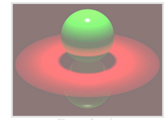
Computer Animation

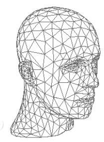
Adam Finkelstein & Tim Weyrich
Princeton University
COS 426, Spring 2008

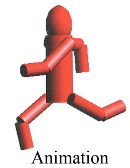
Syllabus

- I. Image processing
- II. Modeling
- III. Rendering
- IV. Animation


Image Processing
(Rusty Coleman, CS426, Fall99)


Rendering
(Michael Bostock, CS426, Fall99)


Modeling
(Dennis Zorin, CalTech)

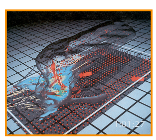

Animation
(Angel, Plate 1)

Computer Animation

- What is animation?
  - Make objects change over time according to scripted actions


Pixar

- What is simulation?
  - Predict how objects change over time according to physical laws

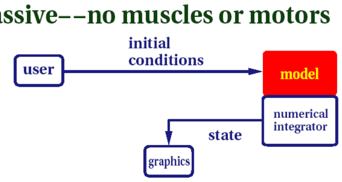

University of Illinois

Simulation

- Dynamics
  - Considers underlying forces
  - Compute motion from initial conditions and physics
- Kinematics
  - Considers only motion
  - Determined by positions, velocities, accelerations

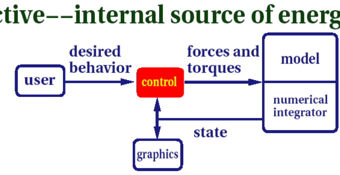
Dynamics

Passive––no muscles or motors



particle systems
leaves
water spray
clothing

Active––internal source of energy

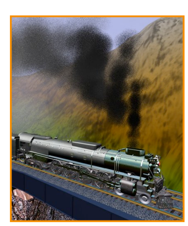


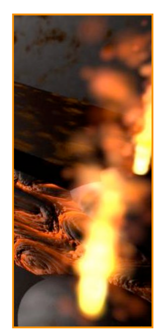
running human
trotting dog
swimming fish

Hodgins

Passive Dynamics

- No muscles or motors
  - Smoke
  - Water
  - Cloth
  - Fire
  - Fireworks
  - Dice





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Passive Dynamics

- Physical laws
  - Newton's laws
  - Hook's law
  - Etc.
- Physical phenomena
  - Gravity
  - Momentum
  - Friction
  - Collisions
  - Elasticity
  - Fracture

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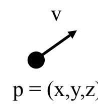
Particle Systems

- A particle is a point mass
  - Mass
  - Position
  - Velocity
  - Forces
  - Color
  - Lifetime



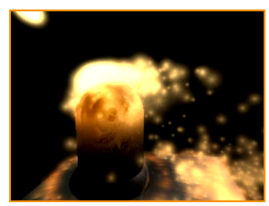
- Use lots of particles to model complex phenomena
  - Keep array of particles
  - Newton's laws

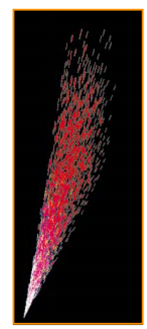
Particle Systems

- For each frame:
  - Create new particles and assign attributes
  - Delete any expired particles
  - Update particles based on attributes and physics
  - Render particles

Creating Particles

- Where to create particles?
  - ➢ Predefined source
  - Surface of shape
  - Where particle density is low
  - etc.





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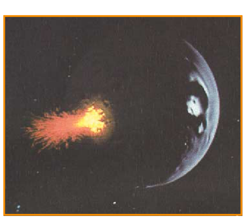
Creating Particles

- Where to create particles?
  - Predefined source
  - ➢ Surface of shape
  - Where particle density is low
  - etc.

Reeves



Deleting Particles

- When to delete particles?
  - Predefined sink
  - Surface of shape
  - Where density is high
  - Life span
  - Random

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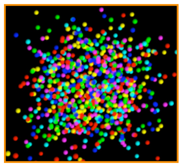
Rendering Particles

- Rendering styles
  - ➢ Points
  - Polygons
  - Shapes
  - Trails
  - etc.



