Bounding Volume Hierarchies and Spatial Partitioning

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COMP-236 lecture
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Introduction

- Bounding Volume Hierarchies vs. Spatial Partitioning
  - What are they and how do they compare?
- Motivation: *Need for Speed!*
  - Demonstration through applications:
    View-frustum culling, ray-tracing, collision detection
- How can hierarchies help?
  - Apply to example applications
- Building bounding volume hierarchies
- Building spatial partitionings
- What's the best choice?
- Can we do better?

What are they? How do they Compare?

Bounding Volume Hierarchies

- Hierarchical object representation
- Object subdivision
- Hierarchical clustering of objects
- Object levels of detail
- Classifies regions of space around objects

Examples:

- OBB-trees
- AABB-trees
- Sphere-trees
- k-DOPs

Spatial Partitioning

- Hierarchical spatial representation
- Spatial subdivision
- Hierarchical clustering of space
- Spatial levels of detail
- Classifies objects around regions of space

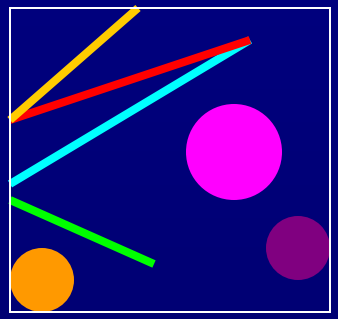
Examples:

- Uniform grids
- Quadtrees & Octrees
- BSP-trees
- kD-trees

Examples

Bounding Volume Hierarchies

- Tightly fits objects
- Redundant spatial representation



Spatial Partitioning

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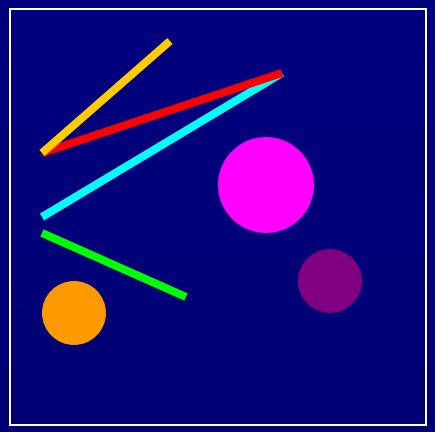
- Redundant object representation



Examples

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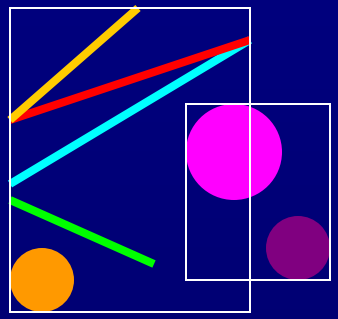

Volumes overlap multiple objects

Spatial Partitioning

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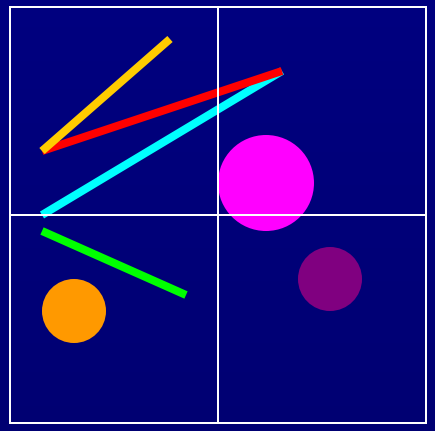

Objects overlap multiple volumes

Examples

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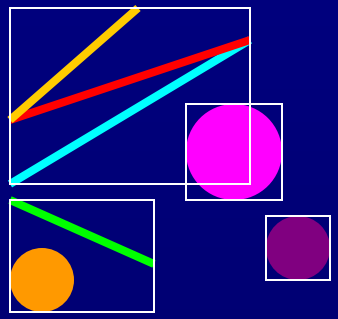

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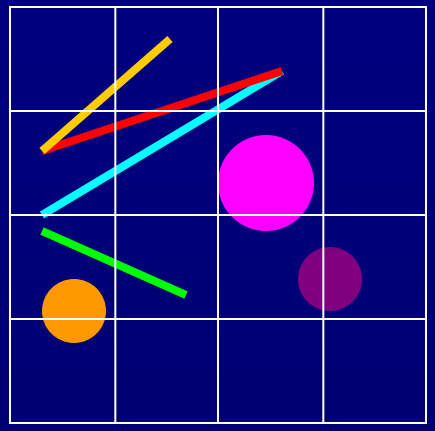

