# Lecture 14: Acceleration Structures

**Fall 2004**
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## Announcements

- HW 2 is out
- Project discussion will be next week
  - Proposals: Oct 26
  - Final projects due date
- Exam moved to Nov 11 or Nov 18 (Thursday)?
  - Vote

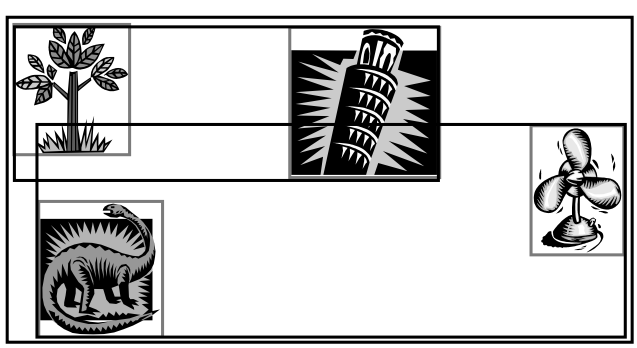
# Fewer Ray-Object Intersections

- From O(N) to O(log N)
- How?
  - Apply the idea of bounding boxes hierarchically
  - Cluster objects hierarchically
  - Single intersection might eliminate cluster
- Bounding volume hierarchy
- Space subdivision
  - Octree, Kd-tree, BSP-trees



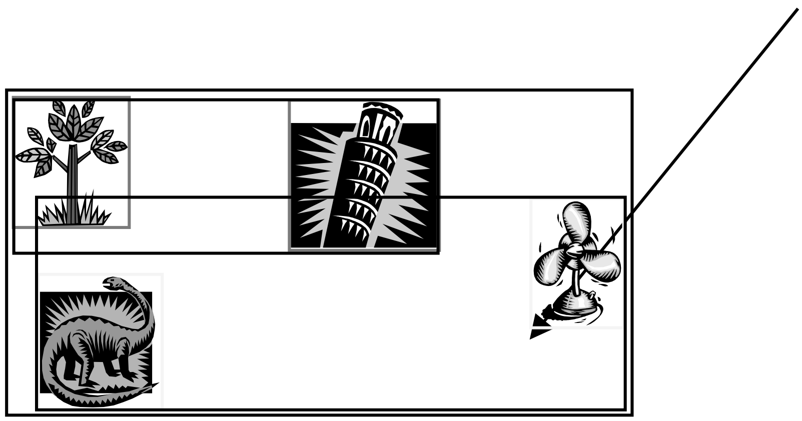
# Bounding Volume Hierarchy

- Hierarchical object bounding volumes
- Spheres, axis-aligned bounding boxes (AABB), oriented bounding boxes(OBB): fast



# Intersection Acceleration

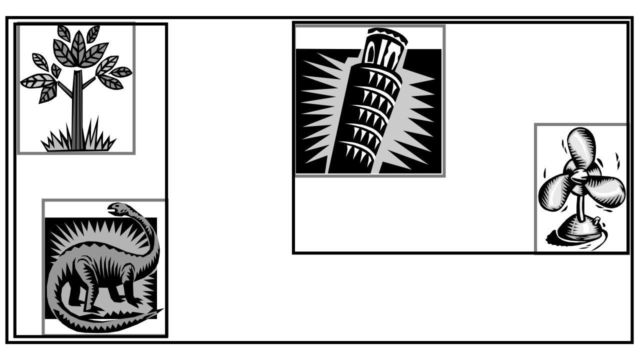
- If no intersection, eliminate tests with all children!





# BVH: Construction

- Group objects together
  - Top-down: how to split?
  - Bottom-up: minimize surface area?



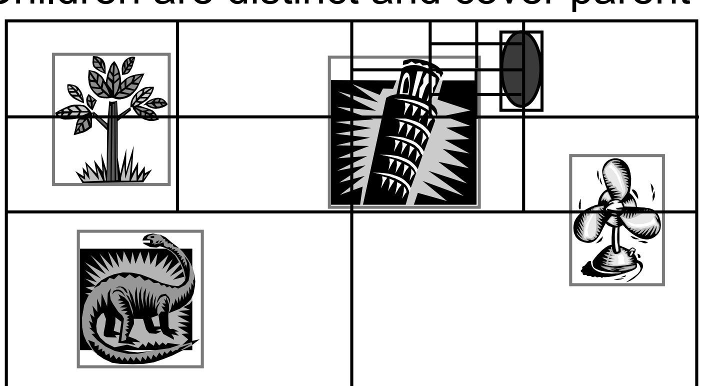
# Fewer Ray-Object Intersections

- From O(N) to O(log N)
- Bounding volume hierarchy
- Space subdivision
  - Octree (Quadtree in 2D)
  - Non-uniform (kd-tree)
  - BSP-tree



