Announcements

- Assignment 3 is out – due Tuesday November 5th at midnight
- Midterm on Thursday
- Midterm grades are posted—beware, they are artificially high because we haven't had any exams yet. Cutoff was just 90/80/70.
- Programming Assignment 3 and Written assignment 3 are graded

Animation--Simulation

Passive Simulations
Behavioral Animations (lightly)
Dynamics
Active Simulations
Control Systems

COMPUTER GRAPHICS

15-462

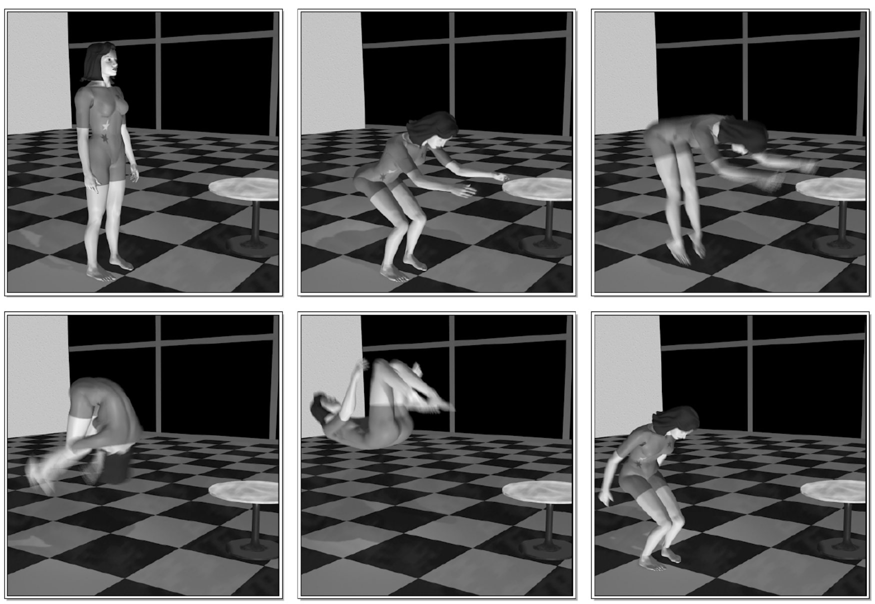
10/21/02

Overview

- Animation techniques
  - –Traditional animation
  - –Keyframing
  - –Motion Capture
  - –Simulation
  - –Behavioral

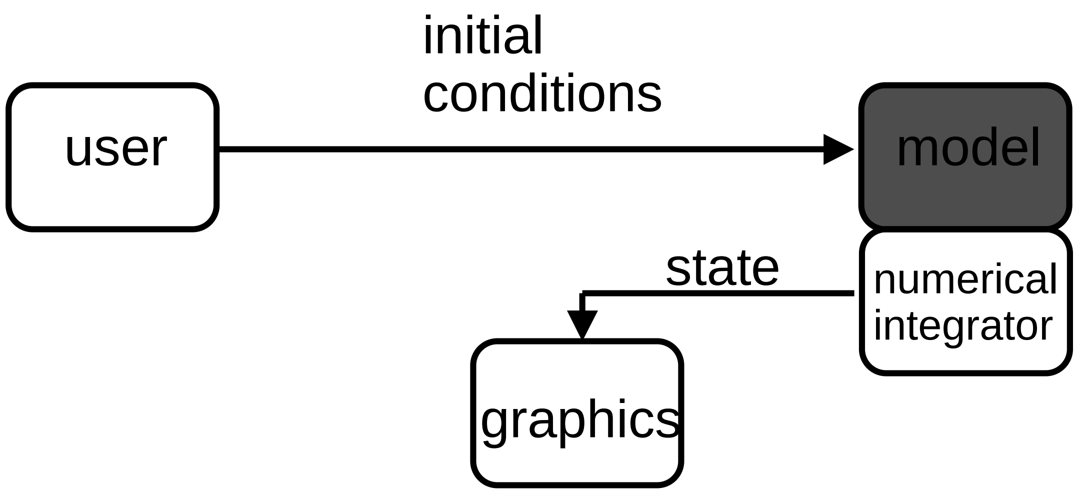
Dynamic Simulation

- Realistic motion
- High-level control
- Design of control routines
- Physics of passive systems
- Control for the animator?



