
good



bad

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 $O(\log(n))$

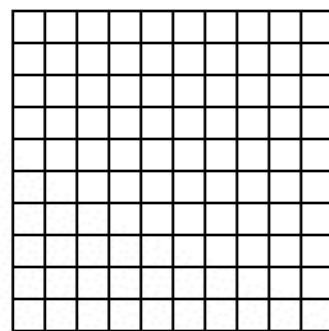


Ray Intersection Algorithm

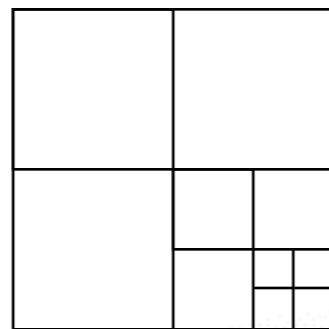
- Recursively descend tree
- If ray misses bounding volume, no intersection
- If ray intersects bounding volume, recurse with enclosed volumes and objects
- Maintain near and far bounds to prune further
- Overall effectiveness depends on model and constructed hierarchy

Spatial Subdivision

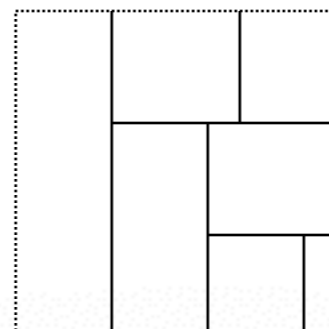
- Bounding volumes enclose objects, recursively
- Alternatively, divide space (as opposed to objects)
- For each segment of space, keep a list of intersecting surfaces or objects
- Basic techniques:



