Implicit Surfaces, Collision Detection, & Volumetric Data Structures

Homework 1:

- Questions/Comments?

Loop Subdivision

Subdivision Rules. The masks for the Loop scheme are shown in Figure 4.3. For boundaries and edges tagged as crease edges, special rules are used. These rules produce a cubic spline curve along the boundary/crease. The curve only depends on control points on the boundary/crease.

Figure 4.3: Loop subdivision. In the picture above, $\beta$ can be chosen to be either $\frac{1}{2} (\frac{5}{8} - (\frac{1}{2} + \cos \frac{2}{3} \phi)^2)$ (original choice of Loop [16]), or, for $n > 3$, $\beta = \frac{1}{3}$ as proposed by Warren [34]. For $n = 3$, $\beta = 3/16$ can be used.

SIGGRAPH 2000 course notes
Subdivision for Modeling and Animation (page 70)
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
- Papers for Friday

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

*Level Set Methods and Fast Marching Methods, Sethian, 1999*
Marching Cubes

- Polygonization: extract triangle mesh from signed distance field


"Marching Tetrahedra"

Similarly, we can create volumetric models:

"Interval volume tetrahedrization" Visualization '97
Nielsen & Sung

“Marching Tetrahedra”

Jules Bloomenthal
“An implicit surface polygonizer”
Graphics Gems IV

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

Questions?
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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!
  - 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

Application: Accelerate 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)

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

Questions?
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  - Fixed/Uniform/Regular Grid
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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

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
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
Bounding Volume Hierarchy

- Find bounding box of objects
- Split objects into two groups
- Recurse

Intersection with BVH

- Check sub-volume with closer intersection first
**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?**
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Reading for Friday:


Papers for Friday:


Cloth Collision

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

OPTIONAL READING FOR FRIDAY

Robert Bridson, Ronald Fedkiw & John Anderson
Robust Treatment of Collisions, Contact and Friction for Cloth Animation
SIGGRAPH 2002

Cloth in Practice (w/ Animation)

- Baraff, Witkin & Kass
  Untangling Cloth
  SIGGRAPH 2003

OPTIONAL READING FOR FRIDAY

- Baraff, Witkin & Kass
  Untangling Cloth
  SIGGRAPH 2003

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

• Collisions are expensive
• Deformation is expensive
• This is a lot of geometry!
• Simplify the simulation model

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

Pop Worksheet!

• For each adaptive grid method (quad tree, k-d tree, binary space partition) sketch the resulting grid if we split cells with > 2 elements and allow a maximum tree height of 5 (max of 4 splits from root).

Teams of 2. Hand in to Jeramey after we discuss.