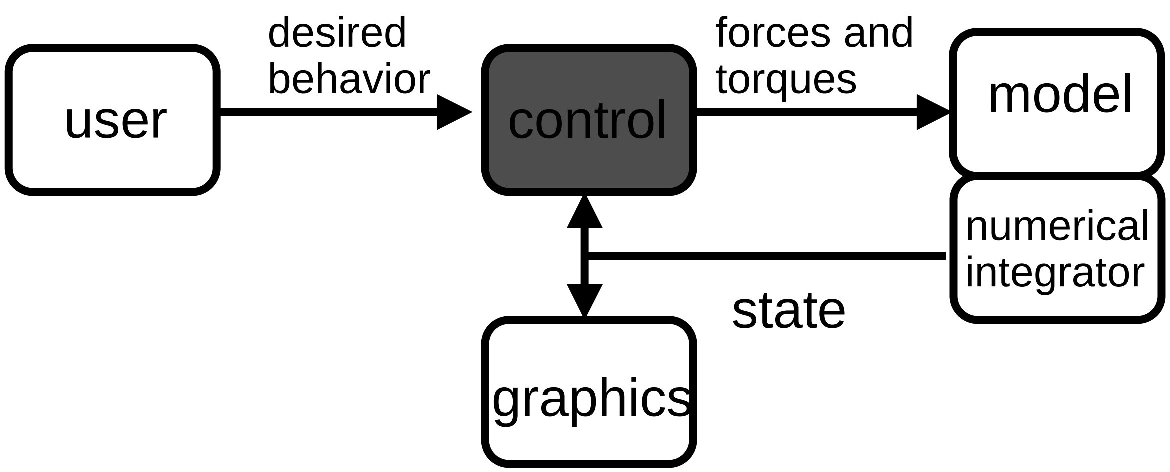
Antz, PDI/Dreamworks

Passive—no muscles or motors



Particle systems
Leaves
Water spray
Clothing

Active—internal sources of energy

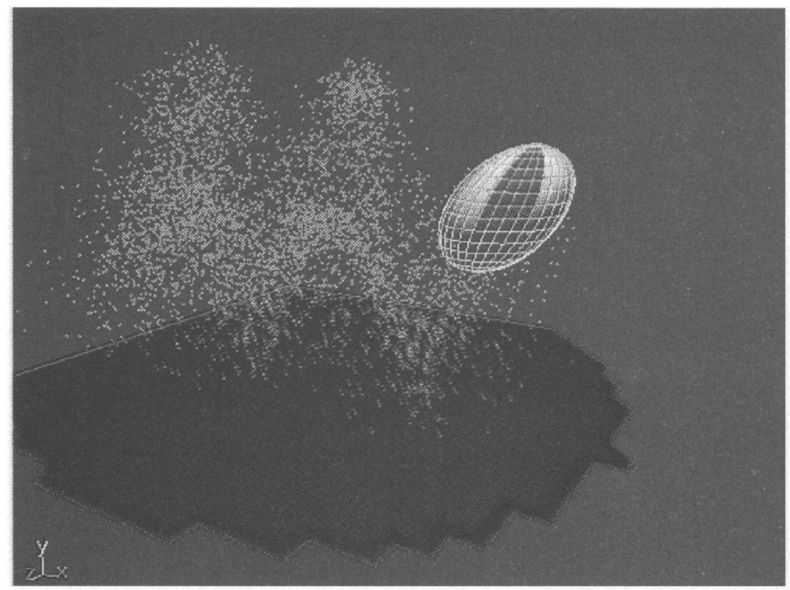


Running human
Trotting dog
Swimming fish

Dynamics

- Generate motion by specifying mass and force, apply physical laws (e.g., Newton's laws)
  - particles
  - soft objects
  - rigid bodies
- Simulates physical phenomena
  - gravity
  - momentum (inertia)
  - collisions
  - friction
  - fluid flow (drag, turbulence, ...)
  - solidity, flexibility, elasticity
  - fracture

Maya Dynamics



Particle Systems

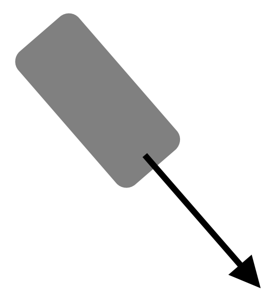
Clouds
Smoke
Fire
Waterfalls
Fireworks

Reeves ’83, the Wrath of Khan
Batman Returns, using Reynold’s flocking algorithms

