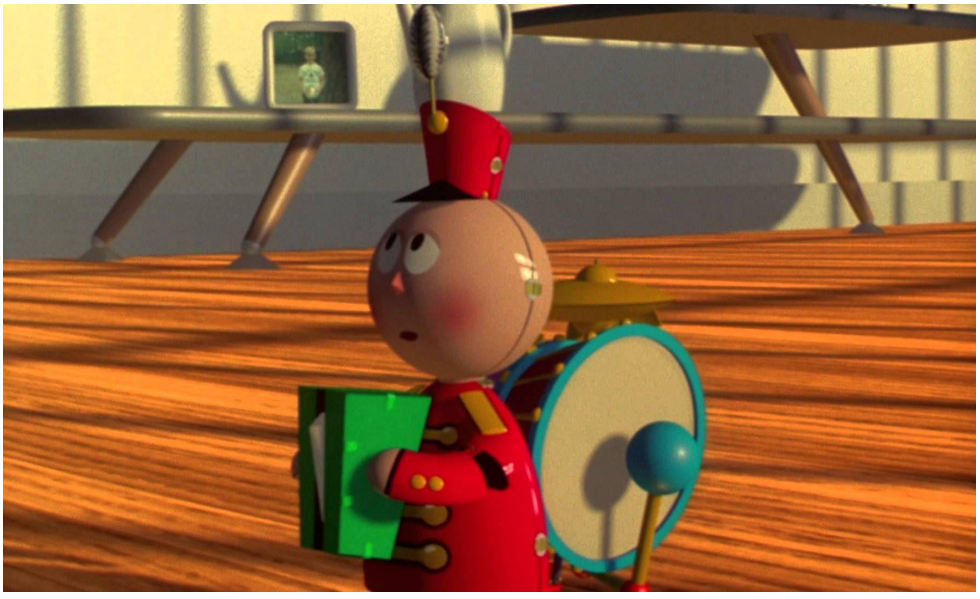
Fracture & Tetrahedral Models

Tin Toy



Pixar Animation Studios, 1988

Tin Toy

Pixar Animation Studios, 1988

Acura Bullet

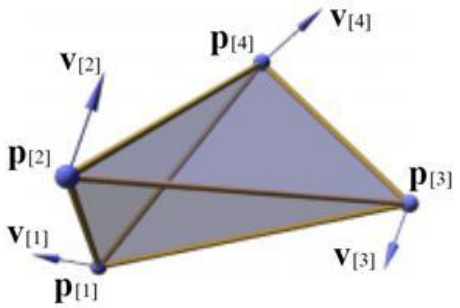
The Mill, SIGGRAPH 2009

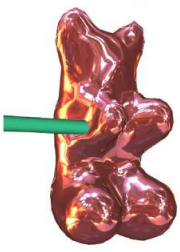
Acura Bullet

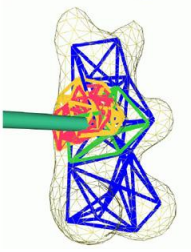
The Mill, SIGGRAPH 2009

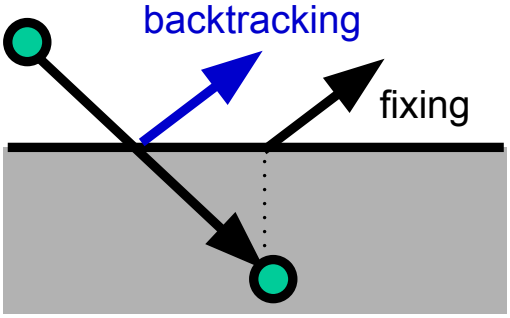
Last Time?

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







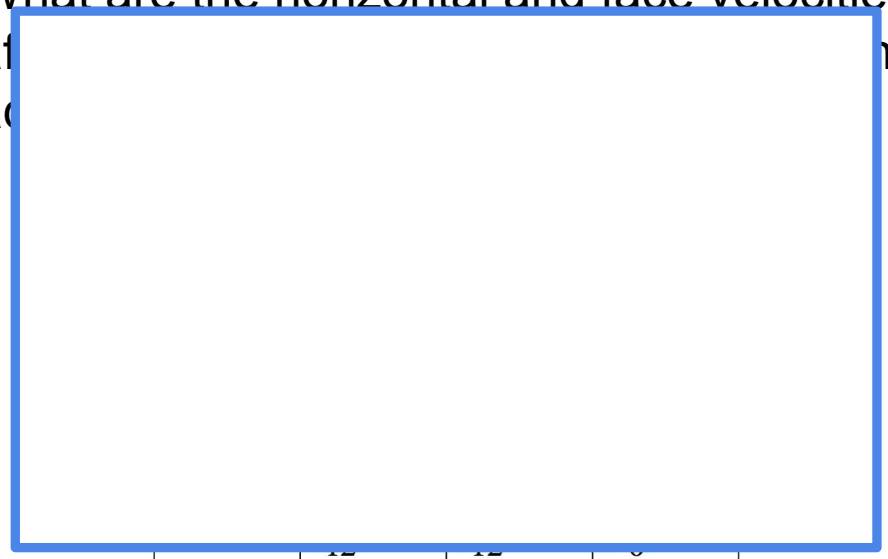


Today

- Worksheet
- Papers for Today
- Continuing from Last Time…
  - Non-Rigid Objects
  - Finite Element Method
  - Level of Detail
- Useful & Related Term Definitions
- Tetrahedral Element Quality
- Papers for Next Time

Pop Worksheet!

What are the horizontal and face velocities af nce ac



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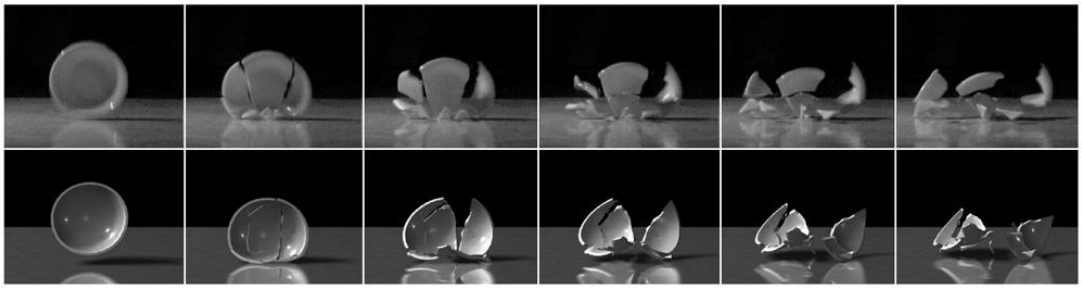
Reading for Today

