Fracture & Tetrahedral Models

Last Time?
- Rigid Body
- Collision Response
- Finite Element Method
  - Stress/Strain
- Deformation
  - Level of Detail

Today
- “Interactive Sculpting” Fracture & Deformation
- 3D Force Feedback Haptics Interface
- Tetrahedral Modeling & Simplification
- Useful & Related Term Definitions
- Readings for Today
  - Graphical Modeling and Animation of Brittle Fracture
  - Nonconvex Rigid Bodies with Stacking

Multiple Materials
Mueller, Dorsey, McMillan, Jagnow, & Culler
Stable Real-Time Deformations
Symposium on Computer Animation 2002

Haptic Device
- “3D mouse” + force feedback
- 6 DOF (position & orientation)
- requires 1000 Hz refresh
  (visual only requires ~30 Hz)

Questions?
3D Mesh Simplification

1.050K tetras (133K faces)  
10K tetras (3K faces)

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3D Mesh Operations

- Tetrahedral Swaps
  - Choose the configuration with the best local element shape
- Edge Collapse
- Vertex Smoothing
- Vertex Addition

Prioritizing Edge Collapses

- Preserve topology
  - Thin layers should not pinch together
- Collapse weight
  - Edge length + boundary error
- No negative volumes
- Local element quality does not significantly worsen

3D Mesh Operations

- Tetrahedral Swaps
- Edge Collapse
  - Delete a vertex & the elements around the edge
- Vertex Smoothing
- Vertex Addition

3D Mesh Operations

- Tetrahedral Swaps
- Edge Collapse
  - Move a vertex to the centroid of its neighbors
  - Convex or concave, but avoid negative-volume elements
- Vertex Addition
3D Mesh Operations

- Tetrahedral Swaps
- Edge Collapse
- Vertex Smoothing
- Vertex Addition
  - At the center of a tetra, face, or edge
  - Useful when mesh is simplified, but needs further element shape improvement

Visualization of Tetrahedra Quality

Octree or Adaptive Distance Field (ADF)

461K tetras
(108K faces)

Visualization of Tetrahedra Quality

After Simplification & Mesh Improvement

10K tetras
(3K faces)

Visualization of Simplification Algorithm

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Some Definitions

• Isotropic: is a property which does not depend on the direction.
• Anisotropic: is a property which is directionally dependent.

Some Definitions

• Elastic Deformation: Once the forces are no longer applied, the object returns to its original shape.
• Plastic Deformation: An object in the plastic deformation range will first have undergone elastic deformation, which is reversible, so the object will return part way to its original shape.


Some Definitions

• Degenerate/Ill-conditioned Element: a.k.a. how “equilateral” are the elements?
  – Ratio of volume\(^2\) to surface area\(^3\)
  – Smallest solid angle
  – Ratio of volume to volume of smallest circumscribed sphere

Some Definitions

• Tension: The direction of the force of tension is parallel to the string, away from the object exerting the stretching force.
• Compression: resulting in reduction of volume

http://www.aero.polimi.it/~merlini/SolidMechanics-FiniteElasticity/CompressionBlock.jpg

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
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Reading for Today:

• Fracture threshold
• Remeshing
  – need connectivity info!
• Material properties
• Parameter tuning

How to read a research paper?

(especially an advanced paper in a new area)
• Multiple readings are often necessary
• Don’t necessarily read from front to back
• Lookup important terms
• Target application & claimed contributions
• Experimental procedure
• How well results & examples support the claims
• Scalability of the technique (order notation)
• Limitations of technique, places for future research
• Possibilities for hybrid systems with other work
Components of a well-written research paper?

- Motivation/context/related work
- Contributions of this work
- Clear description of algorithm
  - Sufficiently-detailed to allow work to be reproduced
  - Work is theoretically sound
    (hacks/arbitrary constants discouraged)
- Results
  - well chosen examples
  - clear tables/illustrations/visualizations
- Conclusions
  - limitations of the method are clearly stated

Fracture Opening Modes

Figure 6: Three loading modes that can be experienced by a crack. Mode I: Opening, Mode II: In-Plane Shear, and Mode III: Out-of-Plane Shear. Adapted from Anderson [1].

Local Mesh Refinement

Images from O’Brien et al. 1999

Managing Fracture Adjacency

Fracture Propagation Difficulties

- Need to track direction of fracture propagation?

- Need to track crack tip?

Controlling Speed of Propagation

(no remeshing)
“Sampling Plausible Solutions to Multi-body Constraint Problems”
Chenney & Forsyth, SIGGRAPH 2000

Reading for Tuesday: (pick one)

• “Real-Time Hand-Tracking with a Color Glove”
  SIGGRAPH 2009, Wang & Popović

“Energy-based Self-Collision Culling for Arbitrary Deformations”
SIGGRAPH 2012, Zheng & James