Objects overlap multiple volumes

Examples

Bounding Volume Hierarchies

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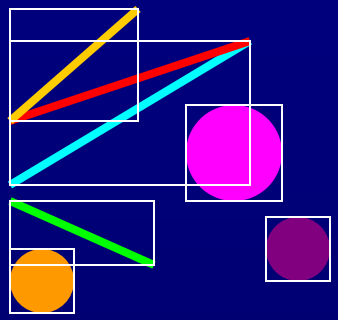

Volumes overlap multiple objects

Spatial Partitioning

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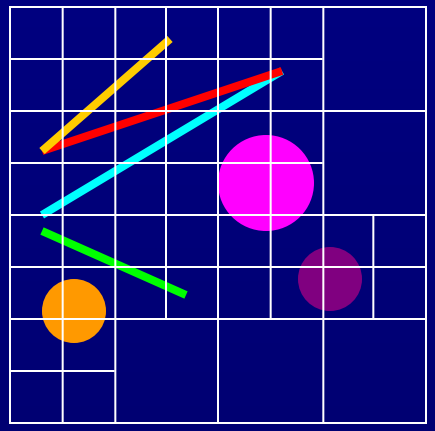
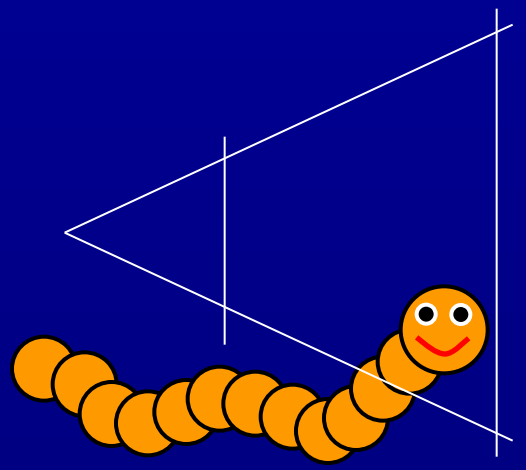


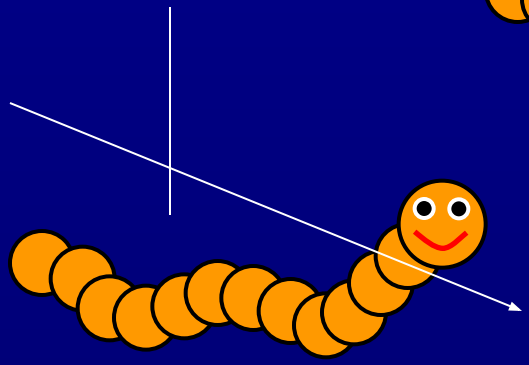
Objects overlap multiple volumes

Motivation: Example Applications

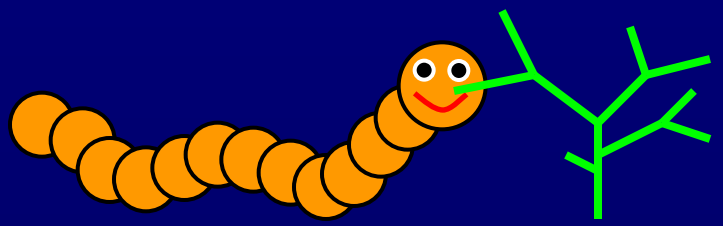
View-frustum culling
O(n)



Ray-tracing
O(n) per ray



Collision detection
$O(n^2)$

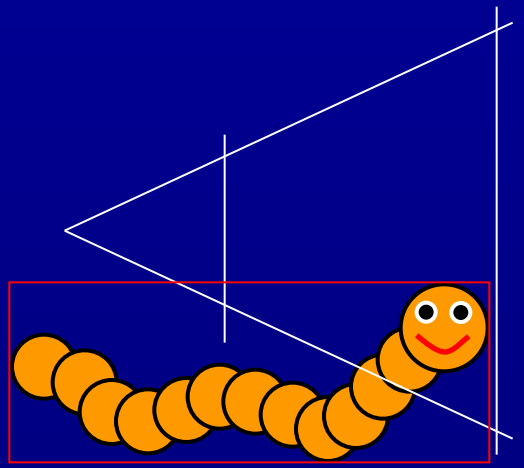


How do we speed it up?