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



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

Fracture Opening Modes

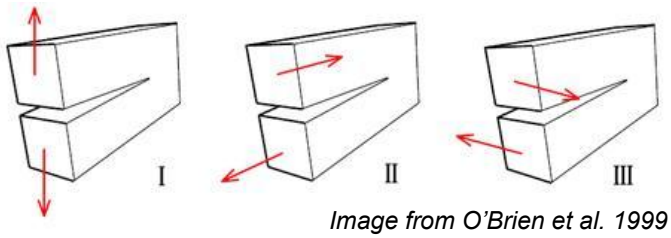
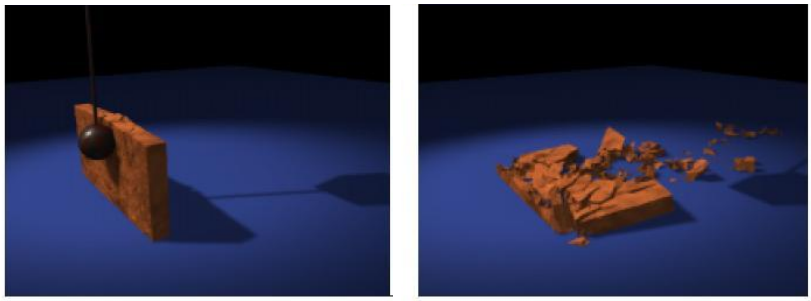
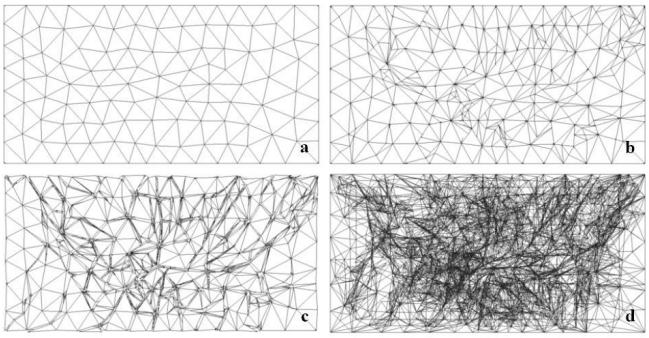


Image from O'Brien et al. 1999

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].

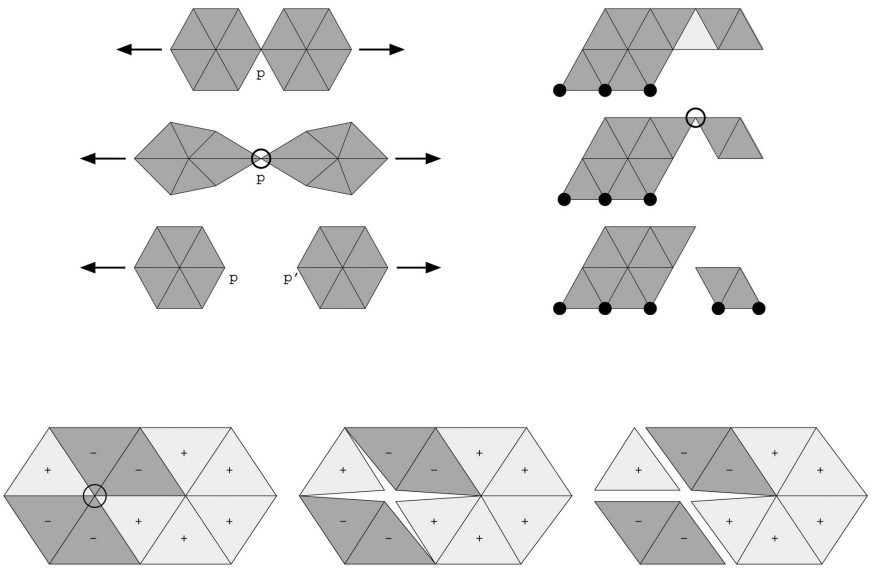
Local Mesh Refinement





Images from O'Brien et al. 1999

Managing Fracture Adjacency



Fracture Propagation Difficulties

- Need to track direction of fracture

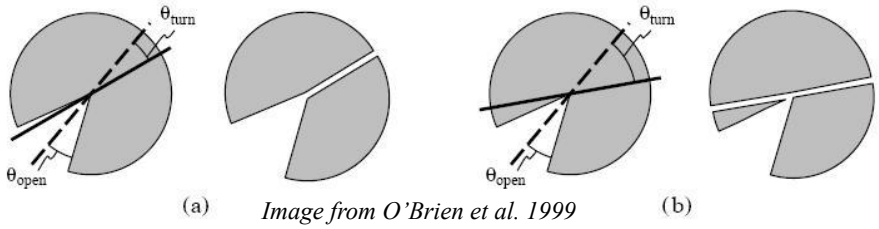
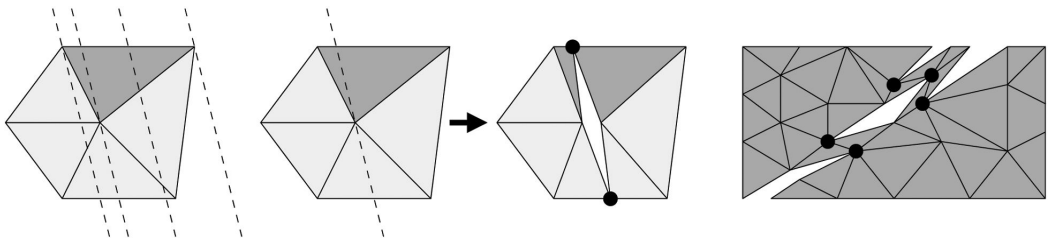
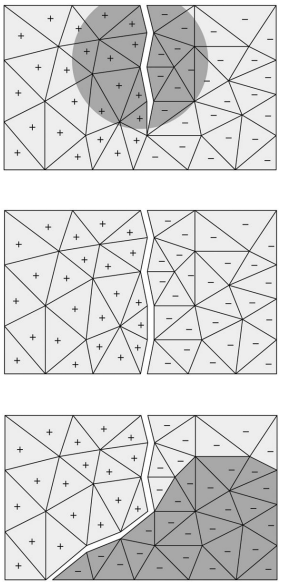


Image from O'Brien et al. 1999

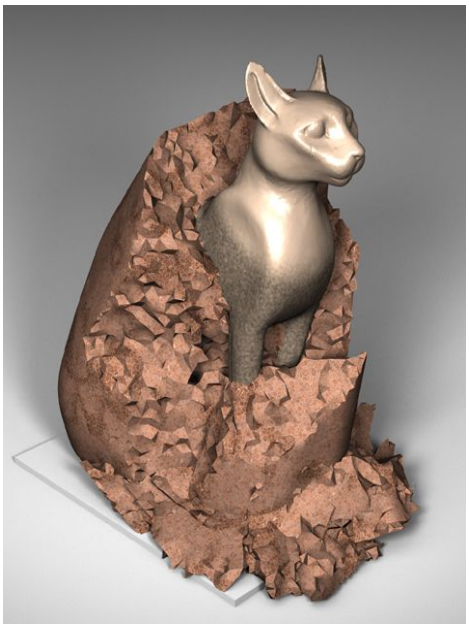
- Need to track crack tip?