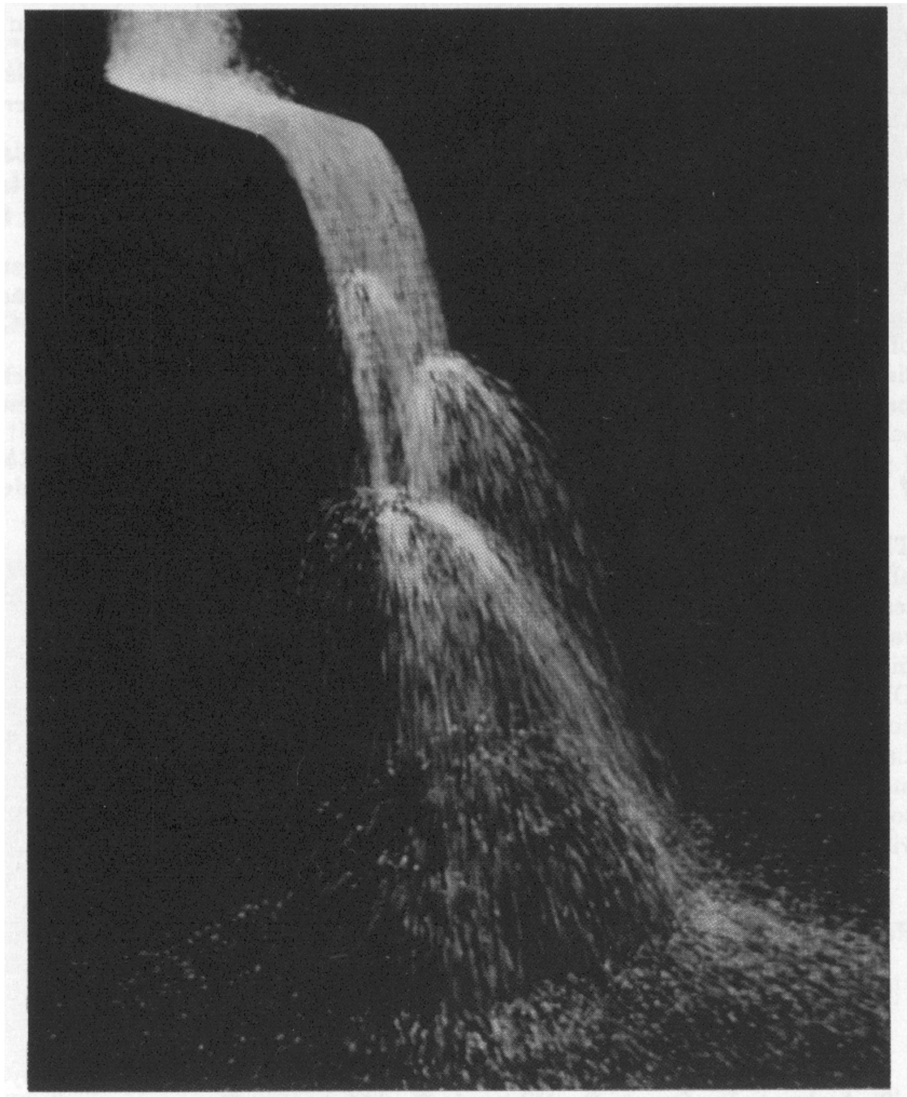
Particle Systems

- Creation—number, initial condiions
  - position/velocity
    - randomly
    - surface of shape
    - vertex of polygonal object
  - size
  - color
  - transparency
  - shape
  - lifetime
- Deletion
- Update of position/velocity
  - translation
  - vortex
- Rendering style – motion blur, compositing

What control handles do we want/need?



Karl Sims, Particle Dreams



Behavioral Animation

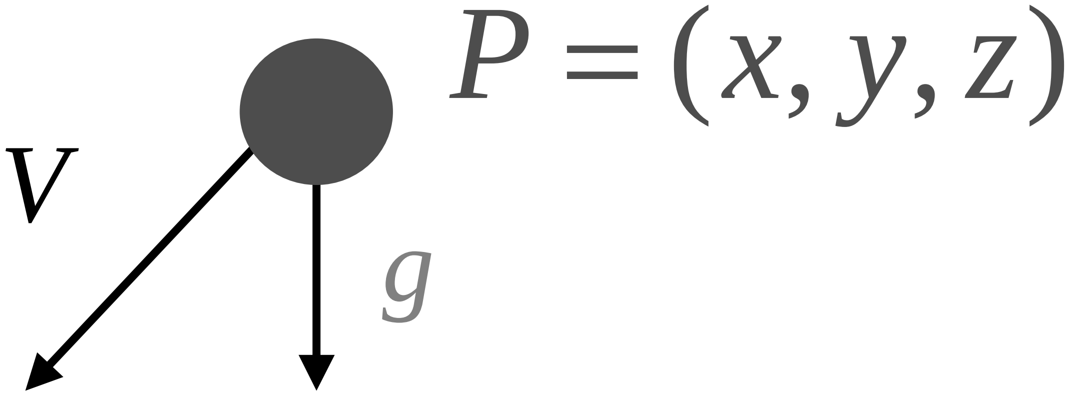
- Define rules for the way an object behaves and interacts
  - models respond to their changing environment
  - programs implement the rules
- Classic example: “boids” (Craig Reynolds)
  - object’s motion is a simple function of nearby objects
    - » Stay near neighbors
    - » Don’t run into them
    - » Move in this general direction
  - emergent behavior: flocking
  - really just a particle system(!)
- *Lion King* wildebeest stampede

