

# Rigid Body Dynamics, Fracture, & Deformation

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## Last Time?

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## Today

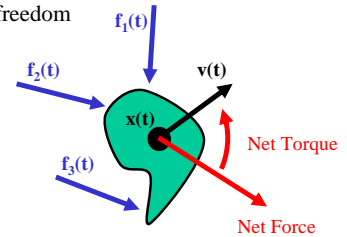
- Rigid Body Dynamics
- Finite Element Method
- Deformation
- Fracture

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## Rigid Body Dynamics

- Could use particles for all points on the object
  - But rigid body does not deform
  - Few degrees of freedom

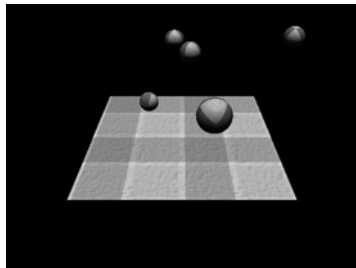
- Use only one particle at the center of mass
- Compute Net Force & Net Torque



Nice Reference Material: <http://www.pixar.com/companyinfo/research/pbm2001/>

## Rigid Body Dynamics

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



from: Darren Lewis

<http://www-cs-students.stanford.edu/~dalewis/cs448a/rigidbody.html>

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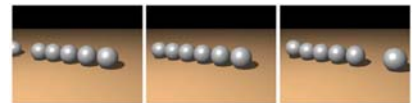
## Collisions

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



## Questions?

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## Today

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

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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*:

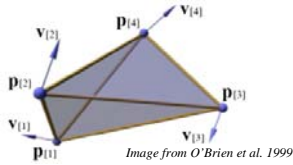


Image from O'Brien et al. 1999

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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

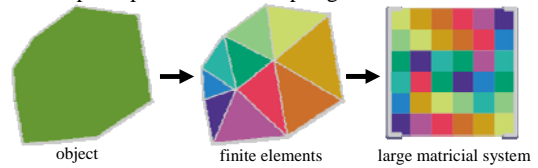
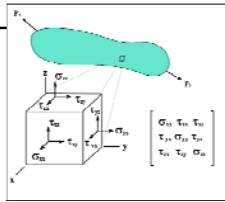


Diagram from Debunne et al. 2001

## 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

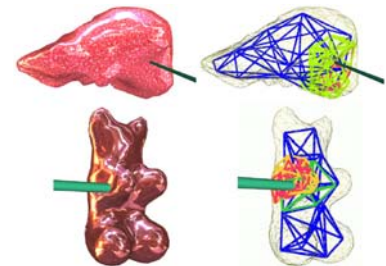


[http://en.wikipedia.org/wiki/Image:Stress\\_tensor.png](http://en.wikipedia.org/wiki/Image:Stress_tensor.png)

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## Level of Detail

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

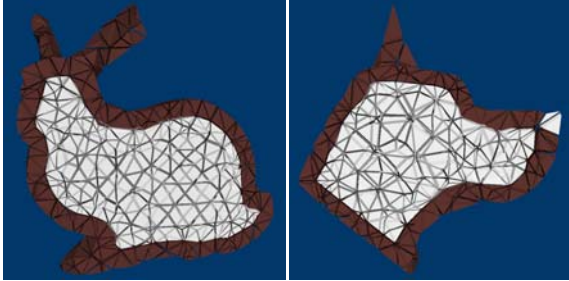


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Gilles Debunne, Mathieu Desbrun, Marie-Paule Cani, & Alan H. Barr  
*Dynamic Real-Time Deformations using Space & Time Adaptive Sampling*  
 SIGGRAPH 2001

## Multiple Materials

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



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## Tree Stump






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- **Fracture**

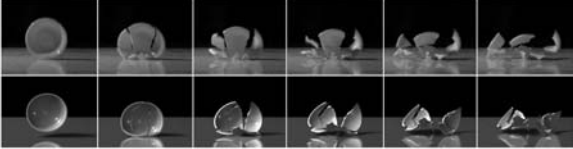
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## Fracture

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

- Fracture threshold
- Remeshing
- Material properties
- Parameter tuning

– need connectivity info!



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## Fracture Opening Modes

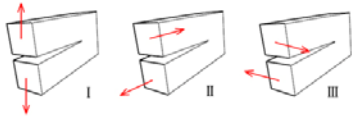
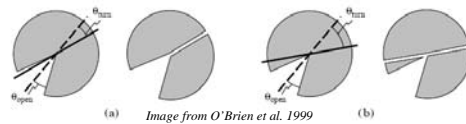


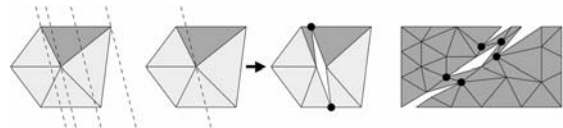
Figure 6: Three loading modes that can be experienced by a crack. Mode I: Opening, Mode II: In-Plane Shear, and Mode III: Out-of-Plane Shear. Adapted from Anderson [1].

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## Fracture Propagation

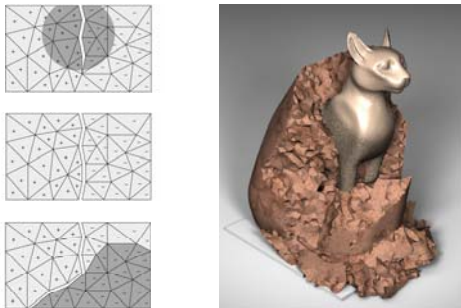


(a) Image from O'Brien et al. 1999 (b)



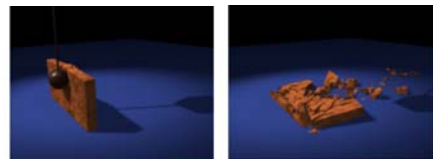
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## Fracture Propagation

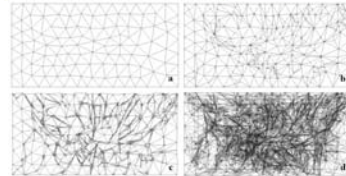


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## Local Mesh Refinement

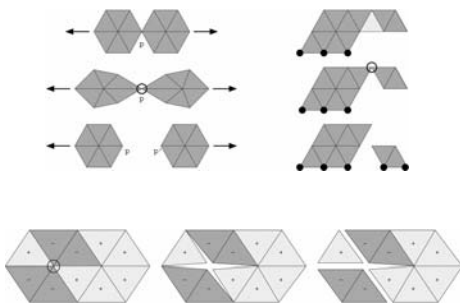


Images from O'Brien et al. 1999



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## Managing Fracture Adjacency



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