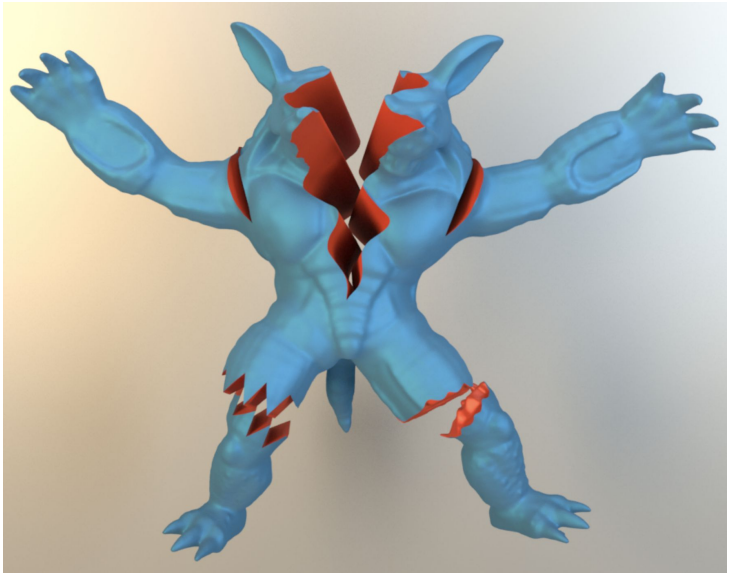
Controlling Speed of Propagation



(*no remeshing*)

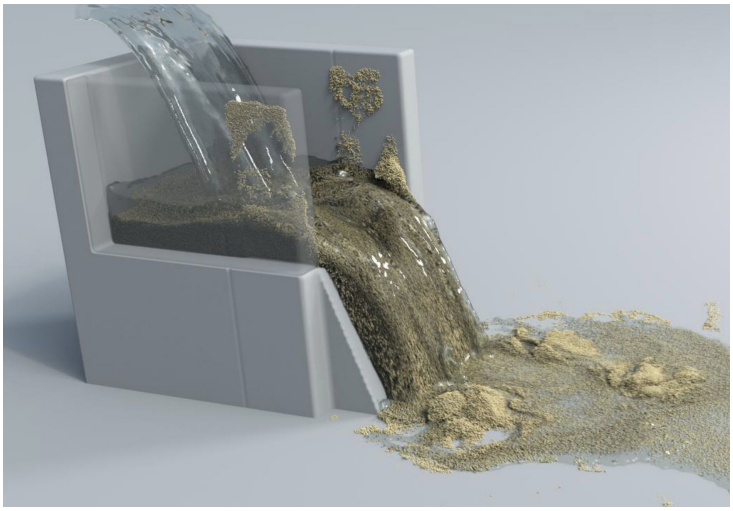


Reading for Today



"Robust eXtended Finite Elements for Complex Cutting of Deformables", Koschier, Bender, & Thuerey, SIGGRAPH 2017

Reading for Today



"Multi-species simulation of porous sand and water mixtures", Pradhana, Gast, Klar, Fu, Teran, Jiang, and Museth, SIGGRAPH 2017.

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Simulation of Non-Rigid Objects

- We modeled string & cloth using mass-spring systems. Can we do the same?
- Yes…
- But a more physically accurate model uses *volumetric elements:*

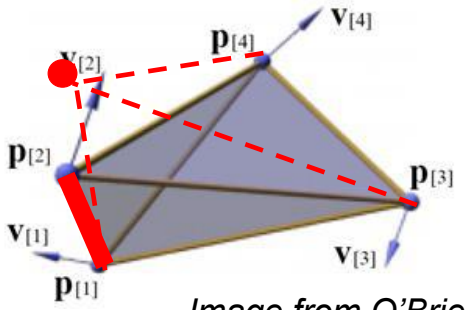
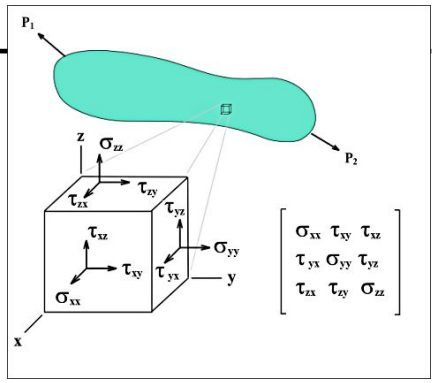


Image from O'Brien et al. 1999

Strain & Stress

- Stress
  - the internal distribution of forces within a body that balance and react to the loads applied to it
  - *normal stress* & *shear stress*



http://en.wikipedia.org/wiki/Image:Stress_tensor.png

- Strain
  - material deformation caused by stress.
  - measured by the change in length of a line or by the change in angle between two lines

$$\varepsilon = \frac{\Delta_l}{l_0}$$

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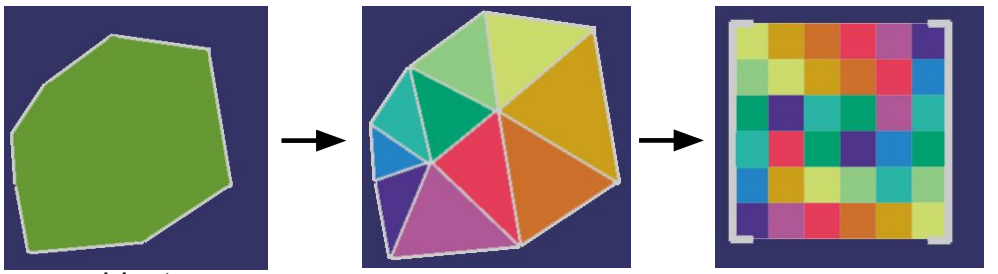
Finite Element Method