# Spatial Hierarchy

- Hierarchical spatial subdivision
  - Divides up space
- Children are distinct and cover parent



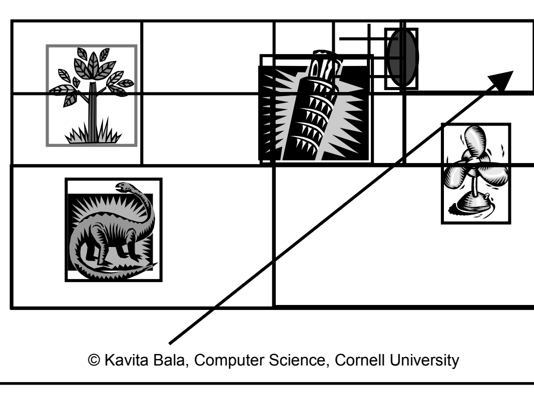
# Intersection Acceleration

1. Intersect ray with root: p = root.intersect(ray)
   – If no intersection, done
2. Find p in tree (node j = root.find(p))
3. Test ray against elements in node j
   – If intersection found, done
   – Else find exit point (q) from node j, p = q, goto 2



# Octree Properties

• Front to back traversal



# Solutions

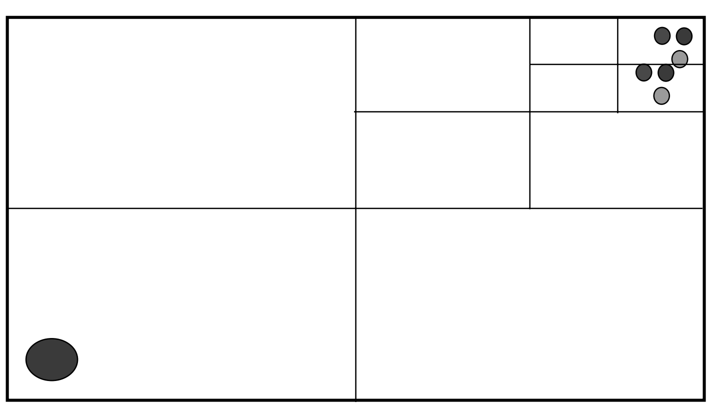
- Split object
  - No repeated intersections and correct
  - But, could create lots of little objects

- Use mailboxes
  - Store intersection in the object: avoids repeated intersection
  - What about correctness?
    - Need to check that intersection is in “current” bounding box



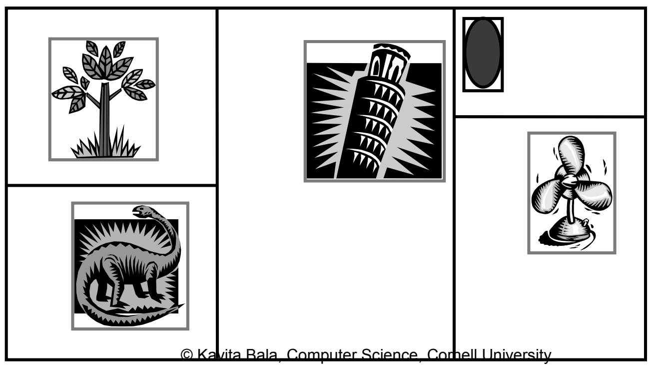
# Octree Problems

- Distribution of objects
- Chops up objects



# K-dimensional (kd) Tree

- Spatial subdivision
  - Subdivide only 1 dimension
  - Do not subdivide at the center
- Tracing with kd-tree unchanged



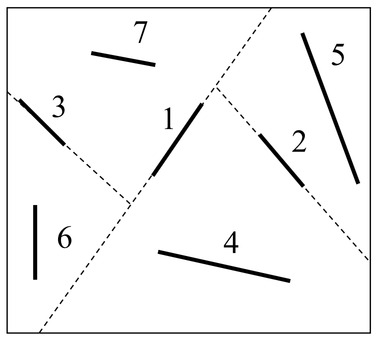


# Construction

- Which axis to pick?
- What point on the axis to pick?
- One heuristic:
  - Sort objects on each axis
  - Pick point corresponding to “middle” object
  - Pick axis that has “best” distribution of objects
  - L = n/2, R = n/2 (ideal)
  - Realistically,
    - minimize (L-R) and
    - L approx. n/2, R approx. n/2

