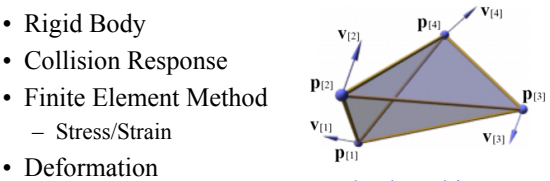
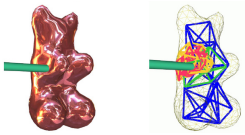
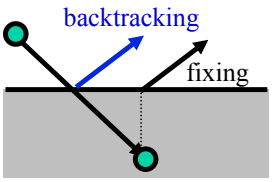
Fracture & Tetrahedral Models

Last Time?

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





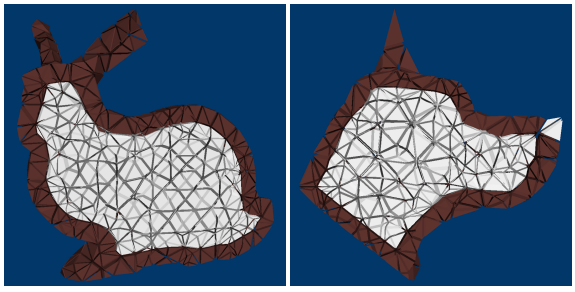


Today

- "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

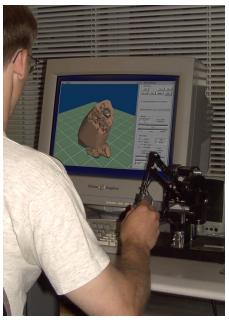
Multiple Materials

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



Haptic Device

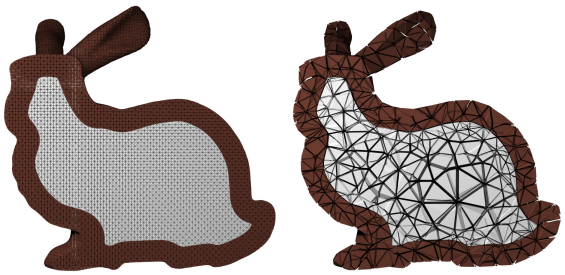
- "3D mouse" + force feedback
- 6 DOF (position & orientation)
- *requires 1000 Hz refresh*
  (*visual only requires ~30 Hz*)



Sensable's Phantom
http://www.sensable.com/

Questions?

3D Mesh Simplification



1,050K tetras
(133K faces)

10K tetras
(3K faces)

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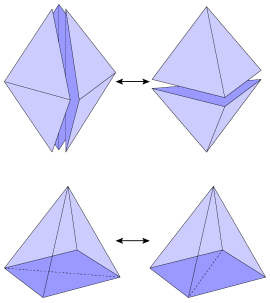
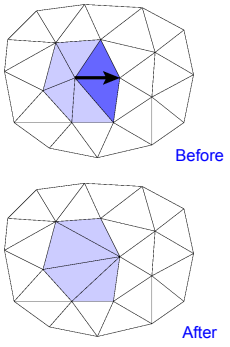
3D Mesh Operations

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



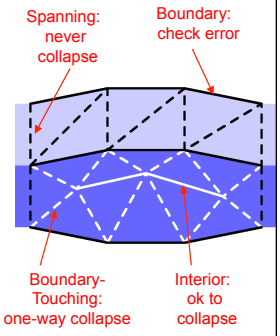
3D Mesh Operations

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



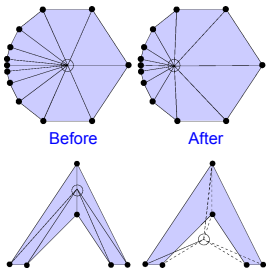
Prioritizing Edge Collapses

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



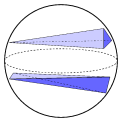
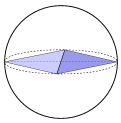
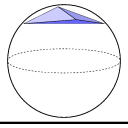
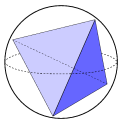
3D Mesh Operations