- To solve the continuous problem (deformation of all points of the object)
  - Discretize the problem
  - Express the interrelationship
  - Solve a big linear system
- More principled than Mass-Spring



object → finite elements → large matricial system

Diagram from Debunne et al. 2001

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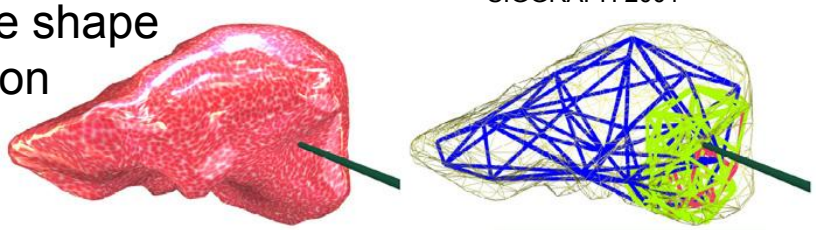
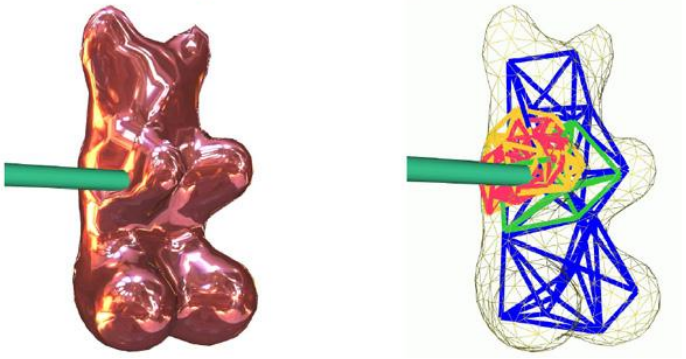
Reading for Next Time

Gilles Debunne , Mathieu Desbrun, Marie-Paule Cani, & Alan H. Barr
Dynamic Real-Time Deformations using Space & Time Adaptive Sampling
SIGGRAPH 2001

- Level of Detail
- Interactive shape deformation

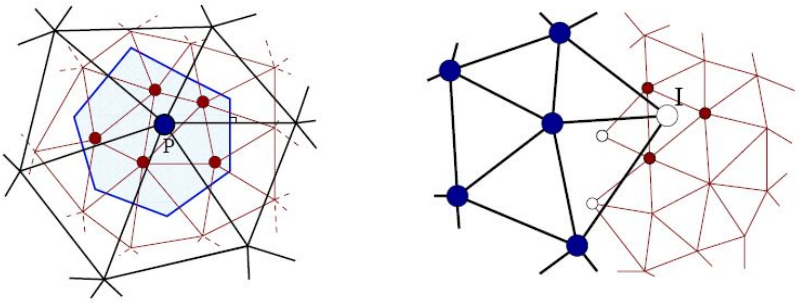


- Use high-resolution model only in areas of extreme deformation



Multi-Resolution Deformation

- Use Voronoi diagrams to match parent & child vertices.
- Interpolate values for inactive interface vertices from active parent/child vertices

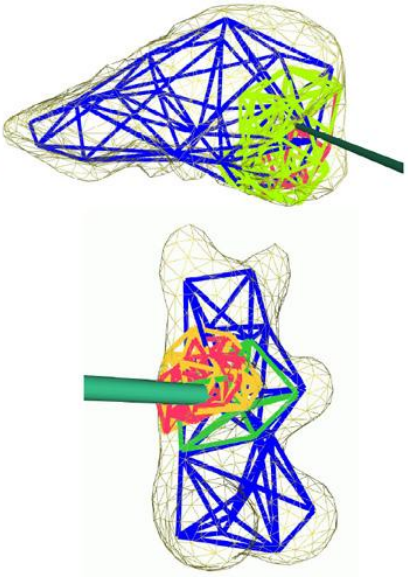


- *Need to avoid interference of vibrations between simulations at different resolutions*

Debunne et al. “Dynamic Real-Time Deformations using Space & Time Adaptive Sampling”, 2001

Pre-computation & Simulation

- FEM matrix pre-computed
- Level of detail coupling pre-computed for rest topology
- What to do if connectivity of elements changes?
  - Cloth is cut or torn
  - Surgery simulation



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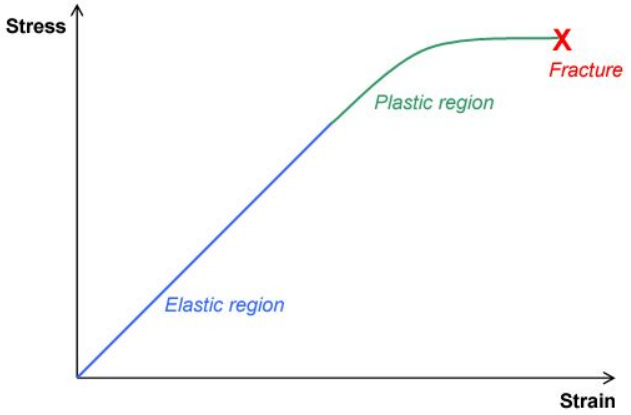
Misc. Definitions

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

Misc. Definitions

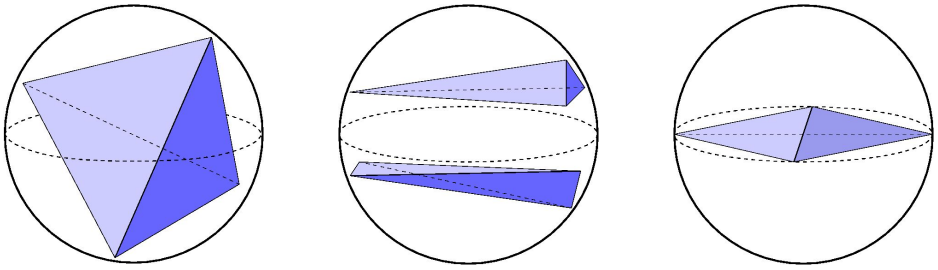
- *Elastic Deformation*: Once the forces are no longer applied, the object returns to its original shape.
- *Plastic Deformation*: An object in the plastic deformation range will first have undergone elastic deformation, which is reversible, so the object will return part way to its original shape.