Equations of Motion

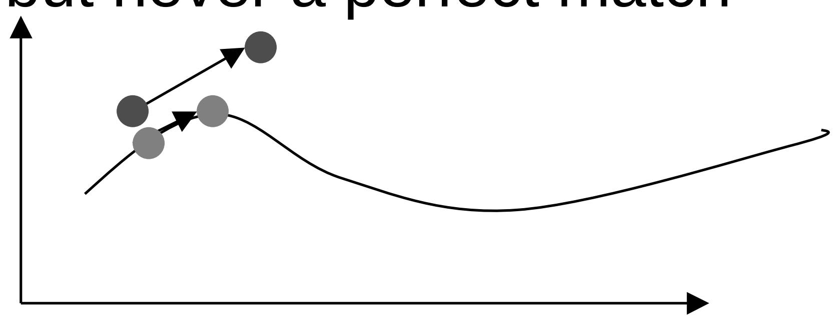
$$A = g$$

$$V' = V + A\Delta t$$

$$P' = P + \frac{V + V'}{2}\Delta t$$



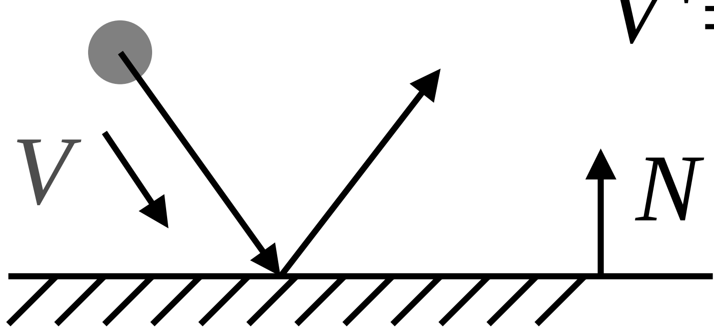
Integration: accuracy improves as step size decreases but never a perfect match



More generally have other forces

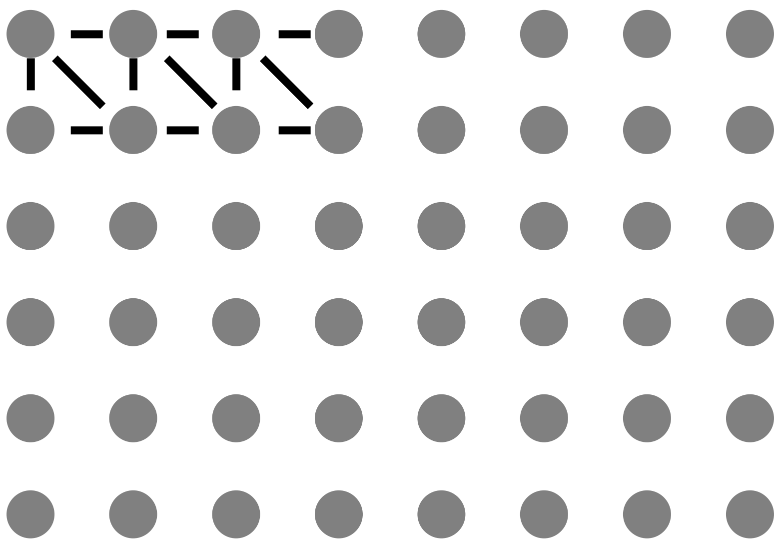
- Unary
  - Gravity f = mg
  - Viscous drag: f=-kv
- N-ary
  - Spring: f=ke
- Spatial interaction forces
  - Collisions with objects in the environment