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

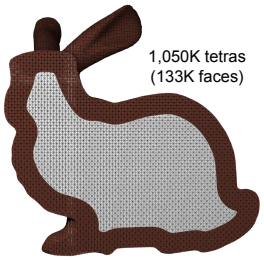


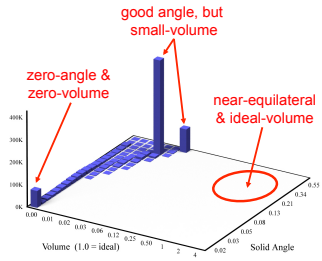
3D Mesh Operations

- 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

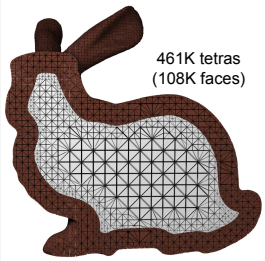





Visualization of Tetrahedra Quality

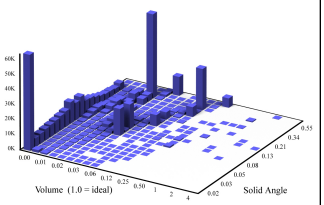




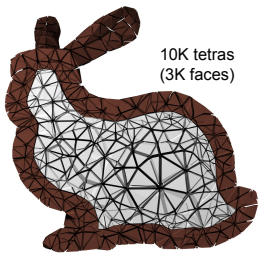
Visualization of Tetrahedra Quality



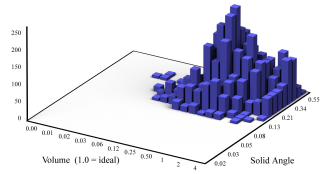
Octree or Adaptive
Distance Field (ADF)



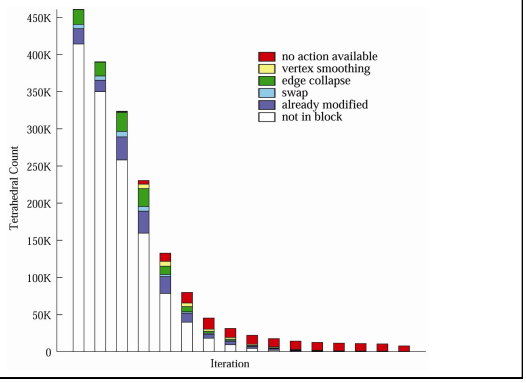
Visualization of Tetrahedra Quality



After Simplification
& Mesh Improvement



Visualization of Simplification Algorithm



Questions?

Today

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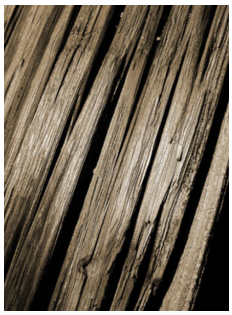
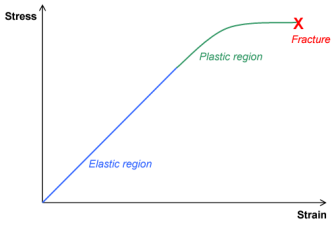
Some Definitions

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



Some Definitions

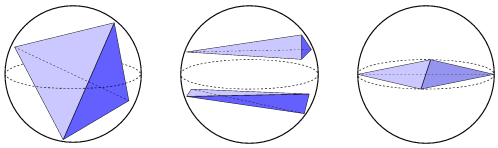
- *Elastic Deformation*: Once the forces are no longer applied, the object returns to its original shape.
- *Plastic Deformation*: An object in the plastic deformation range will first have undergone elastic deformation, which is reversible, so the object will return part way to its original shape.



http://en.wikipedia.org/wiki/Image:Stress-strain1.png

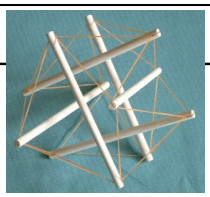
Some Definitions

- *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



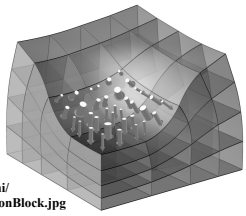
Some Definitions

- *Tension*: The direction of the force of tension is parallel to the string, away from the object exerting the stretching force.



http://fig.cox.miami.edu/~cmallery/255/255chem/tensegrity.sticks.jpg

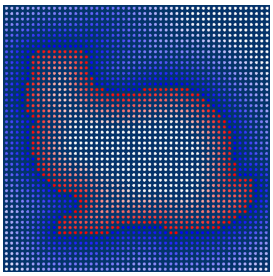
- *Compression*: resulting in reduction of volume



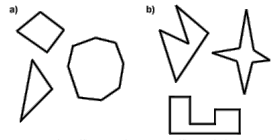
http://www.aero.polimi.it/~merlini/SolidMechanics-FiniteElasticity/CompressionBlock.jpg

Implicit Surfaces

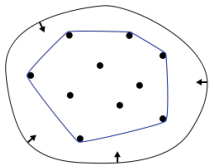
- For a sphere:
  $H(x,y,z) = x^2 + y^2 + z^2 - r^2$
- If $H(x,y,z) = 0$, on surface
- If $H(x,y,z) > 0$, outside surface
- If $H(x,y,z) < 0$, inside surface



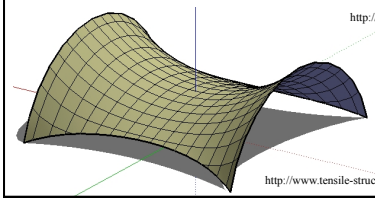
Convex vs. Non-Convex



http://img.sparknotes.com/figures/B/b333d91dce2882b2db48b8ad670cd15a/convexconcave.gif



http://en.wikipedia.org/wiki/File:ConvexHull.svg



http://www.tensile-structures.de/Bilder/SaddleSurface.jpg

Questions?