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

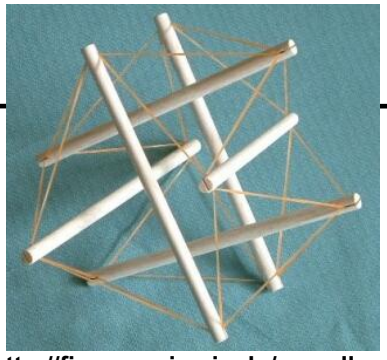
Misc. Definitions

- *Degenerate/Ill-conditioned Element*: a.k.a. how "equilateral" are the elements?
  - Ratio of volume^2 to surface area^3
  - Smallest *solid* angle
  - Ratio of volume to volume of smallest circumscribed sphere



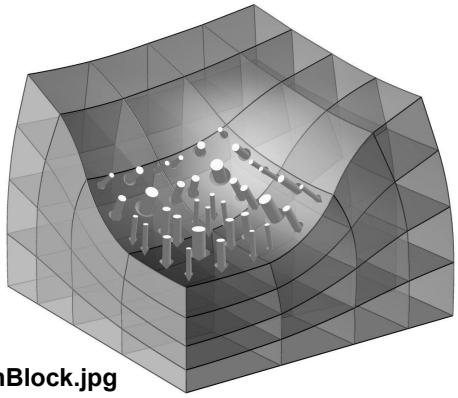
Misc. Definitions

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



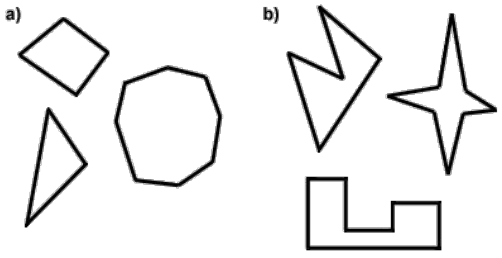
http://fig.cox.miami.edu/~cmallery/255/255chem/tensegrity.sticks.jpg

- *Compression*: resulting in reduction of volume

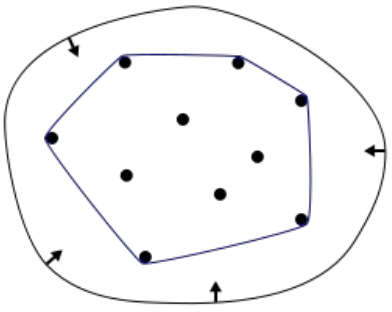


http://www.aero.polimi.it/~merlini/SolidMechanics-FiniteElasticity/CompressionBlock.jpg

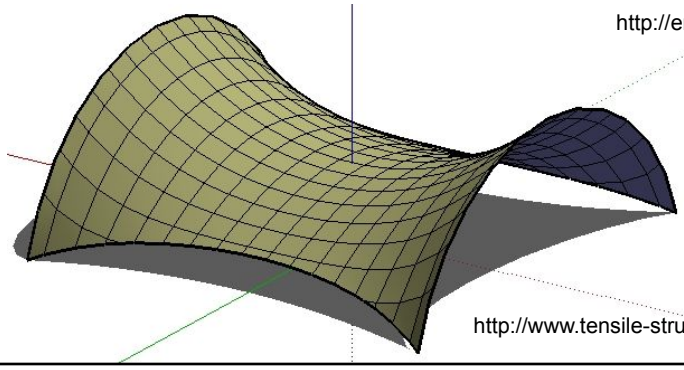
Convex vs. Non-Convex



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

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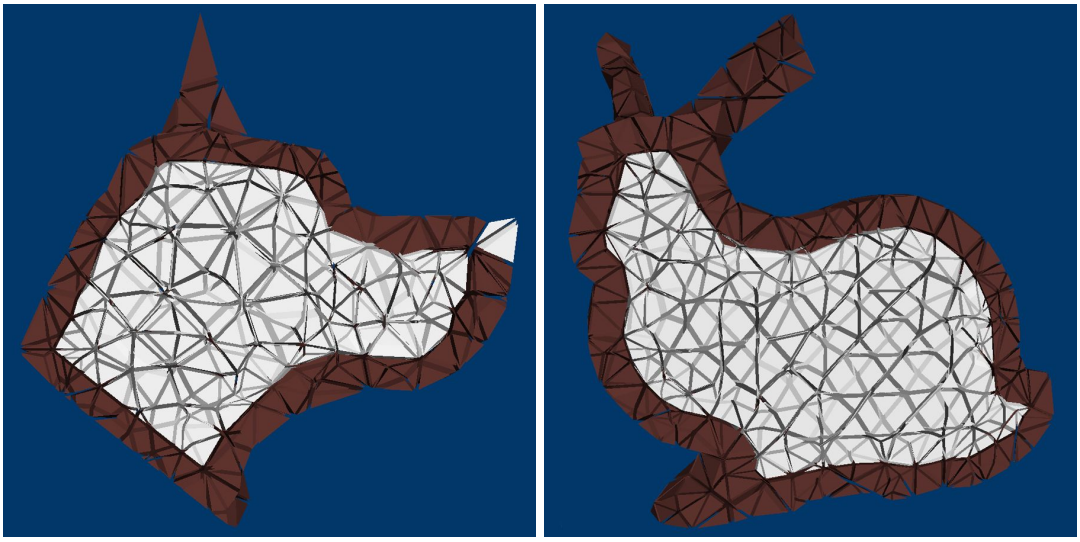
Multiple Materials

