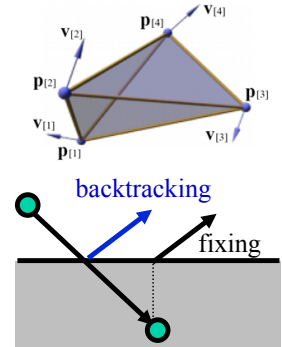
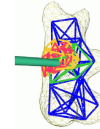
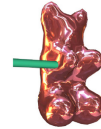


Fracture & Tetrahedral Models

Last Time?

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

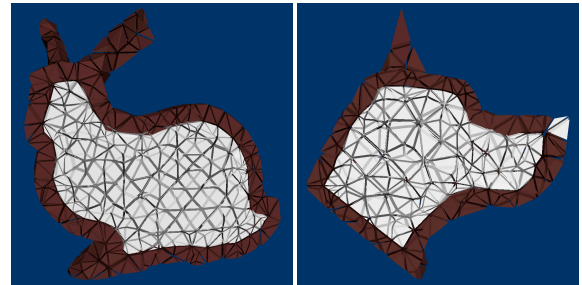


Today

- “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

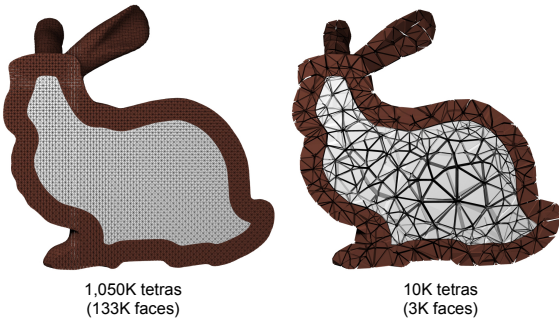
- “3D mouse” + force feedback
- 6 DOF (position & orientation)
- *requires 1000 Hz refresh*
(visual only requires ~30 Hz)



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

Questions?

3D Mesh Simplification

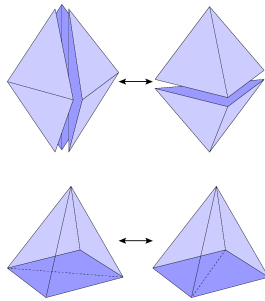


Today

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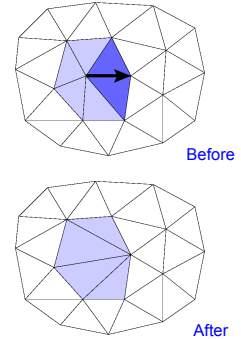
3D Mesh Operations

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



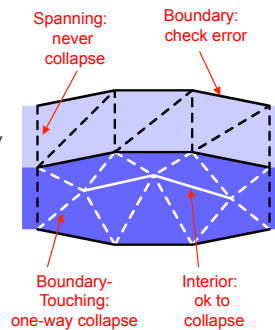
3D Mesh Operations

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



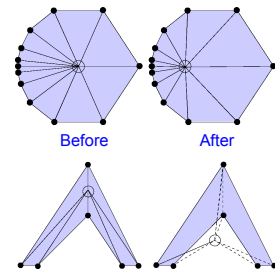
Prioritizing Edge Collapses

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



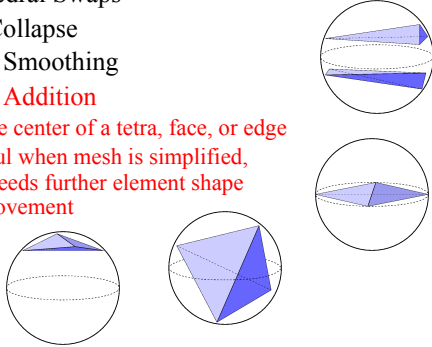
3D Mesh Operations

- 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

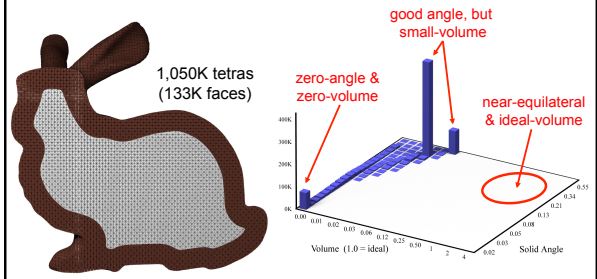


3D Mesh Operations

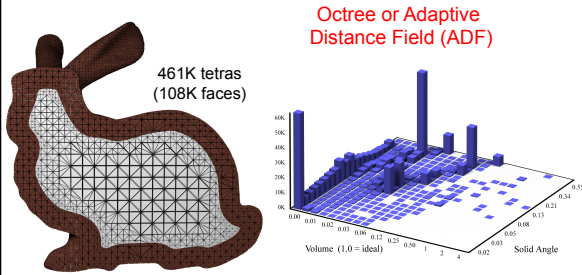
- Tetrahedral Swaps
- Edge Collapse
- Vertex Smoothing
- **Vertex Addition**
 - At the center of a tetra, face, or edge
 - Useful when mesh is simplified, but needs further element shape improvement