$$V' = V - 2(V \bullet N)N$$



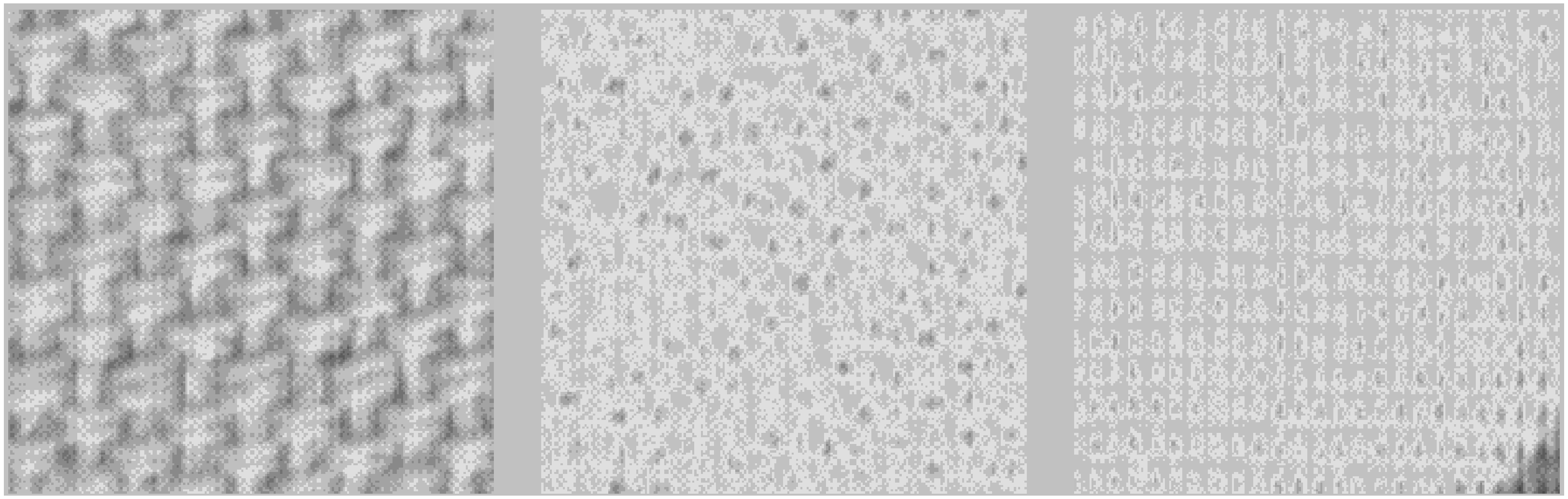
Spring-Mass Systems

Cloth in 2d
Jello in 3D



Spring-Mass Systems

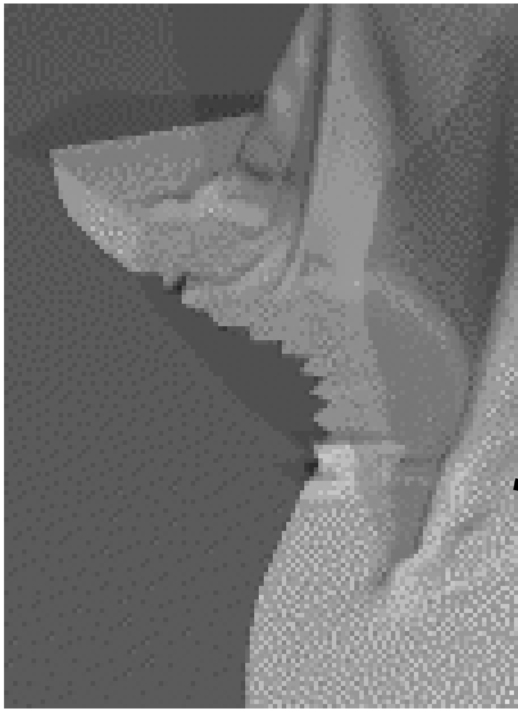
Cloth

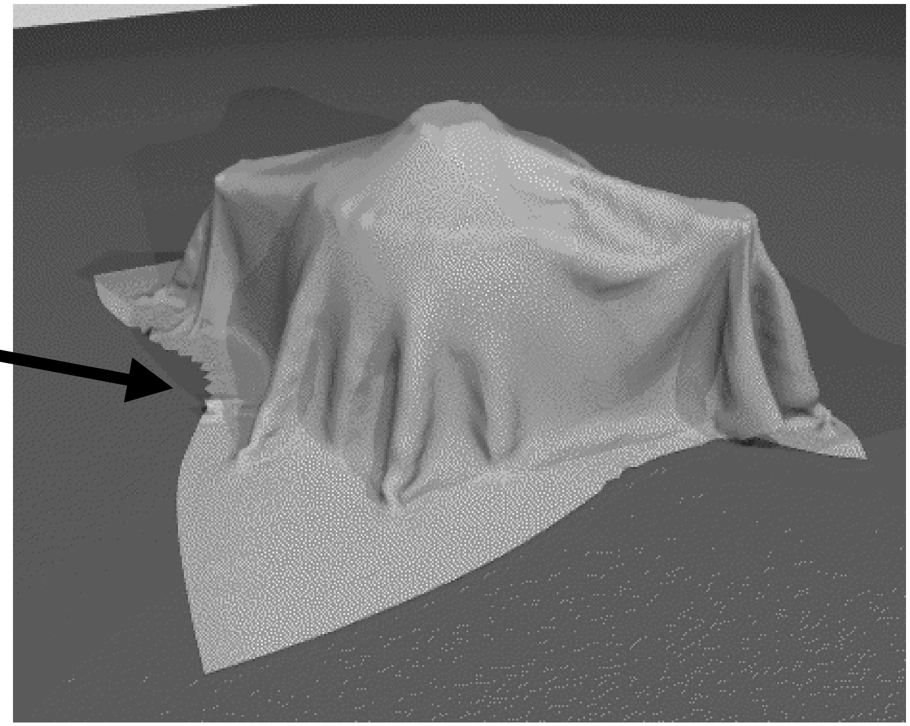


Breen '95

Many types of cloth
Very different properties
Not a simple elastic surface
Woven fabrics tend to be very stiff
Anisotropic