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



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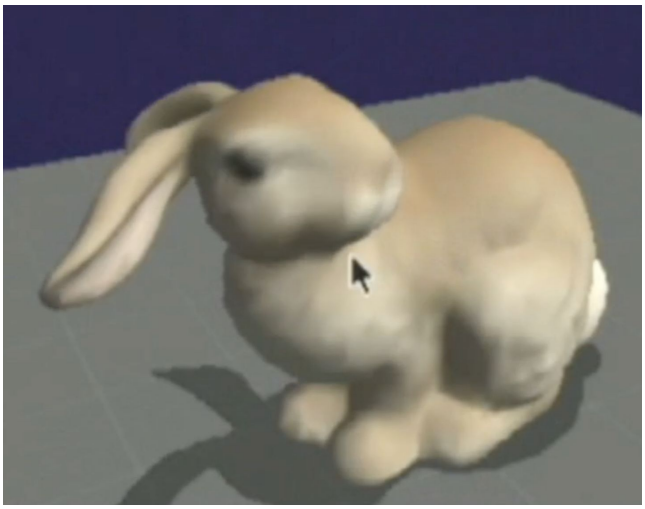
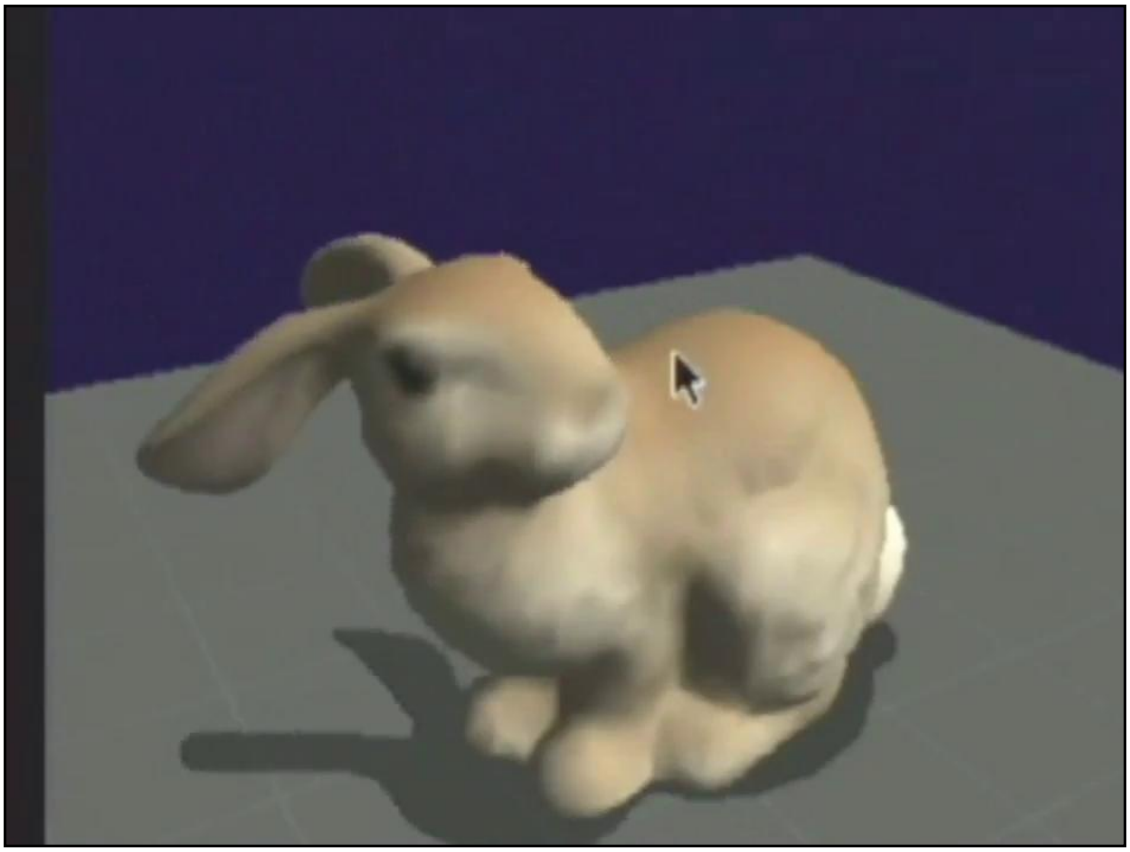




Tree Stump

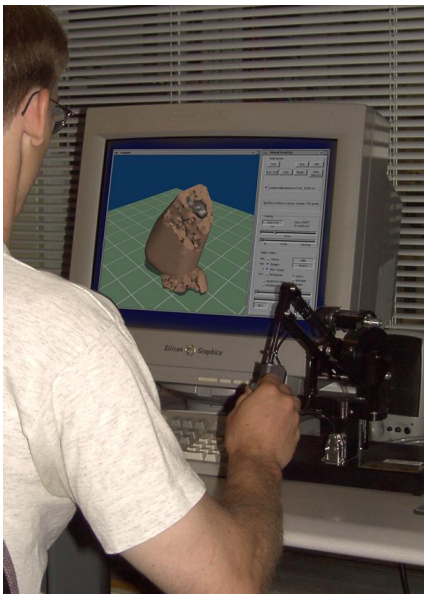
Images from Cutler et al. 2002

Image from Cutler et al. 2002

Image from Cutler et al. 2002

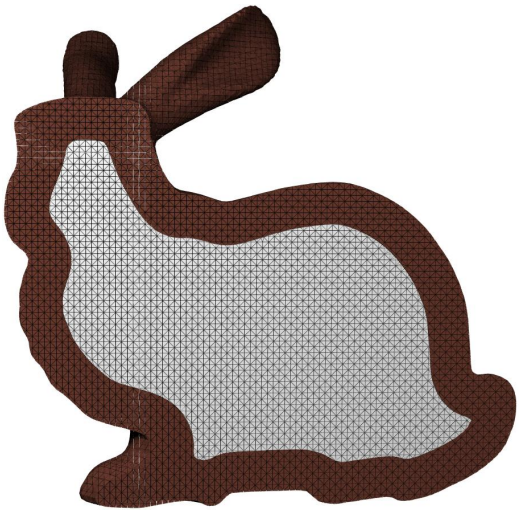
Haptic Device

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

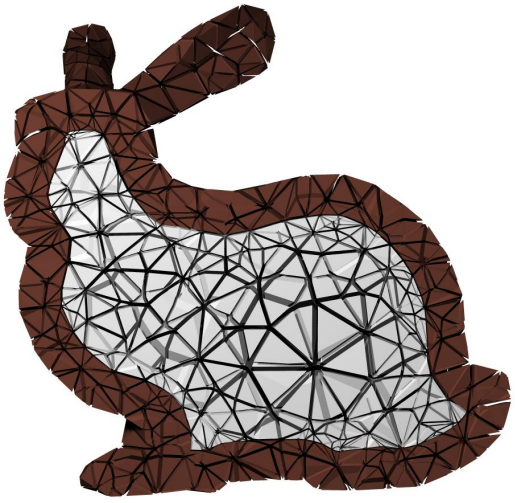


Sensable's Phantom
http://www.sensable.com/

3D Mesh Simplification



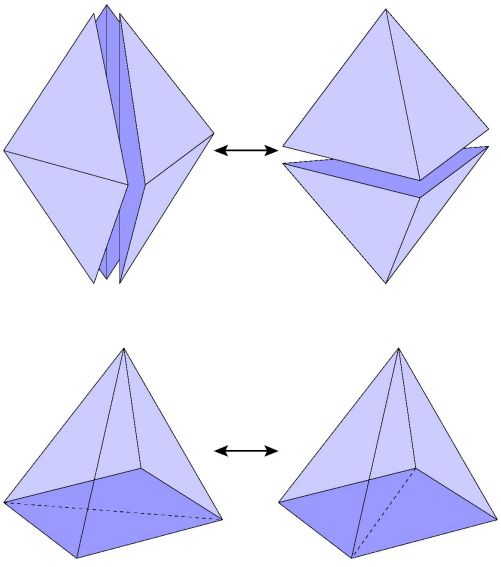
1,050K tetras
(133K faces)



10K tetras
(3K faces)