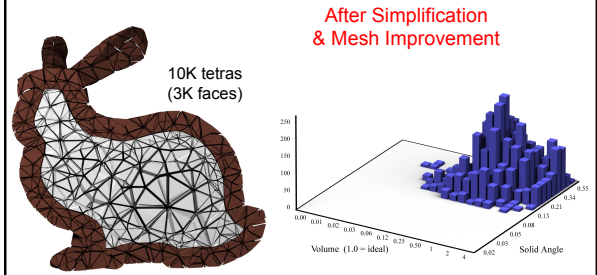
Visualization of Tetrahedra Quality



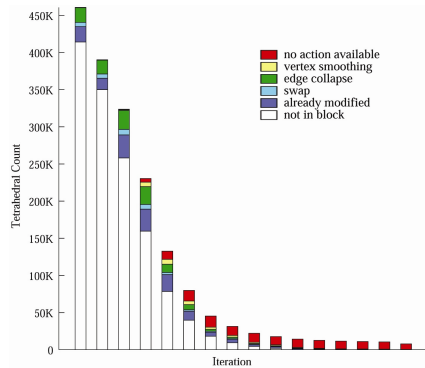
Visualization of Tetrahedra Quality



Visualization of Tetrahedra Quality



Visualization of Simplification Algorithm



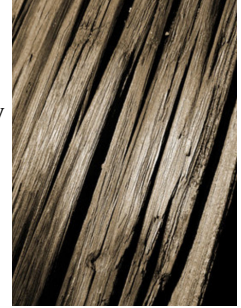
Questions?

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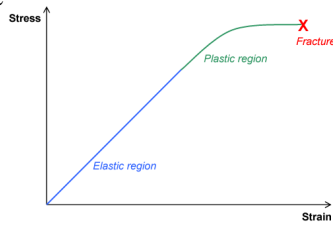
Some Definitions

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



Some Definitions

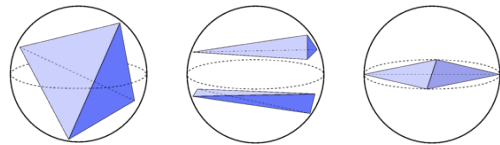
- *Elastic Deformation*: Once the forces are no longer applied, the object returns to its original shape.
- *Plastic Deformation*: An object in the plastic deformation range will first have undergone elastic deformation, which is reversible, so the object will return part way to its original shape.



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

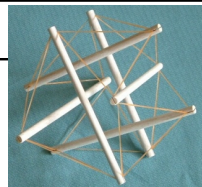
Some Definitions

- *Degenerate/ill-conditioned Element*: a.k.a. how “equilateral” are the elements?
 - Ratio of volume² to surface area³
 - Smallest *solid* angle
 - Ratio of volume to volume of smallest circumscribed sphere



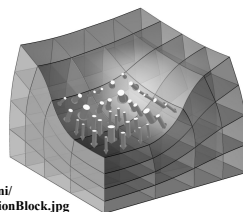
Some Definitions

- *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/258/255chem/tensegrity.sticks.jpg>

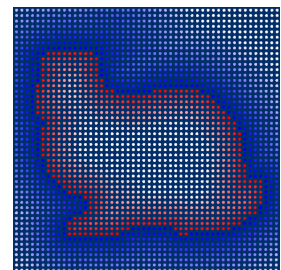
- *Compression*: resulting in reduction of volume



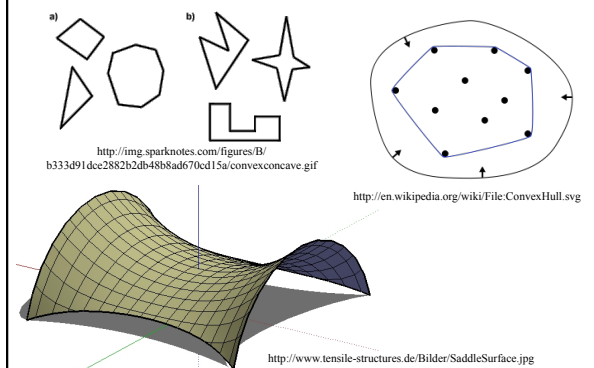
<http://www.aero.polimi.it/~merlini/SolidMechanics-FiniteElasticity/CompressionBlock.jpg>

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



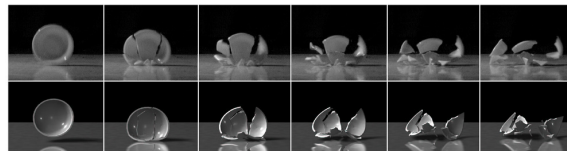
Questions?