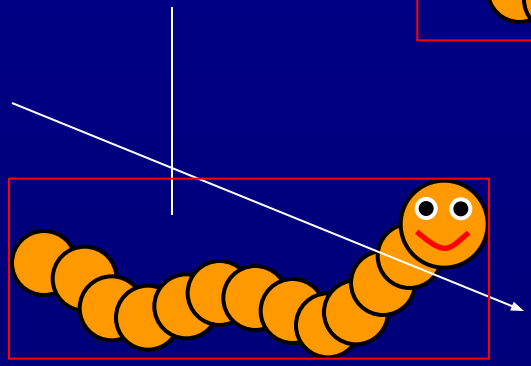
- More efficient intersection calculations
- Avoid intersection calculations
  - Make a single intersection calculation to decide for an entire cluster of objects or space
  - Cluster hierarchically

How can bounding volume hierarchies help?

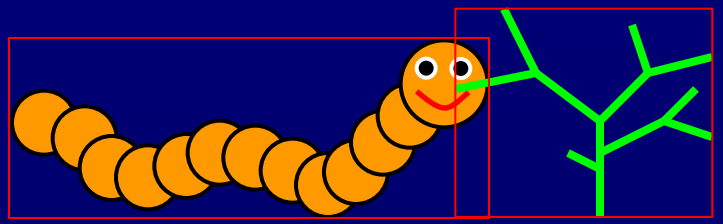
View-frustum culling



Ray-tracing



Collision detection



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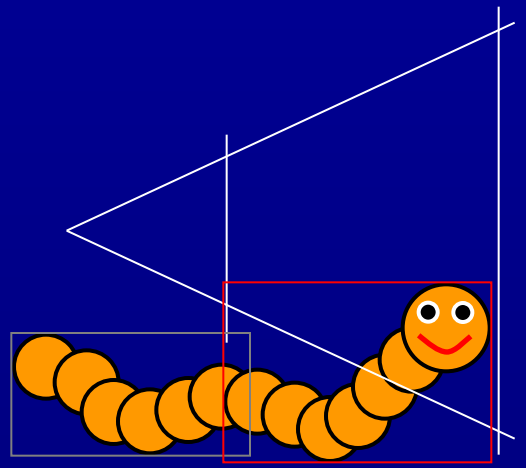
View-frustum culling



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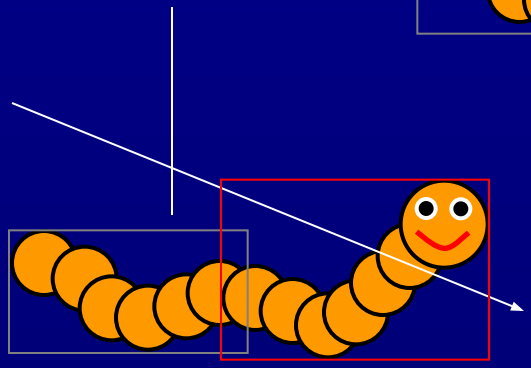

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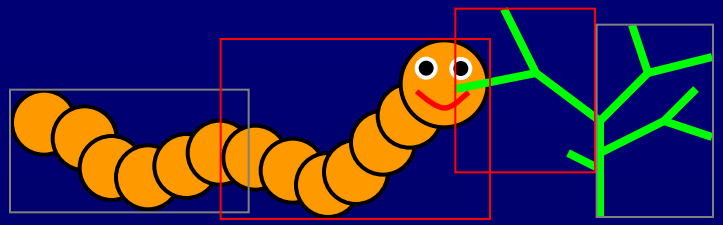

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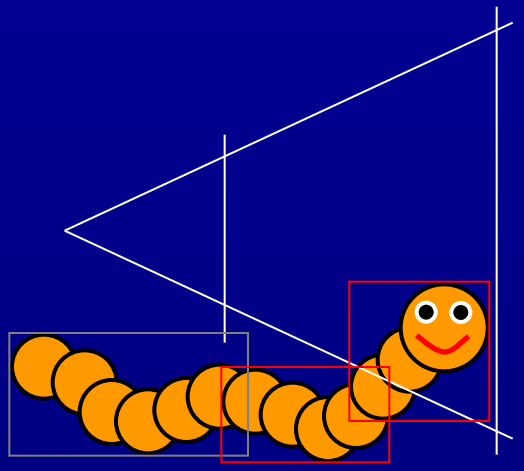
View-frustum culling