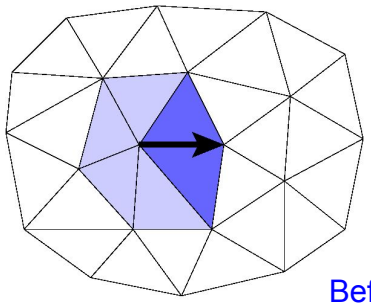
3D Mesh Operations

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

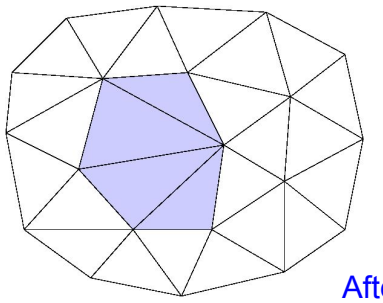


3D Mesh Operations

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



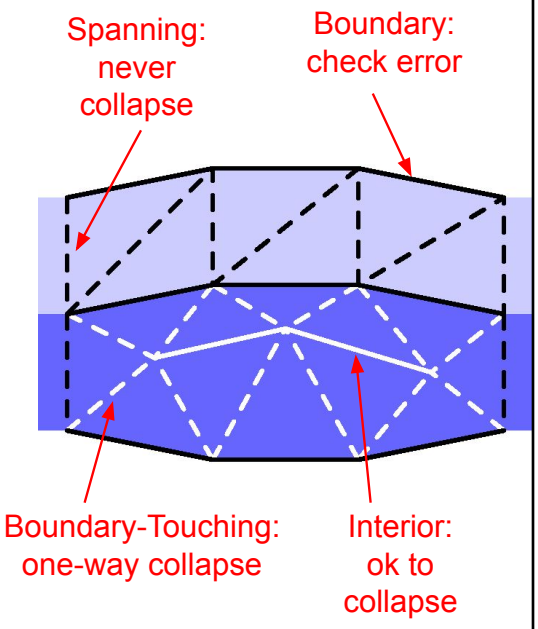
Before



After

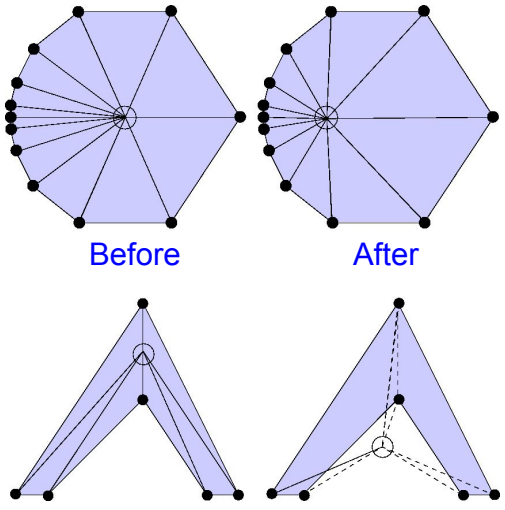
Prioritizing Edge Collapses

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



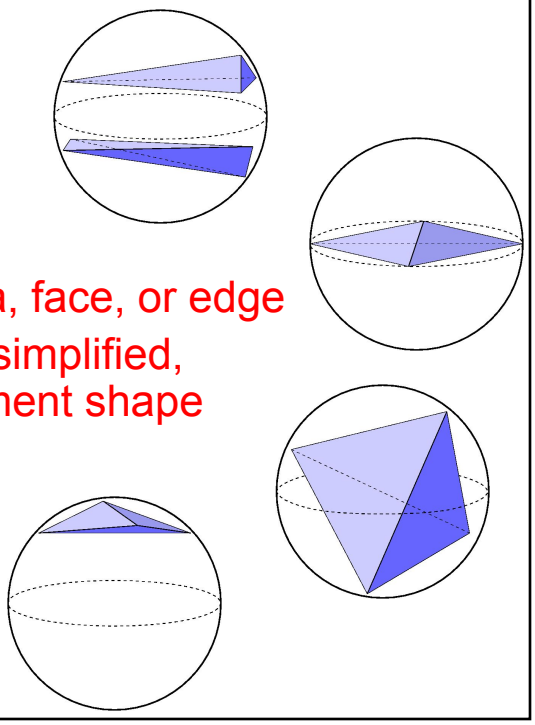
3D Mesh Operations

- 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

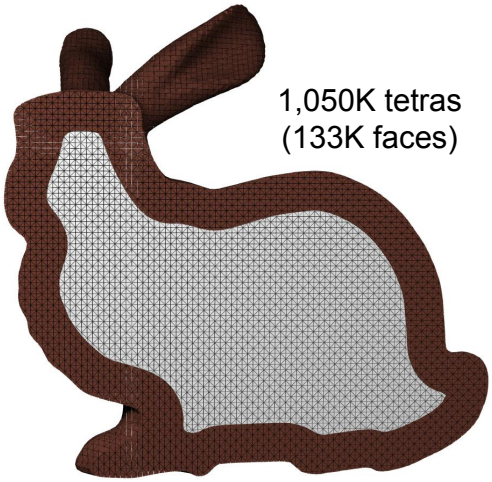


3D Mesh Operations

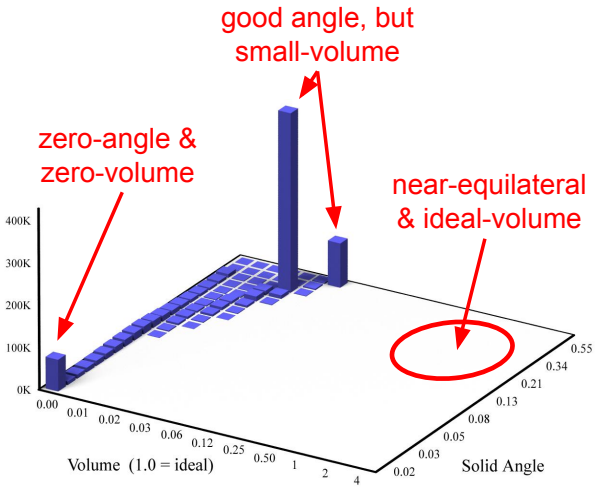
- Tetrahedral Swaps
- Edge Collapse
- Vertex Smoothing
- Vertex Addition
  - At the center of a tetra, face, or edge
  - Useful when mesh is simplified, but needs further element shape improvement



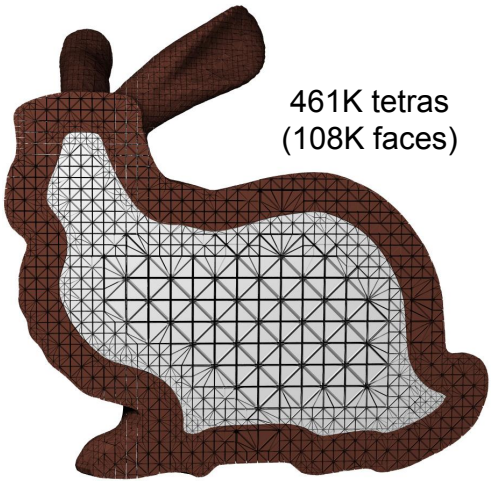
Visualization of Tetrahedra Quality



1,050K tetras
(133K faces)