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Rendering Particles

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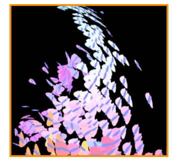


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Rendering Particles

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Rendering Particles

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Particle Systems

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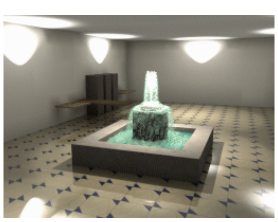

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Equations of Motion

- Newton's Law for a point mass
  - f = ma
- Computing particle motion requires solving second-order differential equation

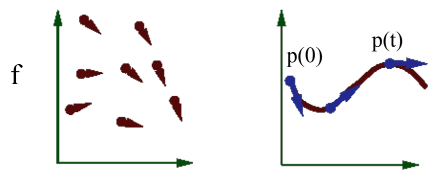
$$\ddot{x} = \frac{f(x, \dot{x}, t)}{m}$$

- Add variable v to form coupled first-order differential equations

$$\begin{cases} \dot{x} = v \\ \dot{v} = \frac{f}{m} \end{cases}$$

Solving the Equations of Motion

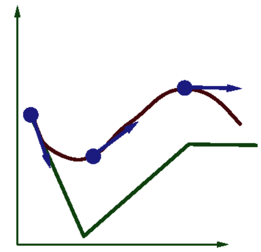
- Initial value problem
  - Know p(0), v(0), a(0)
  - Can compute force at any time and position
  - Compute p(t) by forward integration



Hodgins

Solving the Equations of Motion

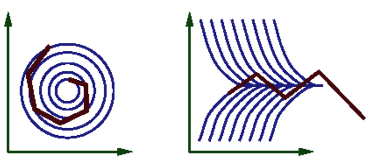
- Euler integration
  - p(t+Δt)=p(t) + Δt v(t)
  - v(t+Δt)=v(t) + Δt f(x,t)/m



Hodgins

Solving the Equations of Motion

- Euler integration
  - p(t+Δt)=p(t) + Δt v(t)
  - v(t+Δt)=v(t) + Δt f(p(t),t)/m
- Problem:
  - Accuracy decreases as Δt gets bigger



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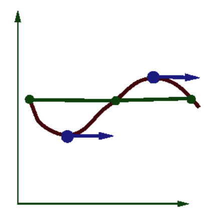
Solving the Equations of Motion

- Midpoint method (2nd order Runge-Kutta)
  - Compute an Euler step
  - Evalute f at the midpoint
  - Take an Euler step using midpoint force
    - » v(t+Δt)=v(t) + Δt f(p(t) + 0.5*Δt v(t),t)



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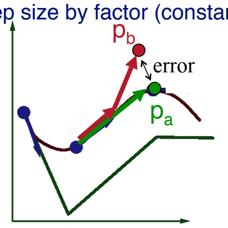
Solving the Equations of Motion

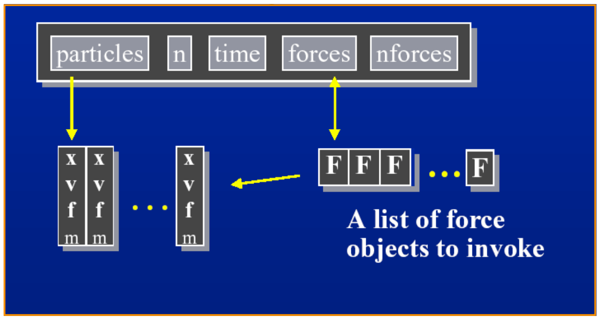
- Adapting step size
  - Compute p_a by taking one step of size h
  - Compute p_b by taking 2 steps of size h/2
  - Error = l p_a - p_b l
  - Multiply step size by factor (constant/error)



