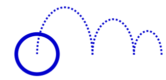
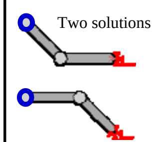
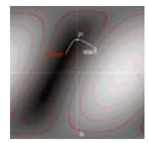
Rigid Body Dynamics, Fracture, & Deformation

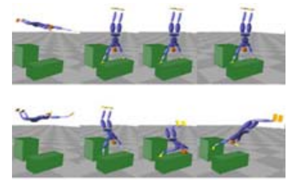
Last Time?

- Keyframing
- Procedural Animation
- Physically-Based Animation
- Forward and Inverse Kinematics
- Motion Capture







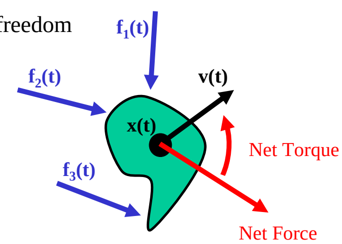


Today

- Rigid Body Dynamics
- Finite Element Method
- Deformation
- Fracture

Rigid Body Dynamics

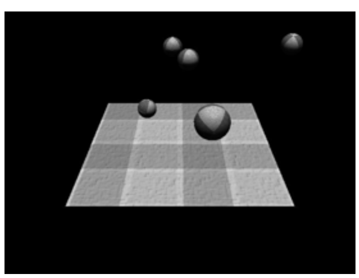
- Could use particles for all points on the object
  - But rigid body does not deform
  - Few degrees of freedom
- Use only one particle at the center of mass
- Compute Net Force & Net Torque



Nice Reference Material: http://www.pixar.com/companyinfo/research/pbm2001/
http://www.myphysicslab.com/collision.html

Rigid Body Dynamics

- Physics
  - Velocity
  - Acceleration
  - Angular Momentum
- Collisions
- Friction

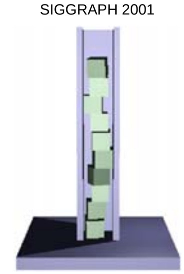


from: Darren Lewis
http://www-cs-students.stanford.edu/~dalewis/cs448a/rigidbody.html

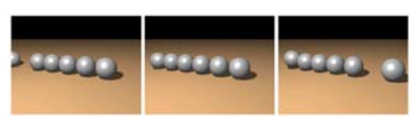
Collisions

Victor J. Milenkovic & Harald Schmidl
Optimization-Based Animation
SIGGRAPH 2001

- We know how to simulate bouncing really well
- But resting collisions are hard to manage



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



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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:*

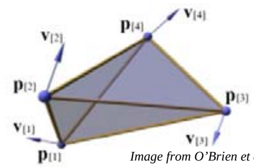


Image from O'Brien et al. 1999

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

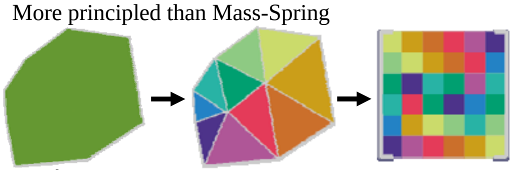
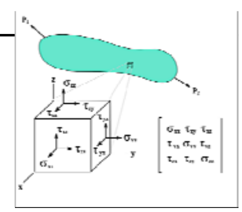


Diagram from Debunne et al. 2001

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

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

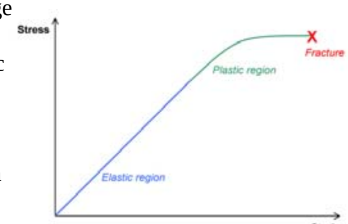
http://en.wikipedia.org/wiki/Image:Stress_tensor.png

Isotropic vs. Anisotropic

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

Elastic vs. Plastic

- *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.



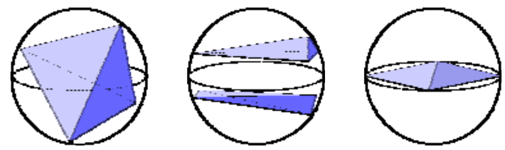
http://en.wikipedia.org/wiki/Image:Stress-strain1.png

Brittle vs. Ductile

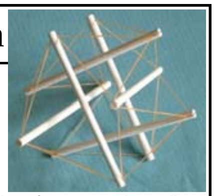
- *Brittle*: Material deforms by fracturing. Glass is brittle. Rocks are typically brittle at low temperatures and pressures.
- *Ductile*: Material deforms without breaking. Metals are ductile. Many materials show both types of behavior. They may deform in a ductile manner if deformed slowly, but fracture if deformed too quickly or too much. Rocks are typically ductile at high temperatures or pressures.
- *Viscous*: Materials that deform steadily under stress. Purely viscous materials like liquids deform under even the smallest stress. Rocks may behave like viscous materials under high temperature and pressure.
- *Viscoelastic*: Combines elastic and viscous behavior. Models of glacio-isostasy frequently assume a viscoelastic earth: the crust flexes elastically and the underlying mantle flows viscously.

