Implicit Surfaces, Collision Detection, & Volumetric Data Structures

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

Today
- Implicit Surfaces, Voxels, & Marching Cubes
- Collision Detection
- Conservative Bounding Region
- Spatial Acceleration Data Structures
  - Fixed Grid
  - Nested Grid
  - Octree
  - Binary Space Partition
  - K-d tree
  - Bounding Volume Hierarchy
- Misc Vocabulary & Advanced Papers

Implicit Surfaces
- For a sphere:
  \[ H(x,y,z) = x^2 + y^2 + z^2 - r^2 \]
  - If \( H(x,y,z) = 0 \), on surface
  - If \( H(x,y,z) > 0 \), outside surface
  - If \( H(x,y,z) < 0 \), inside surface

Level Sets
- Efficient method for computing signed distance field

Homework 1:
- Questions/Comments?
Marching Cubes

- Polygonization: extract triangle mesh from signed distance field


“Marching Tetrahedra”

- Polygonization: extract triangle mesh from signed distance field

“Marching Tetrahedra”

- When the Blobs Go Marching Two by Two”, Jeff Lander, Gamasutra

Similarly, we can create volumetric models:

“Interval volume tetrahedrization” Visualization ’97
Nielson & Sung

Questions?

Today

- Implicit Surfaces, Voxels, & Marching Cubes
- Collision Detection
- Conservative Bounding Region
- Spatial Acceleration Data Structures
  - Fixed Grid
  - Nested Grid
  - Octree
  - Binary Space Partition
  - K-d tree
  - Bounding Volume Hierarchy
- Misc Vocabulary & Advanced Papers

Collisions

- Detection
- Response
- Overshooting problem (when we enter the solid)
Detecting Collisions

• Easy with implicit equations of surfaces
  • \( H(x,y,z)=0 \) at surface
  • \( H(x,y,z)<0 \) inside surface
  • So just compute \( H \) and you know that you’re inside if it’s negative

• More complex with other surface definitions

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!
  – Use spatial hierarchy

Questions?

Today

• Implicit Surfaces, Voxels, & Marching Cubes
• Collision Detection
  • Conservative Bounding Region
• Spatial Acceleration Data Structures
  – Fixed Grid
  – Nested Grid
  – Octree
  – Binary Space Partition
  – K-d tree
  – Bounding Volume Hierarchy
• Misc Vocabulary & Advanced Papers

Conservative Bounding Region

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

Application: Accelerate ray tracing
Intersect object & ray… more later this semester!!
Conservative Bounding Regions

• tight → avoid false positives
• fast to intersect

Overlap test

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

Questions?

Today

• Implicit Surfaces, Voxels, & Marching Cubes
• Collision Detection
• Conservative Bounding Region
• Spatial Acceleration Data Structures
  – Fixed Grid
  – Nested Grid
  – Octree
  – Binary Space Partition
  – K-d tree
  – Bounding Volume Hierarchy
• Misc Vocabulary & Advanced Papers

Collision Pruning via Uniform Grid

• Primitives that overlap multiple cells?

Regular Grid

• 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

Regular Grid Discussion

• Advantages?
  – easy to construct
  – easy to traverse

• Disadvantages?
  – may be only sparsely filled
  – geometry may still be clumped

Today

• Implicit Surfaces, Voxels, & Marching Cubes
• Collision Detection
• Conservative Bounding Region
• Spatial Acceleration Data Structures
  – Fixed Grid
  – Nested Grid
  – Octree
  – Binary Space Partition
  – K-d tree
  – Bounding Volume Hierarchy
• Misc Vocabulary & Advanced Papers

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!

Reading for Today:

• "Multidimensional Binary Search Trees Used for Associative Searching", Bentley, Communications of the ACM, 1975
Primitives in an Adaptive Grid

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

Adaptive Grid Discussion

- Advantages?
  - grid complexity matches geometric density
- Disadvantages?
  - more expensive to traverse (binary tree, lots of pointers)

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

- Implicit Surfaces, Voxels, & Marching Cubes
- Collision Detection
- Conservative Bounding Region
- Spatial Acceleration Data Structures
  - Fixed Grid
  - Nested Grid
  - Octree
  - Binary Space Partition
  - K-d tree
  - Bounding Volume Hierarchy
- Misc Vocabulary & Advanced Papers

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

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

Reading for Today:

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


Reading for Today:

- "Octree Textures", Benson & Davis, SIGGRAPH 2002
- "Painting and Rendering Textures on Unparameterized Models", DeBry, Gibbs, Deleon, and Robins, SIGGRAPH 2002
Questions?

Today
- Implicit Surfaces, Voxels, & Marching Cubes
- Collision Detection
- Conservative Bounding Region
- Spatial Acceleration Data Structures
  - Fixed Grid
  - Nested Grid
  - Octree
  - Binary Space Partition
  - K-d tree
  - Bounding Volume Hierarchy
- Misc Vocabulary & Advanced Papers

Voronoi Diagram/Cells/Regions
- How to re-district the Netherlands into provinces so that everyone reports to the closest capital
- Cell edges are the perpendicular bisectors of nearby points
- 2D or 3D
- Supports efficient Nearest Neighbor queries

“Optimally” site the next Starbucks

Convex vs. Non-Convex

Reduced Deformation
Doug L. James & Dinesh K. Pai
BD-Tree: Output-Sensitive Collision Detection for Reduced Deformable Models
SIGGRAPH 2004

- Collisions are expensive
- Deformation is expensive
- This is a lot of geometry!
- Simplify the simulation model
Cloth Collision

- A cloth has many points of contact
- Stays in contact
- Requires
  - Efficient collision detection
  - Efficient numerical treatment (stability)

Reading for Friday:


Optional Reading for Friday:

- Baraff, Witkin & Kass
  *Untangling Cloth*
  SIGGRAPH 2003

Post a comment/question on the LMS discussion by 10am