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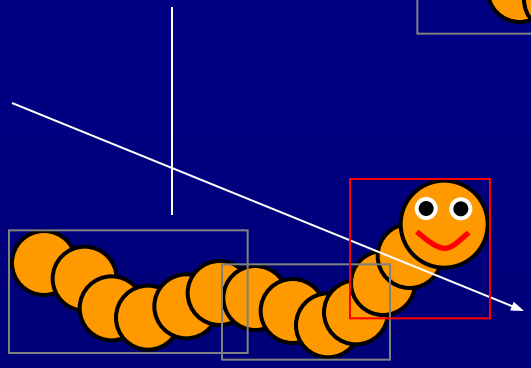

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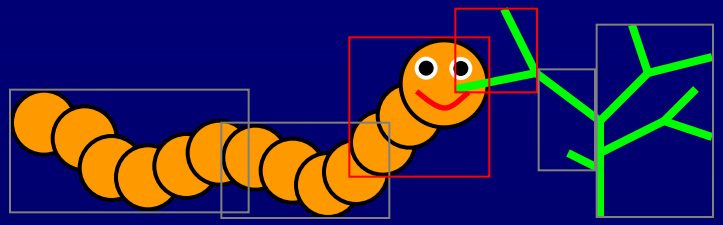
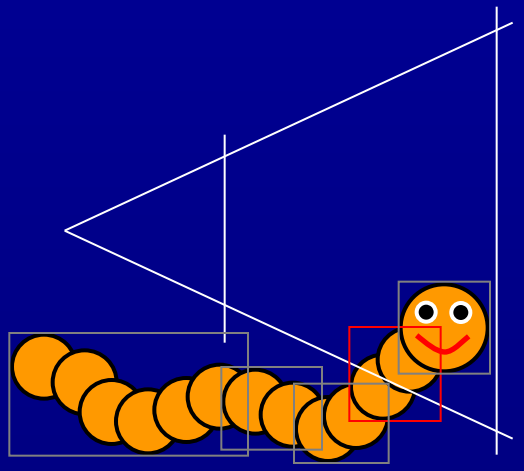


How can bounding volume hierarchies help?

View-frustum culling



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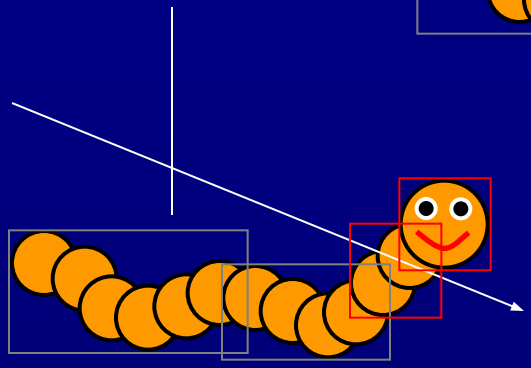

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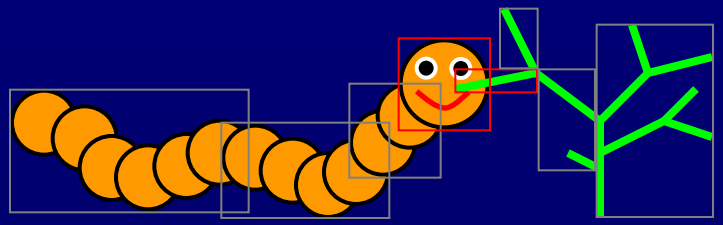
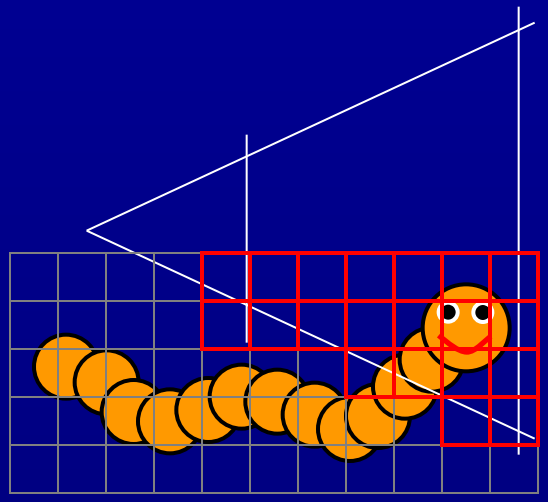


How can bounding volume hierarchies help?

