Rigid Body Dynamics, Fracture, & Deformation

Announcements: Quiz
- On Friday (3/5), in class
- One 8.5x11 sheet of notes allowed
- Sample quiz (from prior year) is posted online
- Focus on “reading comprehension” and material for Homeworks 0, 1, & 2
- Will be curved 😊
- Send Barb email if you have any questions about the quiz

Announcements: Final Projects
- Everyone should post one or more ideas for a final project on the discussion forum over Spring Break
- Connect with potential teammates (teams of 2 strongly recommended)
- Start reading background papers

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

http://www.myphysicslab.com/collision.html
Rigid Body Dynamics

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

Collisions

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

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

Today

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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:

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

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

Diagram from Debunne et al. 2001

Image from O'Brien et al. 1999

Image from Wikipedia


Today

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

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


Haptic Device

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

Sensible’s Phantom
http://www.sensible.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
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.

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.

- **Compression**: resulting in reduction of volume

Reading for Today:


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?

- Need to track crack tip?

Images from O’Brien et al. 1999
Controling Speed of Propagation

Images from Cutler 2003

(no remeshing)

Questions?

Readings for Tuesday 3/16: (read both)


Readings for Friday 3/19:

- 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