Particle System Forces

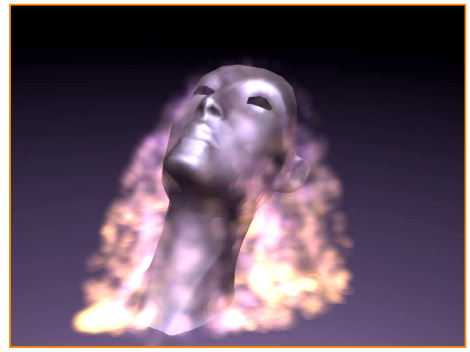
- Force fields
  - Gravity, wind, pressure
- Viscosity/damping
  - Liquids, drag
- Collisions
  - Environment
  - Other particles
- Other particles
  - Springs between neighboring particles (mesh)
  - Useful for cloth

Particle System Forces



Witkin

Example: Gravity



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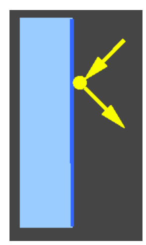
Example: Fire

Example: Bouncing Off Wall

- Requires
  - Collision detection
  - Collision response (dynamic forces)



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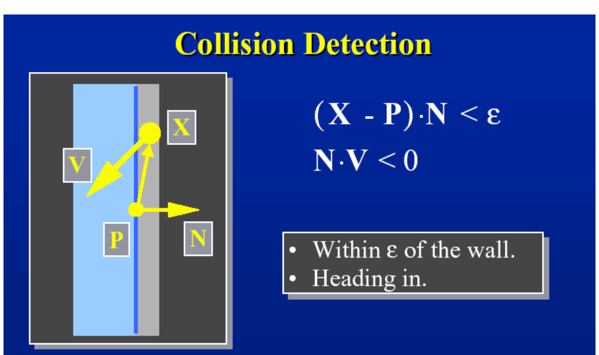
Example: Bouncing Off Wall



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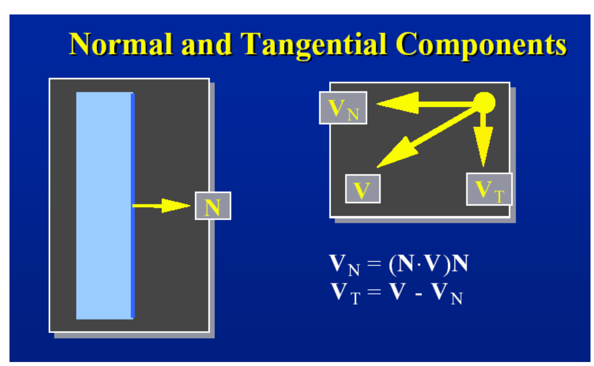
Example: Bouncing Off Wall



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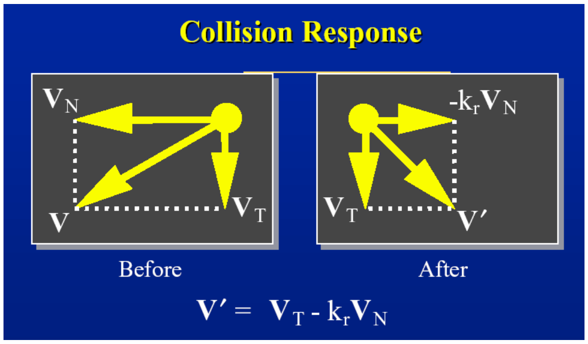

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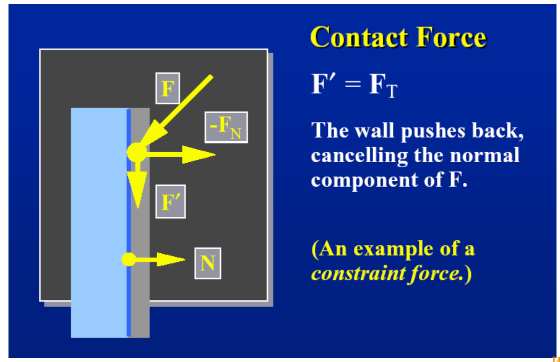

