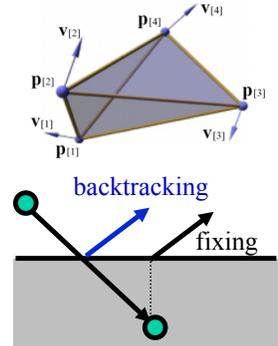
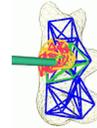
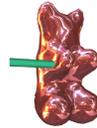


Fracture & Tetrahedral Models

Last Time?

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



Today

- **Useful & Related Term Definitions**
- Reading for Today
 - Graphical Modeling and Animation of Brittle Fracture
- “Interactive Sculpting” Fracture & Deformation
 - 3D Force Feedback Haptics Interface
 - Tetrahedral Modeling & Simplification

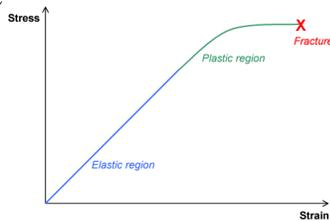
Misc. Definitions

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



Misc. Definitions

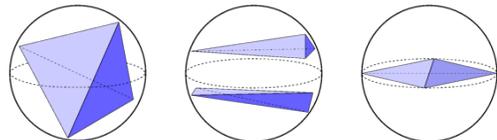
- *Elastic Deformation*: Once the forces are no longer applied, the object returns to its original shape.
- *Plastic Deformation*: An object in the plastic deformation range will first have undergone elastic deformation, which is reversible, so the object will return part way to its original shape.



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

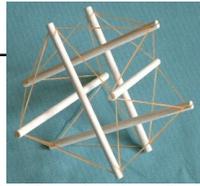
Misc. Definitions

- *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



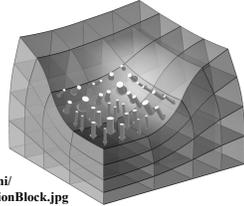
Misc. Definitions

- *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>

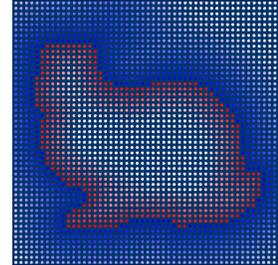
- *Compression*: resulting in reduction of volume



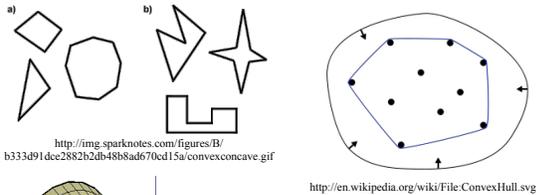
<http://www.aero.polimi.it/~merlini/SolidMechanics-FiniteElasticity/CompressionBlock.jpg>

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

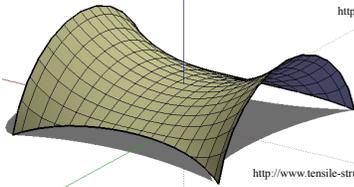


Convex vs. Non-Convex



<http://img.sparknotes.com/figures/B/3333d91dce282b2db48b8ad670cd15a/convexconcave.gif>

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



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

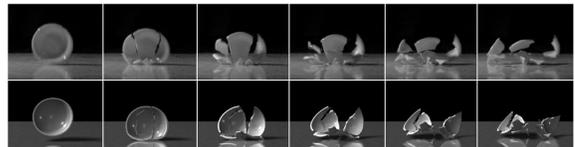
Questions?

Today

- Useful & Related Term Definitions
- **Reading for Today**
 - Graphical Modeling and Animation of Brittle Fracture
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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!