Degenerate Elements

- *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



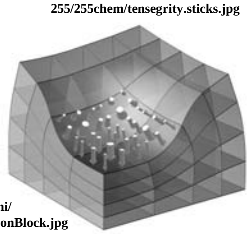
Tension & Compression



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

- *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

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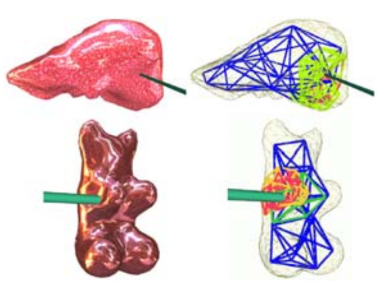
Level of Detail

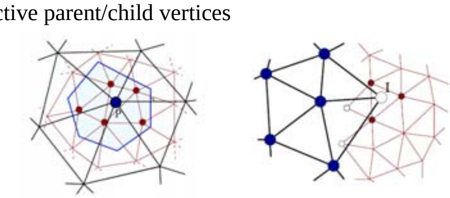
Gilles Debunne , Mathieu Desbrun, Marie-Paule Cani, & Alan H. Barr
Dynamic Real-Time Deformations using Space & Time Adaptive Sampling
SIGGRAPH 2001

- 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

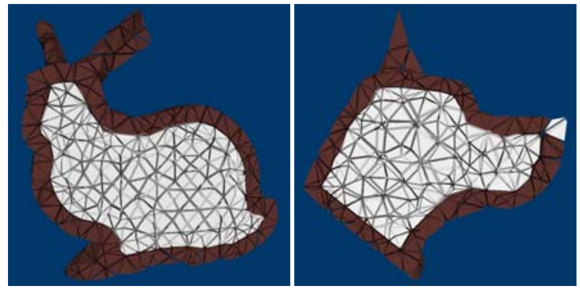
Haptic Device

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

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

Multiple Materials

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



Tree Stump

Images from Cutler et al. 2002

Image from Cutler et al. 2002

Image from Cutler et al. 2002

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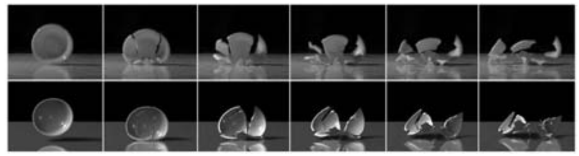
Reading for Today:

- 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

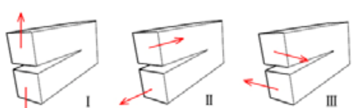
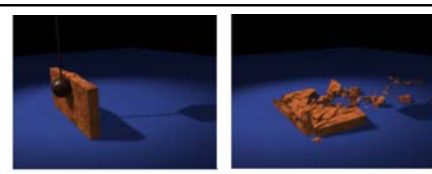
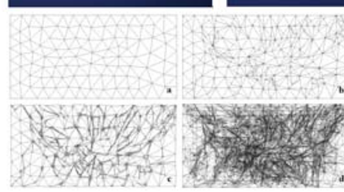


Image from O'Brien et al. 1999

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].

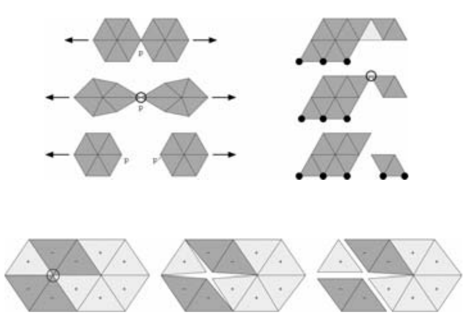
Local Mesh Refinement





Images from O'Brien et al. 1999

Managing Fracture Adjacency



Images from Cutler 2003

Fracture Propagation Difficulties

- Need to track direction of fracture propagation?

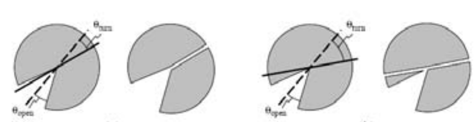


Image from O'Brien et al. 1999

- Need to track crack tip?

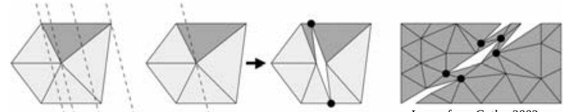
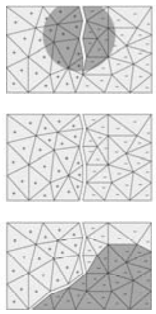
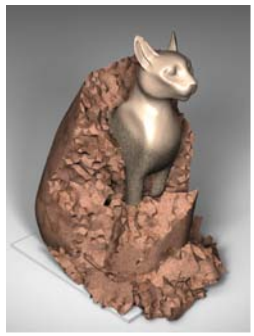


Image from Cutler 2003

Controlling Speed of Propagation



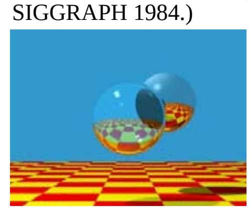
(*no remeshing*)



Images from Cutler 2003

Reading for Friday 2/22:

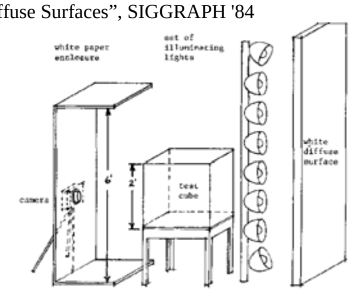
- "An improved illumination model for shaded display" Turner Whitted, 1980.
- ("Distributed Ray Tracing", Cook, Porter, & Carpenter, SIGGRAPH 1984.)



- Post a comment or question on the LMS discussion by 10am on Friday 2/22

Reading for Friday 2/29:

- Goral, Torrance, Greenberg & Battaile "Modeling the Interaction of Light Between Diffuse Surfaces", SIGGRAPH '84



Post a comment or question on the LMS discussion by 10am on Friday 2/29