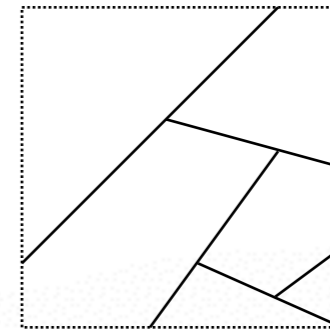
Uniform
Spatial Sub



Quadtree/Octree



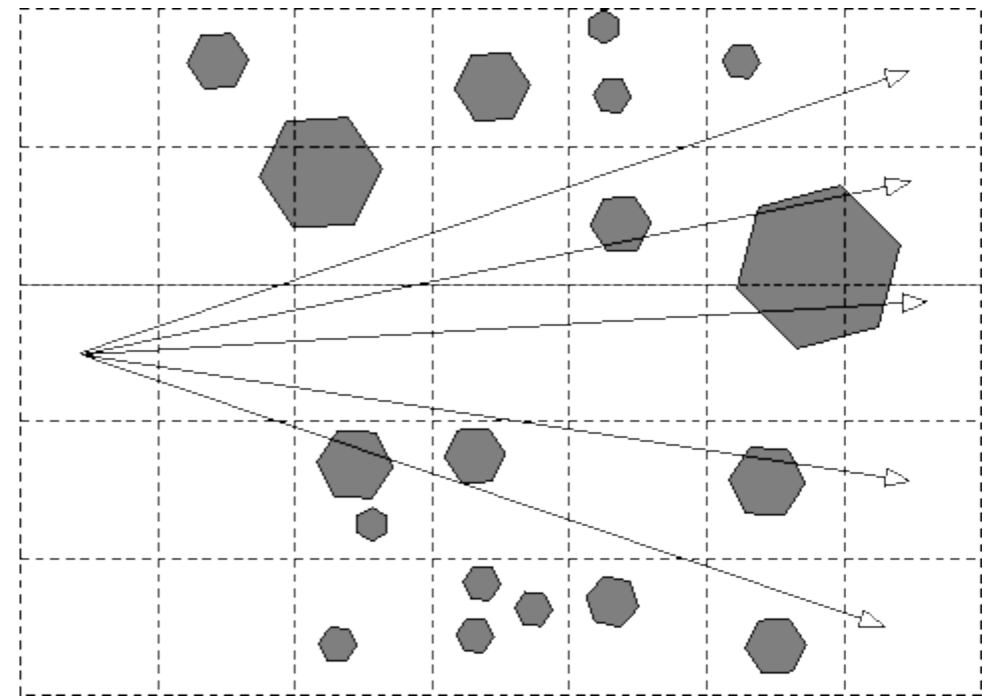
kd-tree



BSP-tree

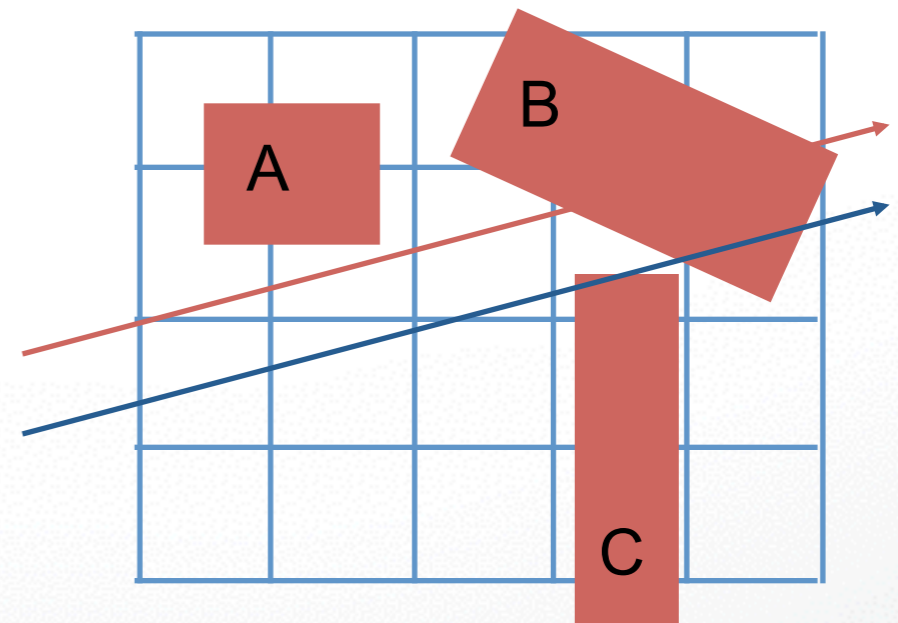
Grids

- 3D array of cells (voxels) that tile space
- Each cell points to 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

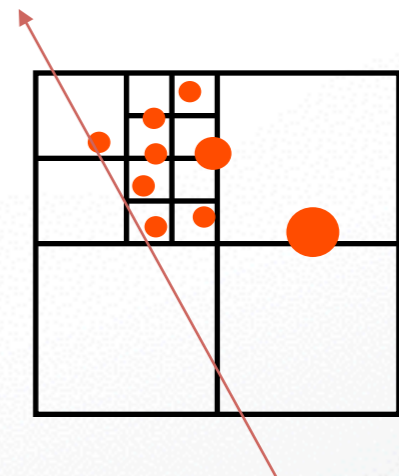
- Poor choice when world is non-homogeneous
- Grid resolution:
 - Too small: too many surfaces per cell
 - Too large: too many empty cells to traverse
 - Can use algorithms like Bresenham's for efficient traversal
- Non-uniform spatial subdivision more flexible
 - Can adjust to objects that are present