# BSP Tree

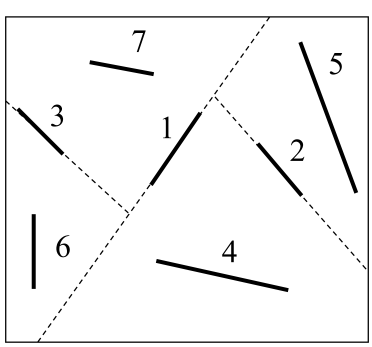
- Generalization of kd-trees
- Splitting plane is not axis aligned
- Used in games: DOOM

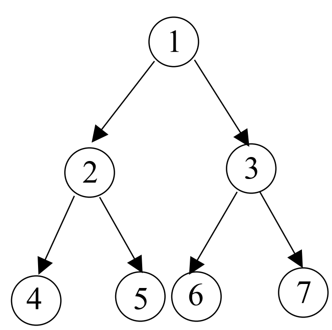





# BSP Construction

- Use a polygon to define the splitting plane
- Other objects either split or stored high up



# How to construct?

- Least-crossed criterion (random selection of polygons)
  - Do not split many polygons
  - Why are polygons split? Depends on use
- Try to make it balanced

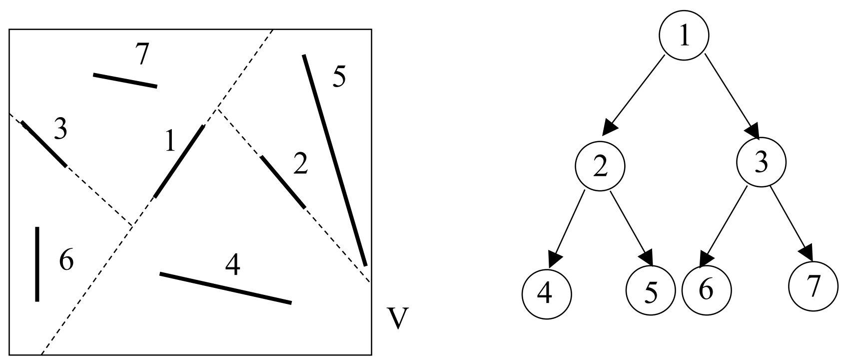


# BSP Construction

- Top-down
- Input: set of polygons
- Select a partition plane
  - $Ax + By + Cz + D = 0$
- Partition the set of polygons with the plane
- Recurse on both new sets

# BSP Traversal

- Front to back ordering
- BSP traversal similar to kd-tree



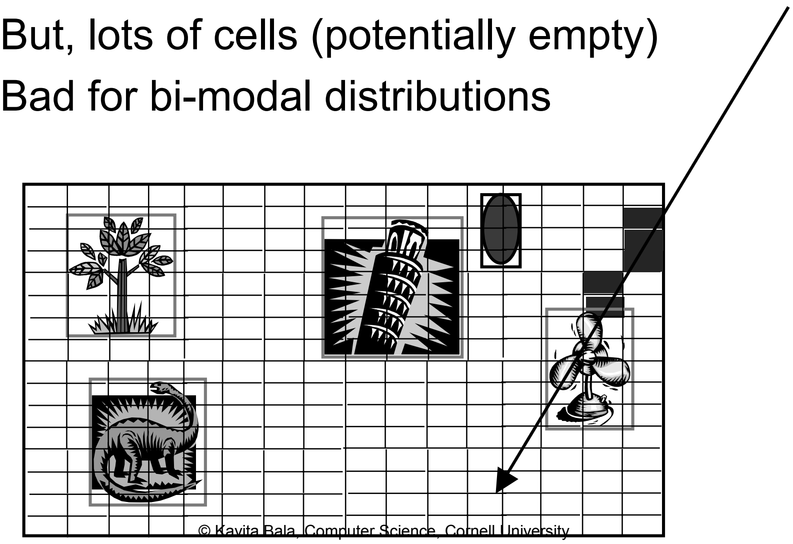



# Other acceleration structures

- Axis-aligned BSP for coherent ray tracing: same as our kd-tree

# Uniform Grid

- Ray marching is trivial (additions)
- But, lots of cells (potentially empty)
- Bad for bi-modal distributions

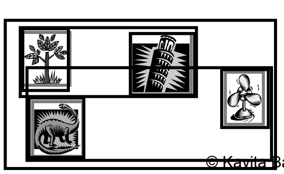


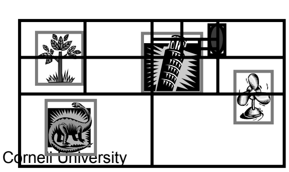


# Bounding Volume vs. Spatial Hierarchy

- Object subdivision
  - Hierarchical object representation
  - Hierarchically cluster objects
- Siblings could overlap
- Object in single leaf
- Ray marches down
- AABB,OBB,Spheres

