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

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

http://www.myphysicslab.com/collision.html

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

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

![Object, Finite Elements, Large Matricial System](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

![Stress Tensor Image](http://en.wikipedia.org/wiki/Image:Stress_tensor.png)

Level of Detail

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

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

Image from Cutler et al. 2002

Image from Cutler et al. 2002
Today

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

Some Definitions

• Isotropic: a property which does not depend on the direction.
• Anisotropic: 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 threshold
  • Remeshing
    – need connectivity info!
  • Material properties
  • Parameter tuning
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

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

Questions?

Images from Cutler 2003
Readings for Friday 2/20:

- "Interactive Depth of Field", Kass, Lefohn, and Owens, Pixar TR 2006.

Reading for Friday 2/27:

- 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.