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Reading for Today:

- James O’Brien & Jessica Hodgins “*Graphical Modeling and Animation of Brittle Fracture*” SIGGRAPH 1999.



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

Fracture Opening Modes

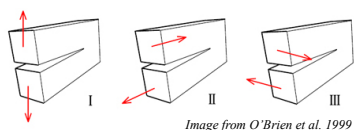
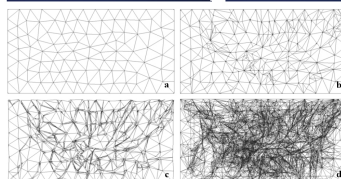
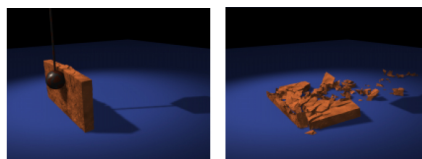


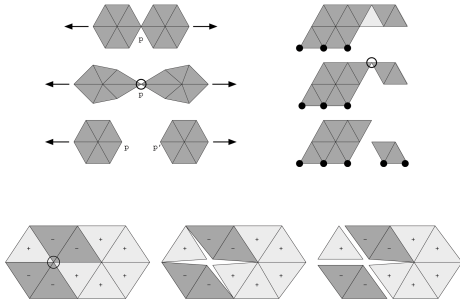
Figure 6: Three loading modes that can be experienced by a crack. Mode I: Opening, Mode II: In-Plane Shear, and Mode III: Out-of-Plane Shear. Adapted from Anderson [1].

Local Mesh Refinement



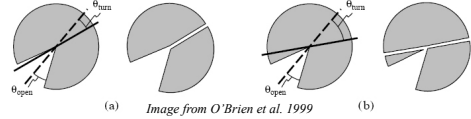
Images from O'Brien et al. 1999

Managing Fracture Adjacency

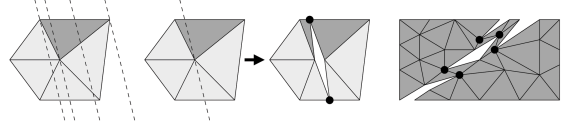


Fracture Propagation Difficulties

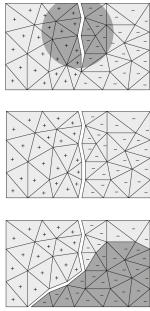
- Need to track direction of fracture propagation?



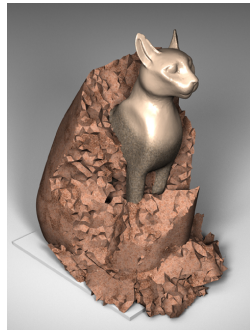
- Need to track crack tip?



Controlling Speed of Propagation

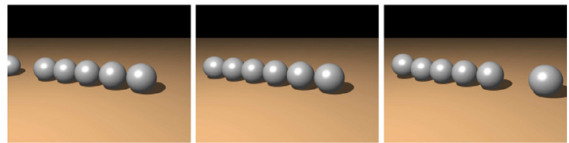
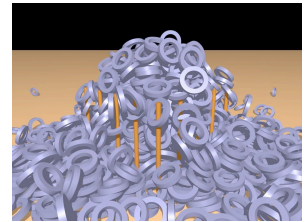


(no remeshing)

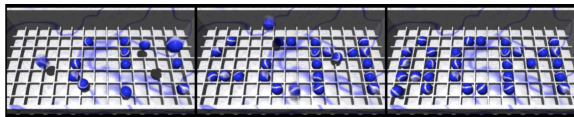
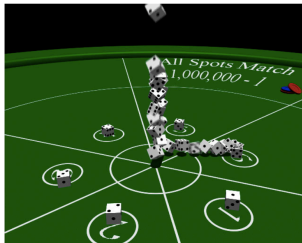


Reading for Today:

Guendelman,
Bridson, & Fedkiw
"Nonconvex Rigid
Bodies with Stacking"
SIGGRAPH 2003



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



Reading for Friday: (pick one)



"Interactive Manipulation of Rigid Body Simulations"
SIGGRAPH 2000, Popović, Seitz, Erdmann, Popović & Witkin

Reading for Friday: *(pick one)*

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