Logarithmic search for intersecting primitives!

How can spatial partitioning help?

View-frustum culling



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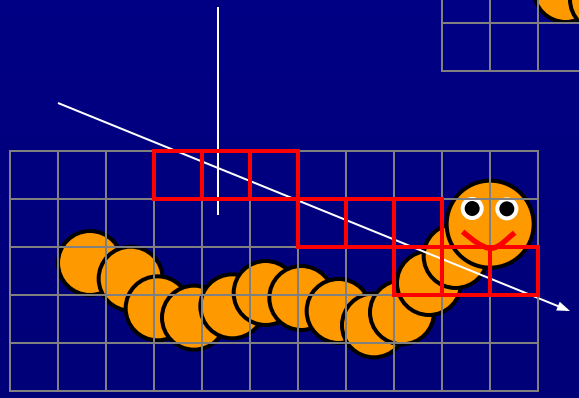
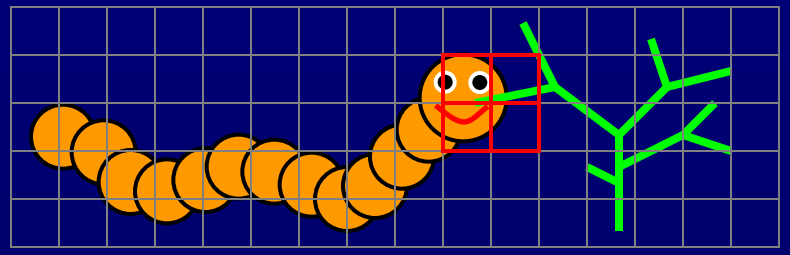


Uniform spatial partitioning

Collision detection



How can spatial partitioning help?

Performance varies for uniform partitioning, but hierarchical approaches also give logarithmic search for intersecting primitives!

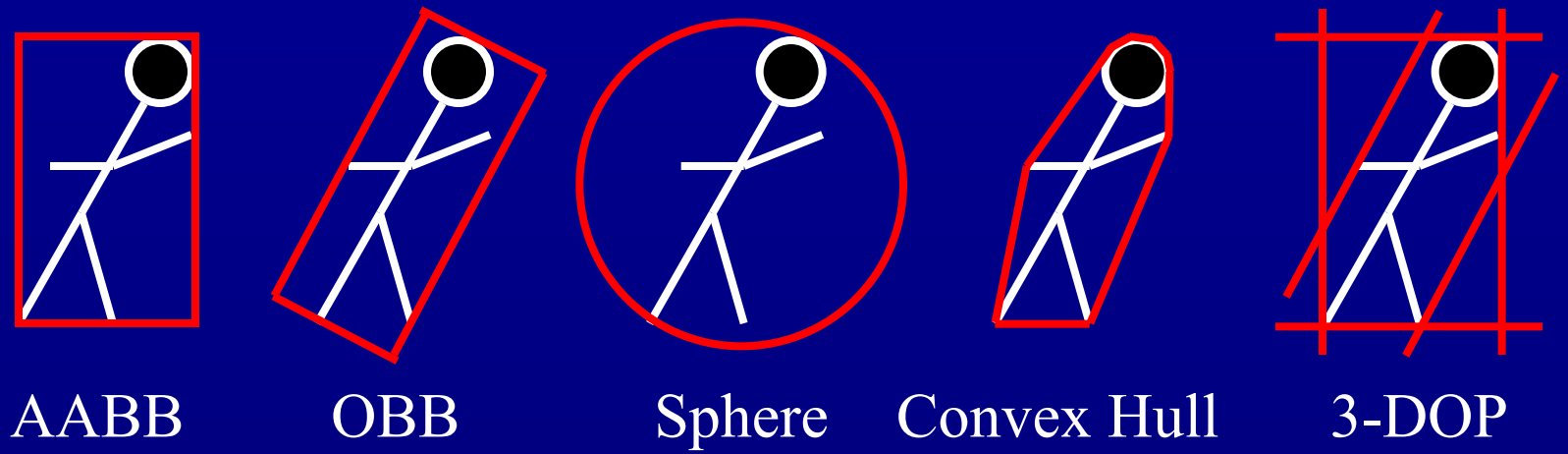
What are the potential problems?