Cloth

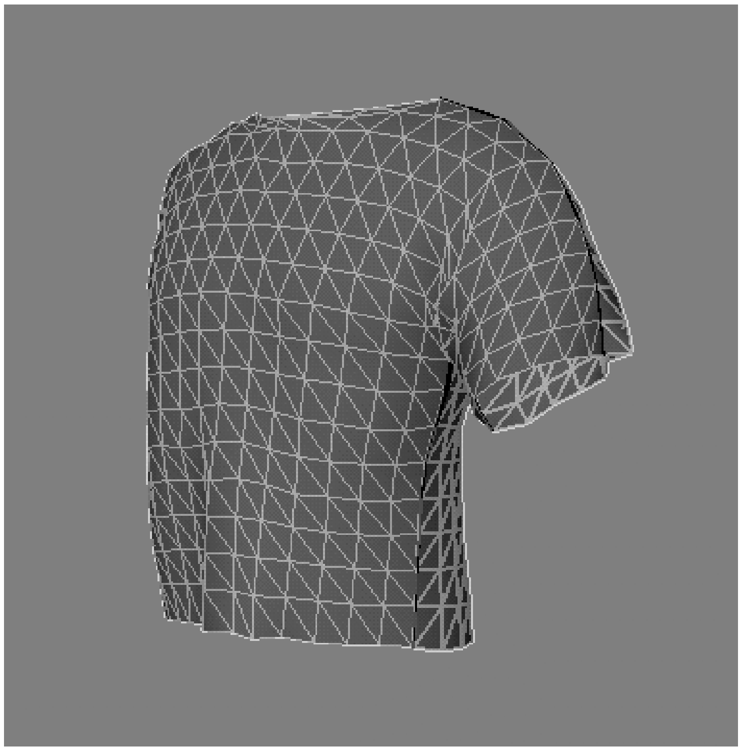


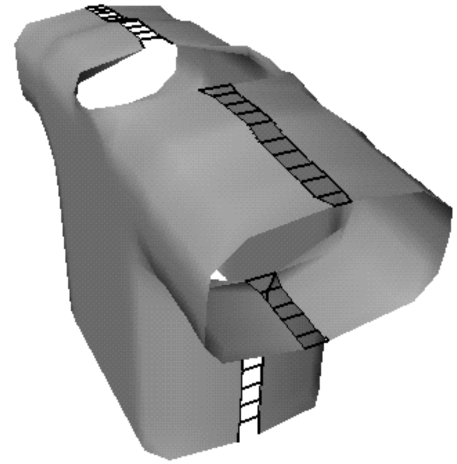


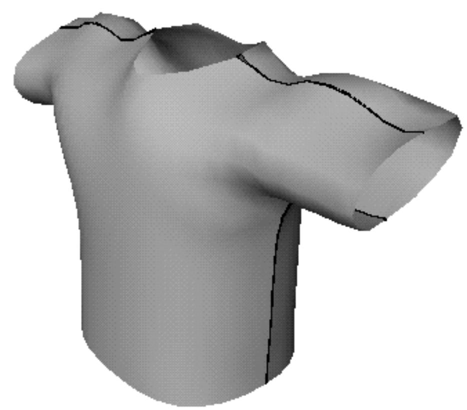
Breen '95

Increased Resolution of Mesh
- +Possible Shapes
- + Smoothness
- - Simulation time