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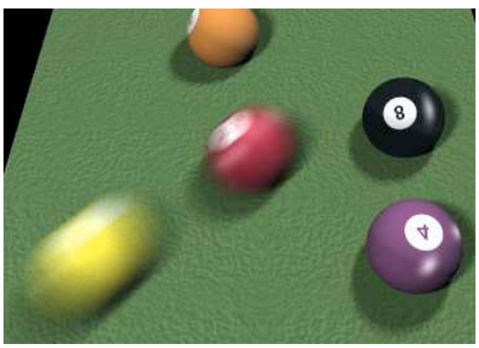
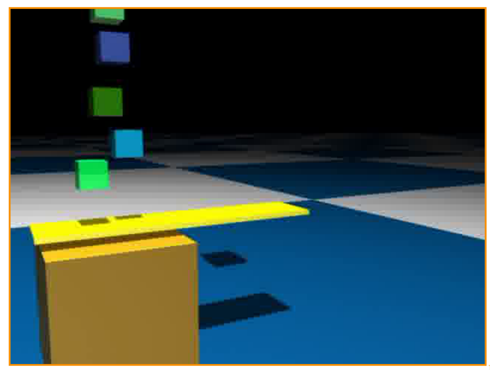
Example: Bouncing Off Particles

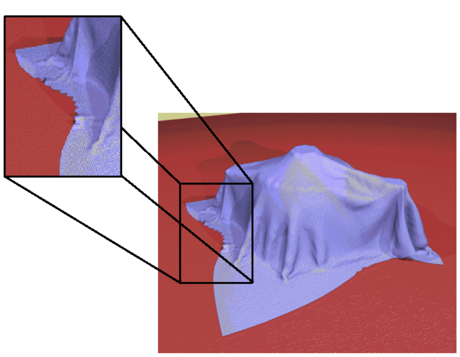


Example: More Bouncing



Bender

Example: Cloth



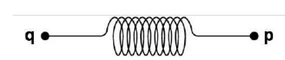
Breen

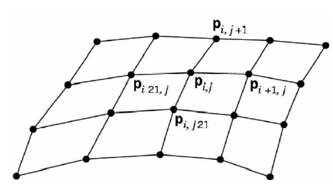
Example: Cloth

- Spring-mass mesh
- Hooke's law

$$\mathbf{f} = -k_s(|\mathbf{d}| - s)\frac{\mathbf{d}}{|\mathbf{d}|}$$

f = force
k_s = spring constant
d = p - q
s = resting length

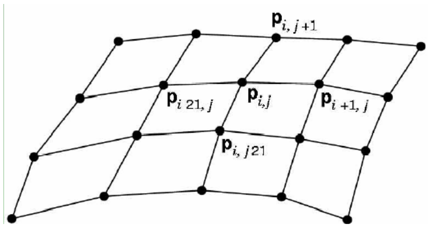


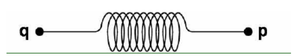


Hodgins

Example: Cloth

- Spring-mass mesh





Hodgins

Example: Cloth

- Hooke's law

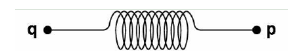
$$\mathbf{f} = -k_s(|\mathbf{d}| - s)\frac{\mathbf{d}}{|\mathbf{d}|}$$

f = force
k_s = spring constant
d = p - q
s = resting length

- Damping term

$$\mathbf{f} = -\left(k_s(|\mathbf{d}| - s) + k_d\frac{\dot{\mathbf{d}}\cdot\mathbf{d}}{|\mathbf{d}|}\right)\frac{\mathbf{d}}{|\mathbf{d}|}$$

$$\dot{\mathbf{d}} = \dot{\mathbf{p}} - \dot{\mathbf{q}}$$



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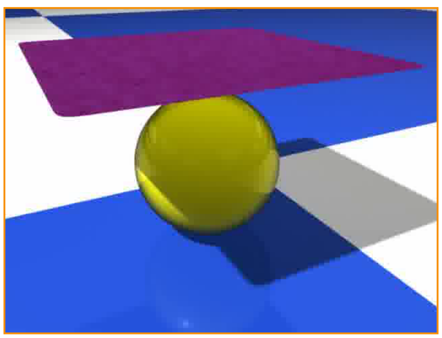
Example: Cloth



Bender

Example: Flocks & Herds

Summary

- Particle systems
  - Lots of particles
  - Simple physics
- Interesting behaviors
  - Waterfalls
  - Smoke
  - Cloth
  - Flocks
- Solving motion equations
  - Simplest method is Euler integration
  - Better to use adaptive step sizes