Implicit Surfaces, Collision Detection, & Volumetric Data Structures

Traveler's Insurance, *Snowball*

Weta Digital, 2007
Output-Sensitive Collision Processing for Reduced-Coordinate Deformable Models

James, Pai, and Twigg, SIGGRAPH 2004
Untitled, 1550 chairs stacked, Doris Salcedo, 2003

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Last Time?

- Spline Surfaces
  - complex topology is challenging, requires trimming curves
- Subdivision Zoo
  - Doo-Sabin
  - Loop
  - Catmull-Clark
- Subdivision w/ Creases

Today

- Readings for Today
- Motivation: Collision Detection is Expensive
- Conservative Bounding Region
- Spatial Acceleration Data Structures
- Papers for Friday
- Questions about Homework 1
- Worksheet on Subdivision Surfaces
Reading for Today

- Oriented Bounding Box (OBB): generalization of the (axis-aligned) BVH


Reading for Today


Searching Configuration Space

- Application: Robot Motion Planning

“The good-looking textured light-sourced bouncy fun smart and stretchy page” Hugo Elias, http://freespace.virgin.net/hugo.elias/models/m_ik.htm
Searching Configuration Space

• What are the unknowns? What are the “degrees of freedom” of our robot arm?
• More degrees of freedom = higher dimensional configuration space

“The good-looking textured light-sourced bouncy fun smart and stretchy page” Hugo Elias, http://freespace.virgin.net/hugo.elias/models/m_ik2.htm

Searching Configuration Space

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Collision Detection for Solids

- How to detect collision between 2 polyhedra?
- Need an inside/outside test
- Test if a vertex is inside the other polyhedron
- But treat also edge-edge intersection
Cost of Detection?

- Test each edge with each face?
  \[ O(N^2) \]
- How would you detect collision between two bunnies?
  - \( O(N^2) \) is too expensive!
  - Let's use a spatial data structure

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Conservative Bounding Region

- First check for an intersection with a conservative bounding region
- Early reject

Another Expensive Application: Ray Tracing
Intersect object & ray… more later this semester!!

Conservative Bounding Regions

- tight → avoid false positives
- fast to intersect
- easy/fast/perfect construction (less important)

arbitrary convex region (bounding half-spaces)
oriented bounding box
axis-aligned bounding box
bounding sphere
Overlap Test

- Overlap between two axis-aligned boxes?
  - Check if the intervals along the 3 dimensions overlap
- Overlap test between two spheres?
  - $D(\text{center}_1, \text{center}_2) < r_1 + r_2$

General Collision Detection

- Put a hierarchy around your objects
- Use the fast overlap test recursively
- Handle exact case at the leaves (when necessary)
- More difficult for self-collision (e.g. cloth)
  - Because there is more overlap
Today

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- **Spatial Acceleration Data Structures**
  - Fixed/Uniform/Regular Grid
  - Nested Grid
  - Octree
  - Binary Space Partition
  - K-d tree
  - Bounding Volume Hierarchy
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**Fixed/Uniform/Regular Grid**

- Separate geometry into regions
- Reduces pairwise comparisons
- Primitives that overlap multiple cells? Insert into multiple cells (use pointers)
For Each Cell Along a Ray

- Does the cell contain an intersection?
- Yes: return closest intersection
- No: continue to march along ray

Fixed/Uniform Grid Discussion

- Advantages?
  - easy to construct
  - easy to traverse

- Disadvantages?
  - may be only sparsely filled
  - geometry may still be clumped
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Adaptive Grids

• Subdivide until each cell contains no more than $n$ elements, or maximum depth $d$ is reached
Adaptive Grids

- Subdivide until each cell contains no more than $n$ elements, or maximum depth $d$ is reached.

Variations of Adaptive Grids

- **When to split?** When a cell contains “lots” of geometry, but has not yet reached the max tree depth.
- **Where to split?**
  - Quadtree/Octree: split *every* dimension in half, always axis aligned.
  - kd-tree: choose *one* dimension (often the largest dimension) and split it axis aligned (but not necessarily at the midpoint).
  - Binary Space Partition (BSP): choose an *arbitrary* cut plane.
- **Which one is best?** *It depends…* Often they are all equally good!
Primitives in an Adaptive Grid

- Can live at intermediate levels, or be pushed to lowest level of grid

Octree/(Quadtree)

Adaptive Grid Discussion

- Advantages?
  - grid complexity matches geometric density

- Disadvantages?
  - more expensive to traverse (binary tree, lots of pointers)
Early k-d tree paper


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Bounding Volume Hierarchy

- Find bounding box of objects
- Split objects into two groups
- Recurse
Where to split objects?

• At midpoint  OR
• Sort, and put half of the objects on each side  OR
• Use modeling hierarchy

Data Structures Homework 8
Intersection with BVH

- Check sub-volume with closer intersection first

Bounding Volume Hierarchy Discussion

- Advantages
  - easy to construct
  - easy to traverse
  - binary

- Disadvantages
  - may be difficult to choose a good split for a node
  - poor split may result in minimal spatial pruning
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Reading for Next Time:

Everyone should read this
(simple cloth model used in HW2)


Simple mass-spring system

Improved solution
Cloth in Practice (w/ Animation)

OPTIONAL READING FOR NEXT TIME

• Baraff, Witkin & Kass
  Untangling Cloth
  SIGGRAPH 2003

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Homework 1:

• Questions/Comments?

Pop Worksheet!

Sketch the polygonal mesh after performing 2 iterations of subdivision (Loop/Butterfly, Catmull-Clark, and Doo-Sabin). If necessary, pre-process the mesh to allow use of the specified method.