Outline

- Hierarchical Bounding Volumes
- Regular Grids
- Octrees
- BSP Trees

Quadrees

- 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

- 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

- 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

Outline

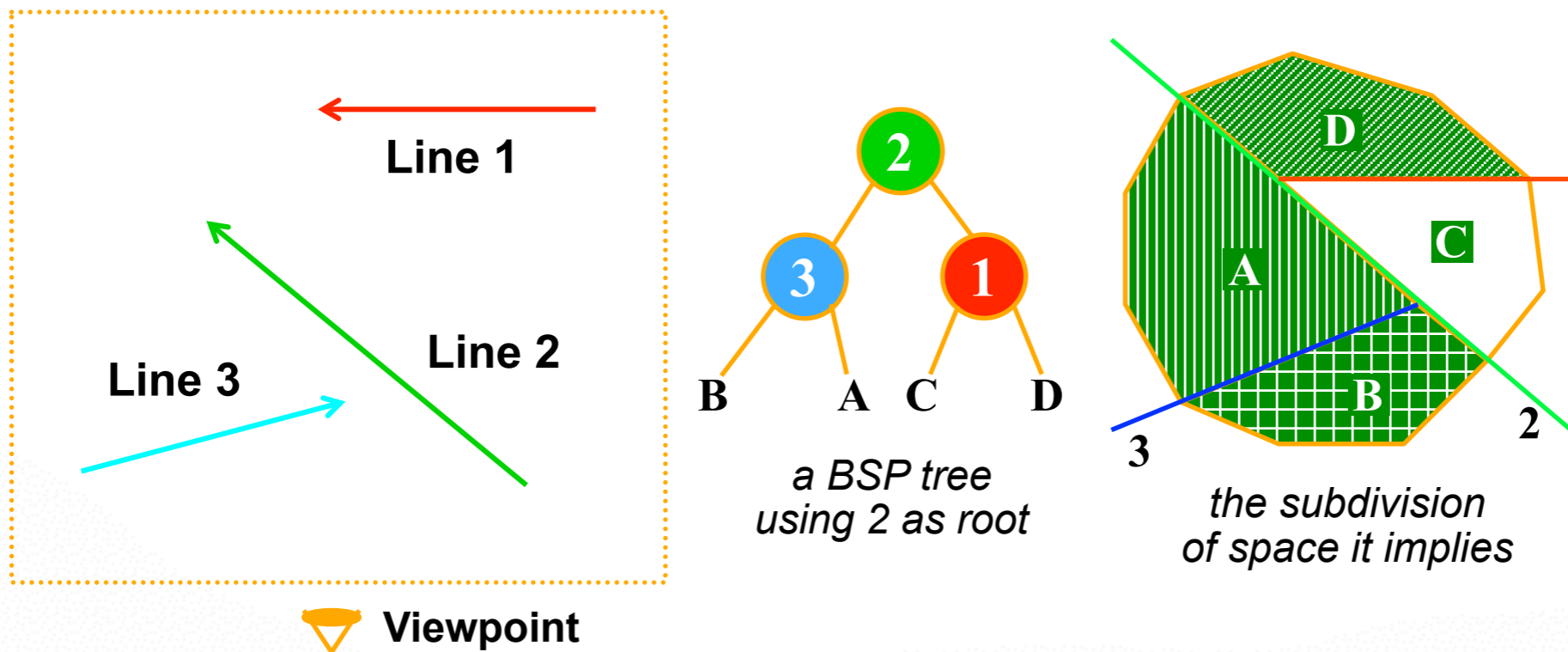
- Hierarchical Bounding Volumes
- Regular Grids
- Octrees
- **BSP Trees**

BSP Trees

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

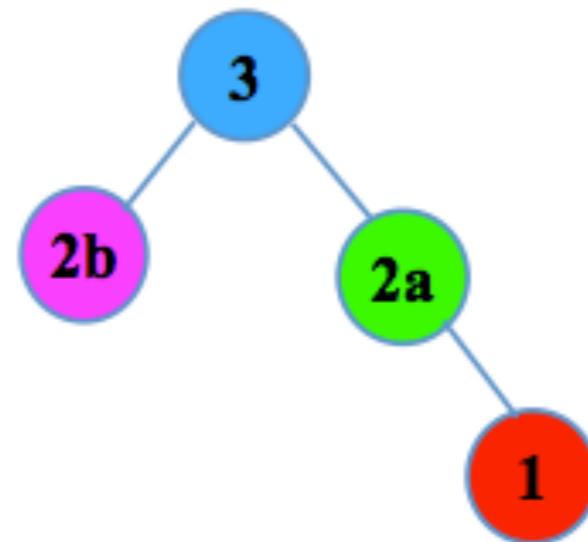
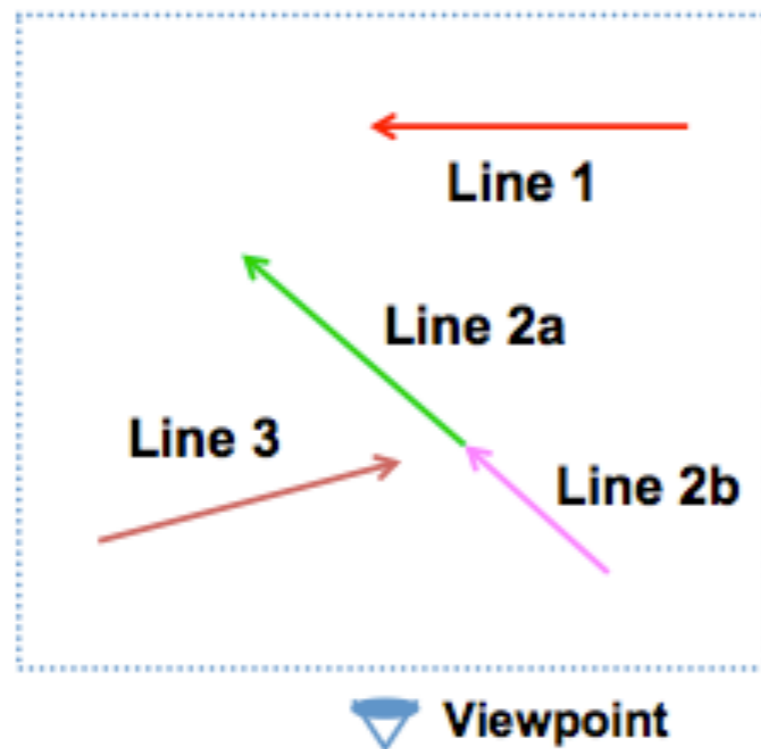
Building a BSP Tree