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

Fracture Opening Modes

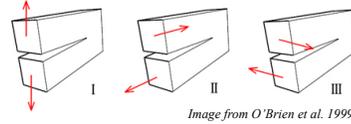
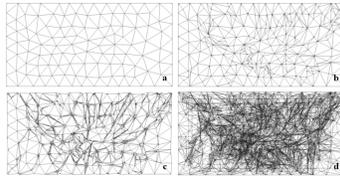
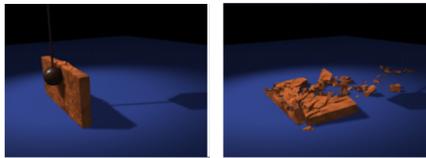


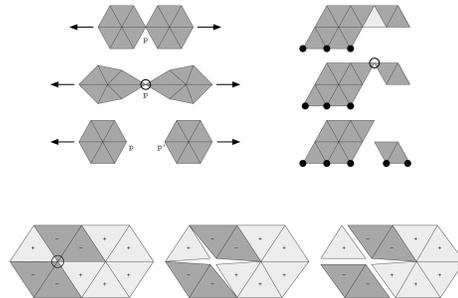
Image from O'Brien et al. 1999
 Figure 6: Three loading modes that can be experienced by a crack. Mode I: Opening, Mode II: In-Plane Shear, and Mode III: Out-of-Plane Shear. Adapted from Anderson [1].

Local Mesh Refinement



Images from O'Brien et al. 1999

Managing Fracture Adjacency



Fracture Propagation Difficulties

- Need to track direction of fracture propagation?

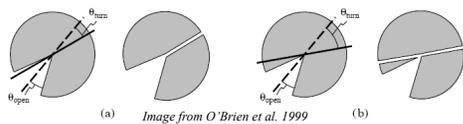
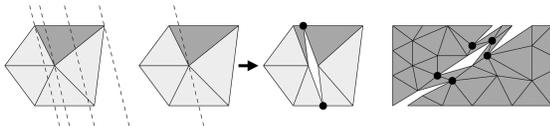
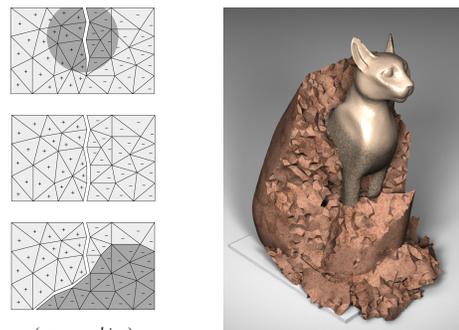


Image from O'Brien et al. 1999

- Need to track crack tip?



Controlling Speed of Propagation



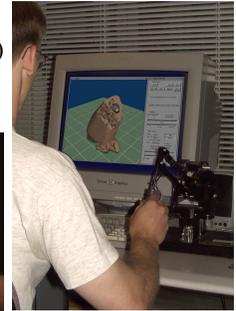
(no remeshing)

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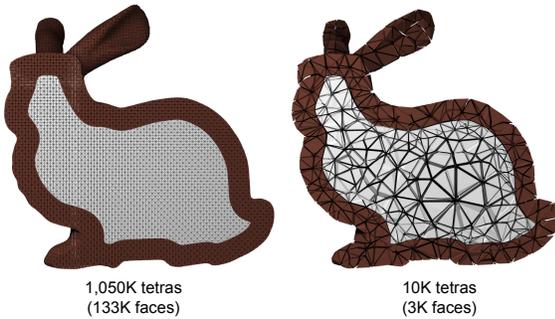
Haptic Device

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



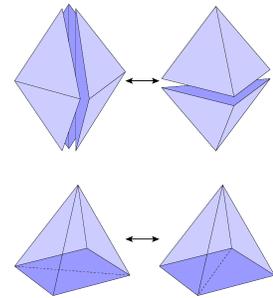
Sensable's Phantom
<http://www.sensable.com/>