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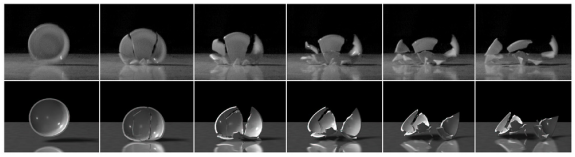
Reading for Today:

- James O'Brien & Jessica Hodgins *"Graphical Modeling and Animation of Brittle Fracture"* SIGGRAPH 1999.



- Fracture threshhold
- Remeshing
  - need connectivity info!
- Material properties
- Parameter tuning

- "intuition"-based vs physics-based
- Physics not fully accurate? Looks too brittle? Due to lack of plastic deformation?
- Qualitative comparison to video impresssive!
- Quantitative validation?
- Conservation of momentum
- Complexity of mesh, LOD? Adaptive meshing
- Debris is triangulated, and not small enough, button popping artifact
- Frature not dictated by original mesh
- Not real time ☹ Parallelize?
- Multiple materials in same model?
- 6 degrees of math/physics separation
- Dicretized vs continuous?
- LMS sucks

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

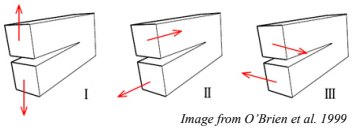
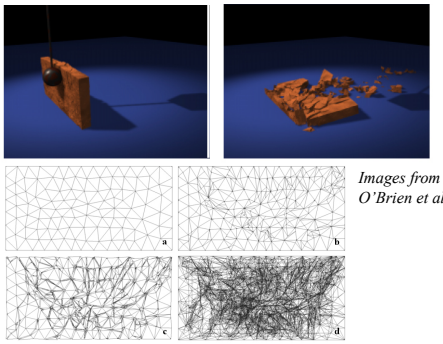


Image from O'Brien et al. 1999

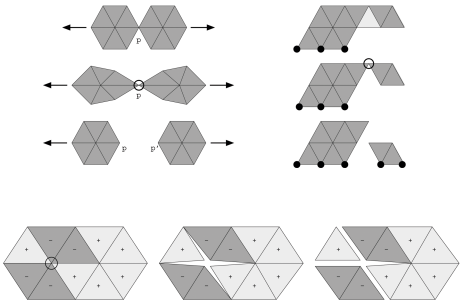
Figure 6: Three loading modes that can be experienced by a crack. Mode I: Opening, Mode II: In-Plane Shear, and Mode III: Out-of-Plane Shear. Adapted from Anderson [1].

Local Mesh Refinement



Images from O'Brien et al. 1999

Managing Fracture Adjacency



Fracture Propagation Difficulties

- Need to track direction of fracture propagation?

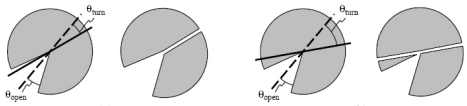
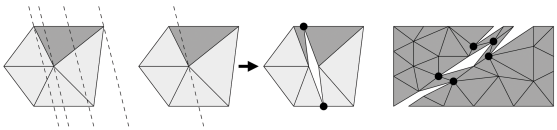
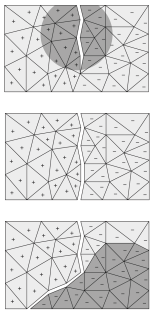


Image from O'Brien et al. 1999

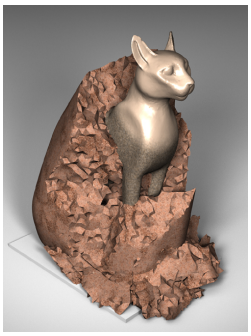
- Need to track crack tip?



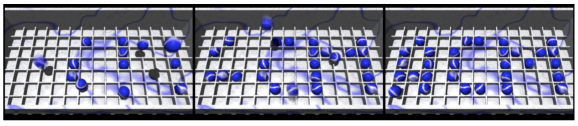
Controlling Speed of Propagation



(*no remeshing*)

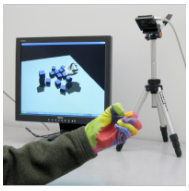


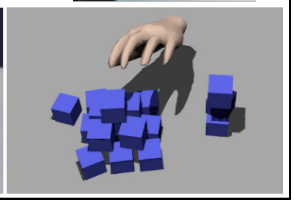
"Sampling Plausible Solutions to Multi-body Constraint Problems" Chenney & Forsyth, SIGGRAPH 2000



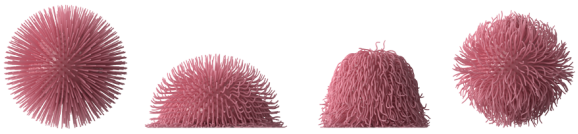
Reading for Tuesday: *(pick one)*

- "Real-Time Hand-Tracking with a Color Glove" SIGGRAPH 2009, Wang & Popović





Reading for Tuesday: *(pick one)*



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