- Spatial subdivision
  - Hierarchical spatial representation
  - Hierarchically cluster space
- Siblings distinct
- Object in >1 leaf (higher)
- Ray marches across
- Octree,kd-tree,Grid





## Fewer Ray/Object Intersections

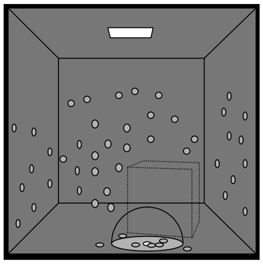
- Issues with hierarchical data structures:
  - Does it take long to initialize?
  - Does it require a lot of memory?
  - Is it as efficient for shadow and secondary rays as for view rays?
  - Can it accommodate time-varying data?



## Using Acceleration Structures

- Acceleration structures for:
  - Ray tracing
  - Visibility determination
    - Culling: hardware and software
  - Point finding
  - Collision detection

# Photon Maps



- Find n closest photons



# Photon Maps: Balanced kd-tree

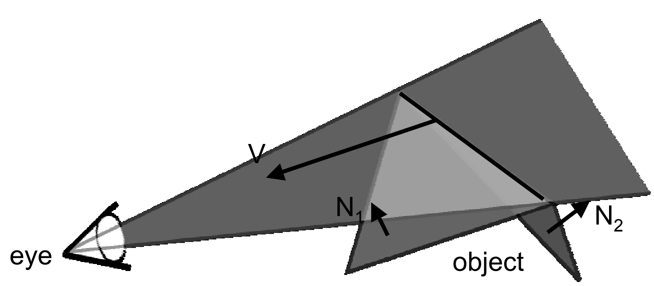
- Find n closest photons
- Balanced kd-tree for photon maps
  - Points (photons) as nodes
    - Compact
  - Balanced: implicit structure
    - Child of node i is 2i and 2i+1
  - Search: Same as before

# Edge-and-point Rendering

- Kd-tree for edge-and-point rendering to find silhouettes and shadows
- How to efficiently find silhouette and shadow discontinuities in complex scenes made of polygon meshes?

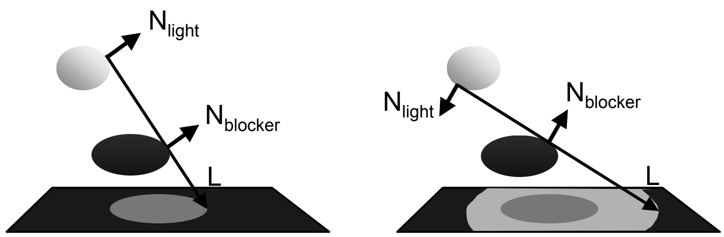


# Silhouettes




$N_1 \cdot V > 0$ (forward facing)
$N_2 \cdot V < 0$ (backward facing)

# Umbral and Penumbral Conditions




umbral penumbral

- Event plane tangential to light and blocker

  $L \cdot N_{blocker} = L \cdot N_{light} = 0$

  $N_{light} \cdot N_{blocker}$ = 1 (umbral), -1 (penumbral)



# Normal–Position Tree

- Novel data structure similar to bounding-volume hierarchy
- Node represents a set of object polygons: stores boxes for normals and positions
  - Position interval: $[x_0, x_1] \times [y_0, y_1] \times [z_0, z_1]$
  - Can be computed efficiently
- Equations (e.g., $L \cdot N_{blocker} = 0$) evaluated conservatively using interval arithmetic

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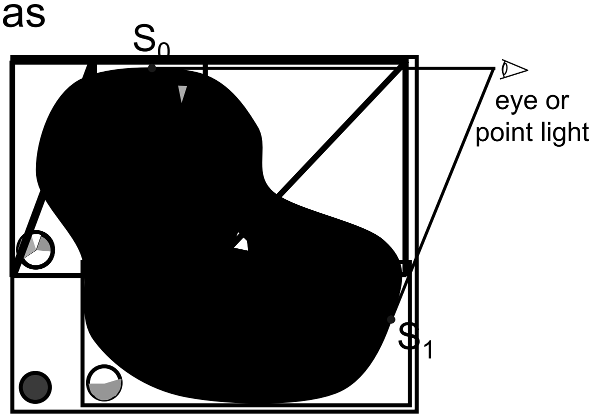
# Tree Traversal

- Fast traversal with interval evaluation of formulas




- Efficient shadow event computation with non-convex objects and area lights



# Culling of Complex Scenes

- Remove geometry that is not visible … cull it away
  - View Frustum Culling
  - Hierarchical z-buffer
  - Cell-portal visibility
  - Many others….