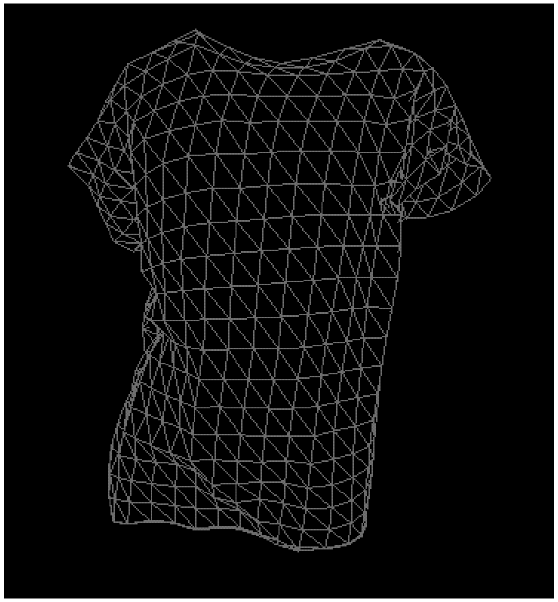
Modeling for Clothing

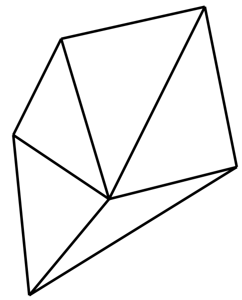




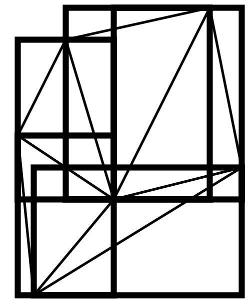


Collisions for Clothing

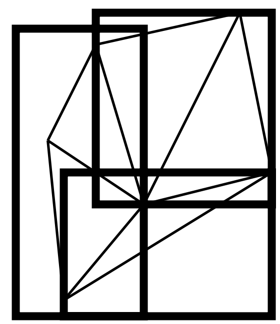




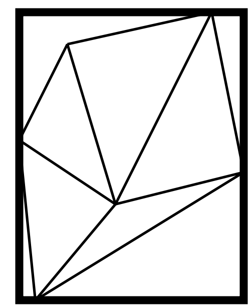
Polygons



Primitive Level



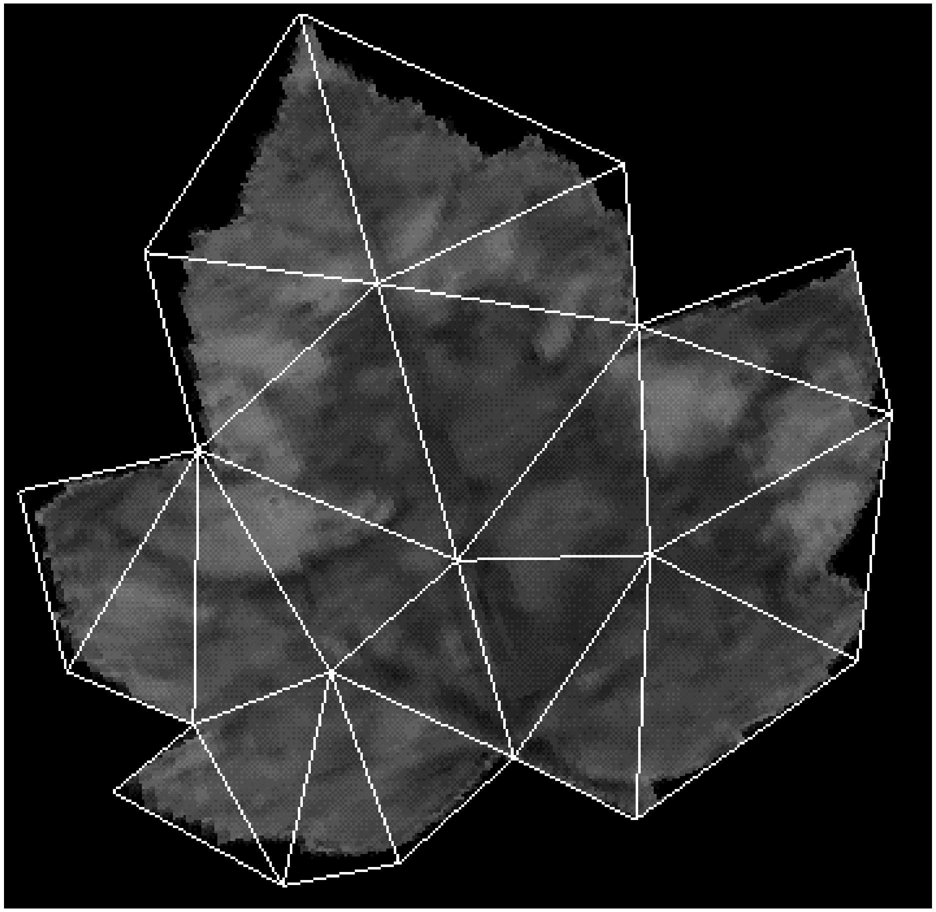
Intermediate
Level(s)