- 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

- 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

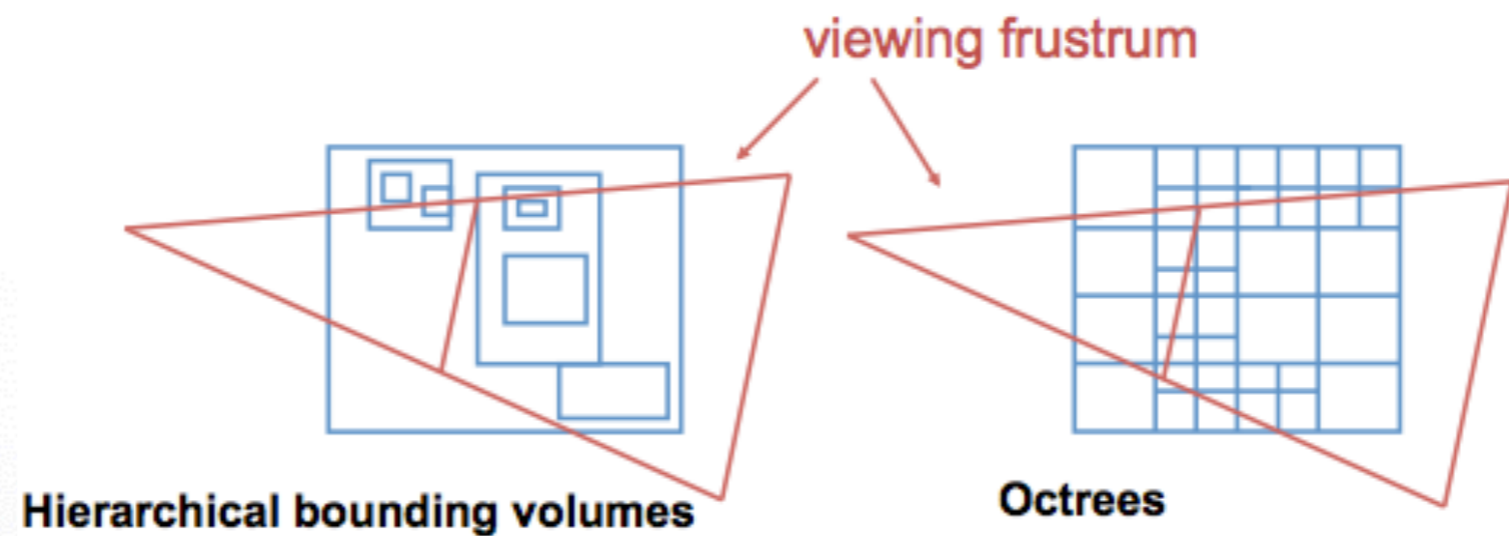
- Building the tree
 - May need to split some polygons
 - Slow, but done only once
- Traverse back-to-front or front-to-back
 - Order is viewer-direction dependent
 - What is front and what is back of each line changes
 - Determine order on the fly

Details of Painter's Algorithm

- Each face has form $Ax + By + Cz + D$
- 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)

Clipping With Spatial Data Structures

- Accelerate clipping
 - Goal: accept or reject whole sets of objects
 - Can use an spatial data structures
- Scene should be mostly fixed
 - Terrain fly-through
 - Gaming



Data Structure Demos

- BSP Tree construction

<http://symbolcraft.com/graphics/bsp/index.html>

- KD Tree construction

<http://donar.umiacs.umd.edu/quadtree/points/kdtree.html>

Real-Time and Interactive Ray Tracing

- Interactive ray tracing via space subdivision
<http://www.cs.utah.edu/~reinhard/egwr/>
- State of the art in interactive ray tracing
<http://www.cs.utah.edu/~shirley/irt/>

Summary

- Hierarchical Bounding Volumes
- Regular Grids
- Octrees
- BSP Trees