# View Frustum Culling

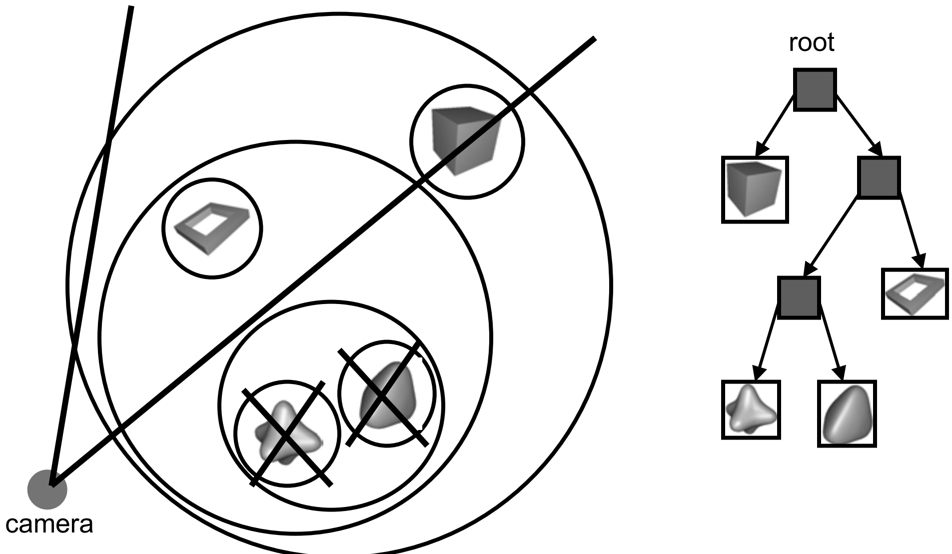
- Construct view frustum
  - 6 plans
- Test objects in scene against frustum
  - Cull them if they do not lie in frustum
- Complexity: O(n)
  - So what's the point?



# Hierarchical View Frustum Culling

- Use an octree/BVH
- Start at o = root of  octree/BVH
- Test(Node o) {
  - Check 6 planes of frustum for intersection with bbox(o)
  - If in or out, terminate testing
  - If it intersects
    - For each child c = child[i], Test (c)

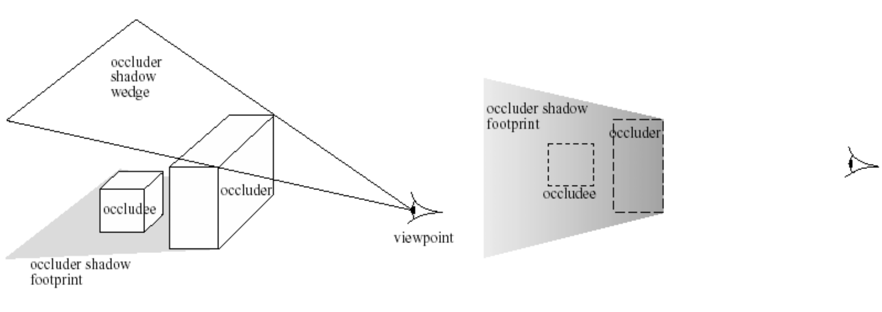
# Example






# Occlusion Culling

- Occlusion Culling/Visibility Culling
- Don't send all polygons to hardware
  - Remove polygons that are not visible
  - Conservative: find visible superset



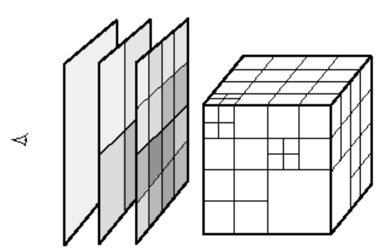
# Occlusion Culling

- On-line
  – Remove geometry on-the-fly
- Off-line
  – Determine potentially visible set (PVS)
  – When rendering only display PVS



# Hierarchical Z-buffer

- On-line
- Use nearby polygons to remove far polygons
- Construct an octree subdivision of scene
  – Could use other data structures as well



## How Hierarchical Z-buffer works

- When rendering:
  - Traverse octree from front to back
    - Enumeration order of octree cells can be determined by ray direction
- Test z-value in z-buffer against octree cell
- Consider cell b from octree
- Let b project to pixels p0, …, pn
- If pi.z < b.Minz Eliminate octree cell
- Else recurse



## Hierarchical

- Have to do it for every pixel
  - Too slow
- Instead do it for a quadtree subdivision of z-buffer
  - Check if the whole square of pixels is in front of the box b