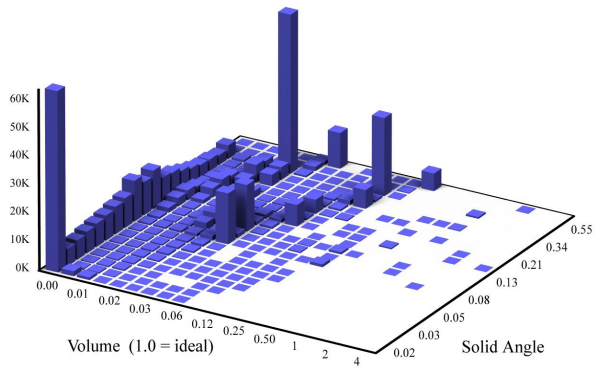


Visualization of Tetrahedra Quality

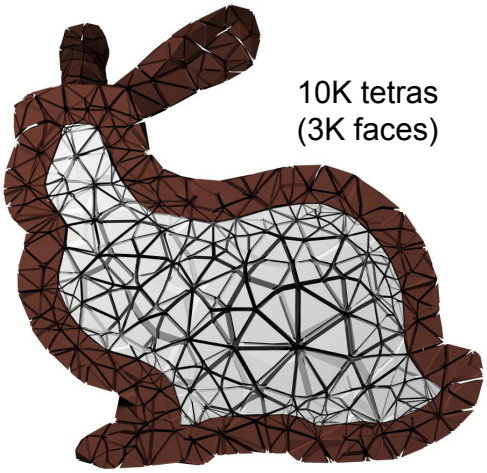


461K tetras
(108K faces)

Octree or Adaptive
Distance Field (ADF)

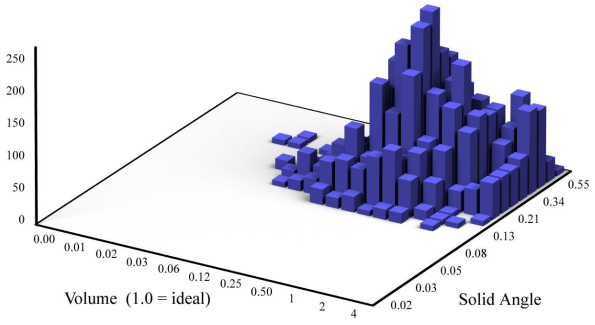


Visualization of Tetrahedra Quality

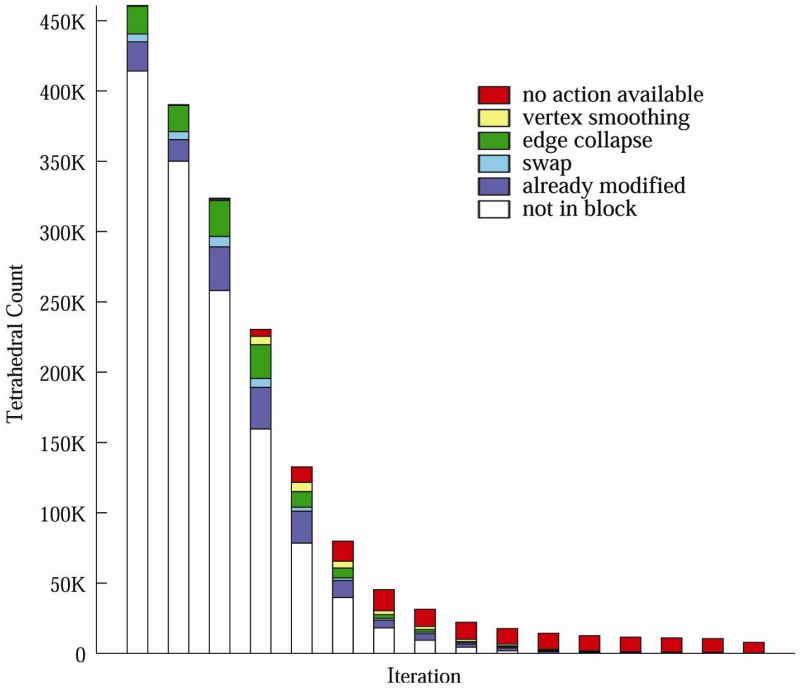


10K tetras
(3K faces)

After Simplification
& Mesh Improvement



Visualization of Simplification Algorithm

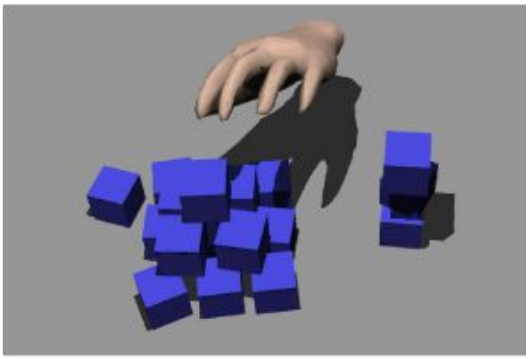


Today

- Worksheet
- Papers for Today
- Continuing from Last Time…
  - Non-Rigid Objects
  - Finite Element Method
  - Level of Detail
- Useful & Related Term Definitions
- Tetrahedral Element Quality
- Papers for Next Time

Reading for Friday: *(pick one)*

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



Reading for Friday: *(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

Reading for Friday: *(pick one)*

"Artist-Directed Dynamics for 2D Animation", Bai, Kaufman, Liu, & Popović, SIGGRAPH 2016

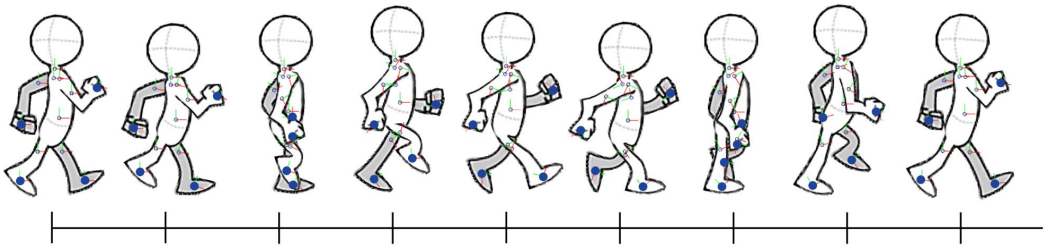


Figure 6: ***Keyframes used in the articulated character walk example.*** *The artist only specifies keyframes for a subset of handles (handles at hands and feet) which are shown as blue dots. Nine keyframes are used to create a walking cycle. Their timing is visualized by the black lines at the bottom. The artworks are adapted from Angryanimator.com (http://www.angryanimator.com/)*