- What are the hidden costs?
  - When nothing intersects?
  - When nearly everything intersects?
  - What are the worst cases?
- Is it worth it?
- What applications get the most benefit?
- What about just using my modeling hierarchy?
  - Too shallow (not fine enough level of detail
  - Designed for object manipulation rather than minimizing intersections
  - Insensitive to actual positions of objects

Building Bounding Volume Hierarchies

- Choose a bounding volume type
  - Axis-aligned bounding box (AABB)
  - Oriented bounding box (OBB)
  - Sphere
  - Convex Hull
  - k-DOPs
- Choose a clustering strategy
  - Top-down:
    how do we partition objects among children?
  - Bottom-up:
    how do we find leaf clusters and merge into parents?

Bounding Volume Type



- Intersection cost vs. tightness of fit vs. storage overhead vs. implementation complexity
- How do we find the best fit for a particular bounding volume?
  - AABBs and convex hulls are clear.
    What about spheres, k-DOPs, and OBBs?
- How do we compare the quality of fit between different BVs?
  - Min volume, min surface area, etc.

Hierarchical Clustering Strategy

Top-down: how do we partition objects among children?

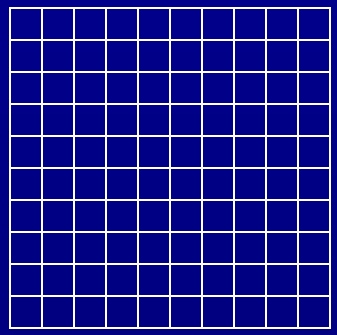
- Choosing splitting axis
  - longest dimension, largest spread of objects, etc.
- Choosing split point
  - mean, median, largest gap, etc.

Bottom-up: how do we find leaf clusters and merge into parents?

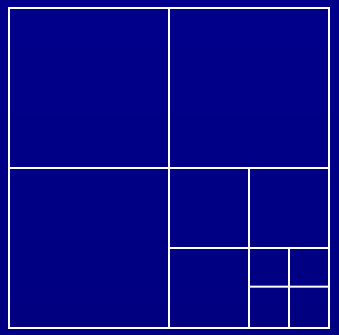
- Leaf object clusters
  - single primitive, specific minimum size cluster, etc.
- Merging children into parent
  - Nearest neighbors: uniform subdivision, Voronoi diagram

Building Spatial Partitionings

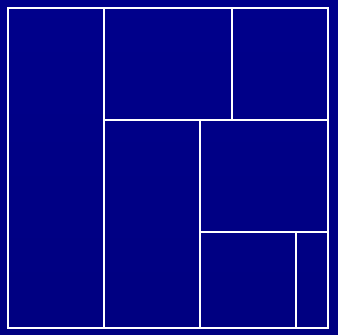
Decide how to recursively subdivide space (top-down)



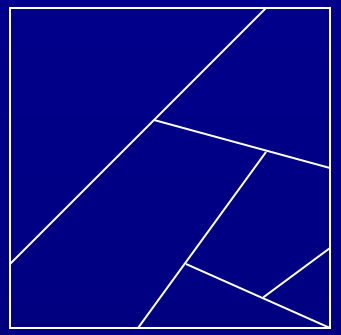
Uniform subdivision



Quadtree

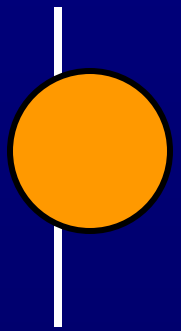


kD-tree



BSP-tree

Decide how to classify objects into regions of space with respect to partitioning plane



Store in both regions,
Store with partition, or
Split geometry

What's the best choice?

- Depends on the application
  - trial and error?
  - "Gut" feeling?
  - Careful analysis based on a cost function?
- Factors:
  - Complexity of implementation
  - Storage overhead
  - Computational overhead
  - Type of geometry: static or dynamic

Can we do better?

- Combining bounding volume hierarchies and spatial partitioning
  - Examples:
    - Occlusion culling: octrees of BSP-trees
    - Radiosity: 3D BSP-trees of 2D BSP-trees
- Hybrid bounding volume hierarchies
  - adaptive nodes
  - adaptive trees
  - performance driven metrics

Conclusion

- These hierarchical data structures are fundamental in a wide variety of graphics problems
  - most common way of obtaining high performance
- Important to be very familiar with the possible variations
  - these structures appear everywhere!
- Despite tremendous amount of previous publications, still lots of room for further research
  - warning: difficult problems ahead!

References

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