3D Mesh Simplification



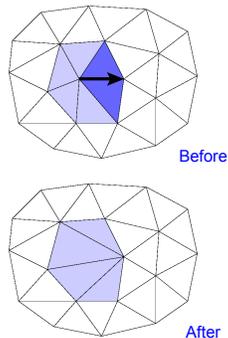
3D Mesh Operations

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



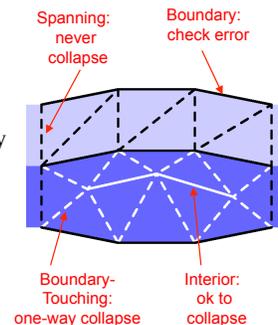
3D Mesh Operations

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



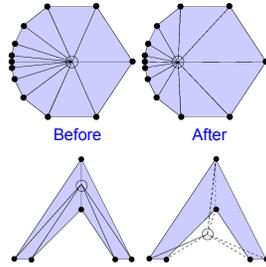
Prioritizing Edge Collapses

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



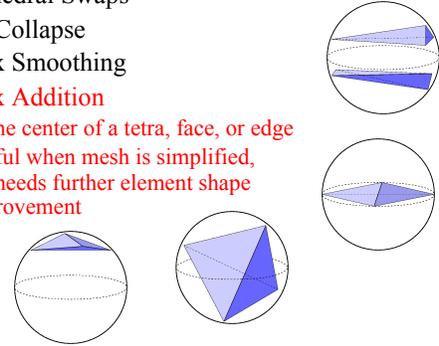
3D Mesh Operations

- 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

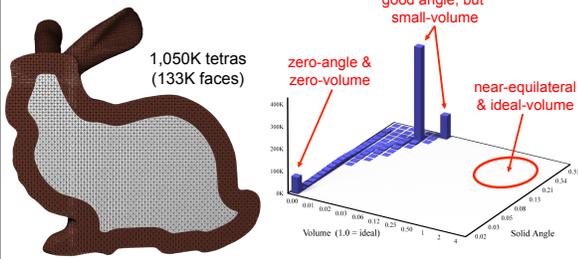


3D Mesh Operations

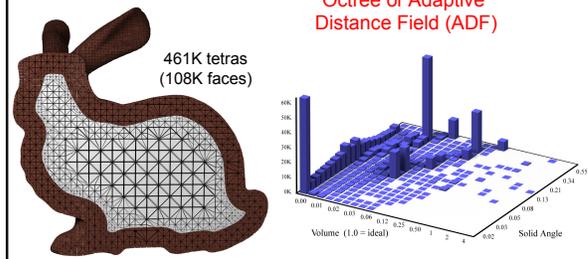
- Tetrahedral Swaps
- Edge Collapse
- Vertex Smoothing
- **Vertex Addition**
 - At the center of a tetra, face, or edge
 - Useful when mesh is simplified, but needs further element shape improvement



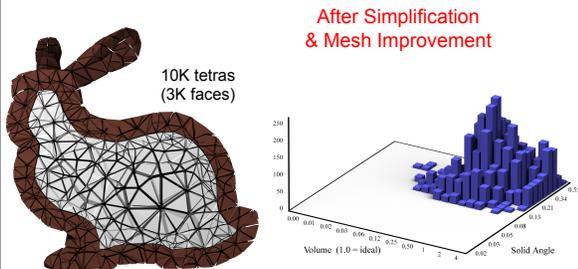
Visualization of Tetrahedra Quality



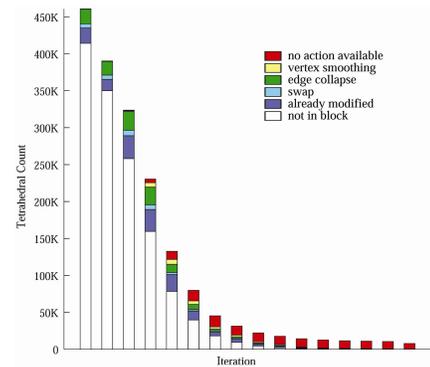
Visualization of Tetrahedra Quality



Visualization of Tetrahedra Quality



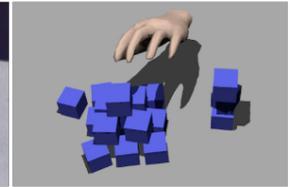
Visualization of Simplification Algorithm



Questions?

Reading for Tuesday: *(pick one)*

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



Reading for Tuesday: *(pick one)*

- “Synthesis of Complex Dynamic Character Motion from Simple Animation”, Liu & Popović, 2002



- Rapid prototyping of realistic character motion *from rough low-quality animations*
- Obey the laws of physics & stay within space of naturally-occurring movements