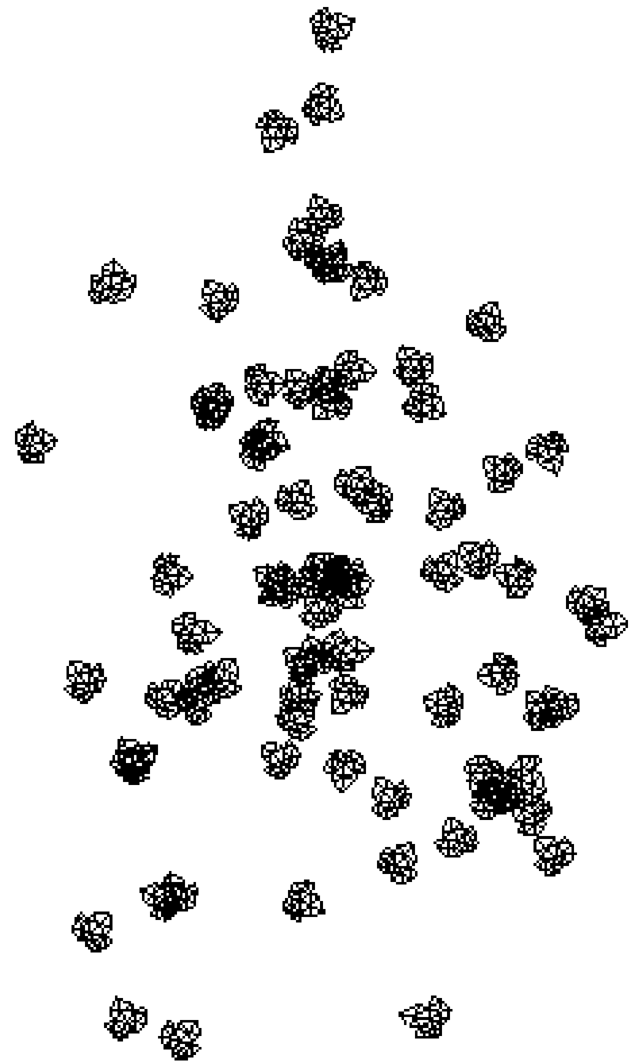


Top Level

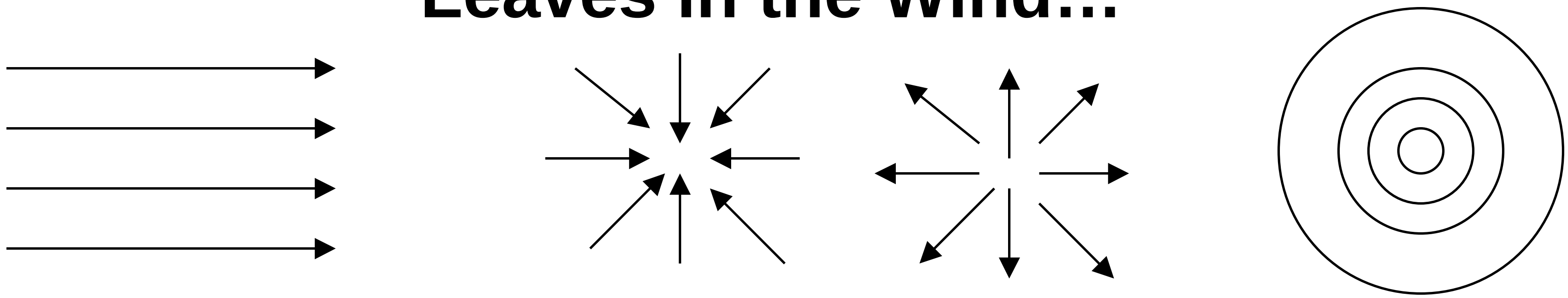
Potentially VERY expensive
Bounding Box Hierarchy
- Partition space or objects
- Avoid expensive primitive tests

Leaves in the Wind…



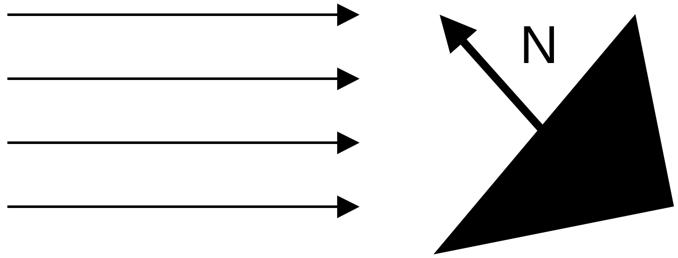


Leaves in the Wind…



uniform sink source vortex

Add together to make interesting fields…



$$F = F^n + F^t$$

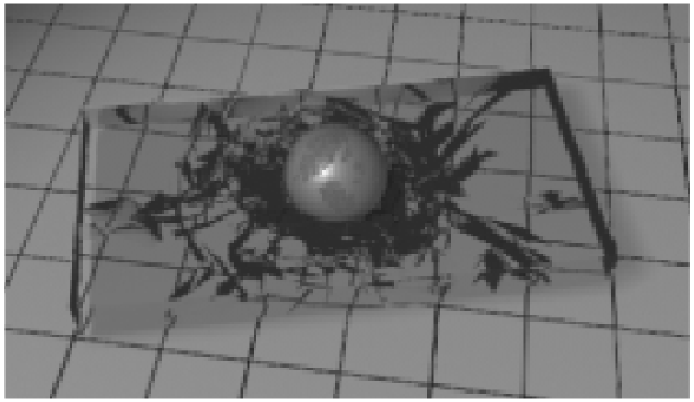
$$F^n = \alpha^n A w^n$$

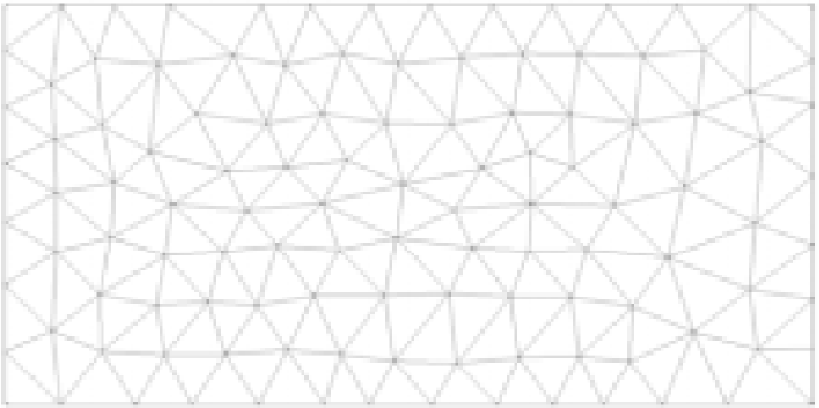
$$F^t = \alpha^t A v^t$$

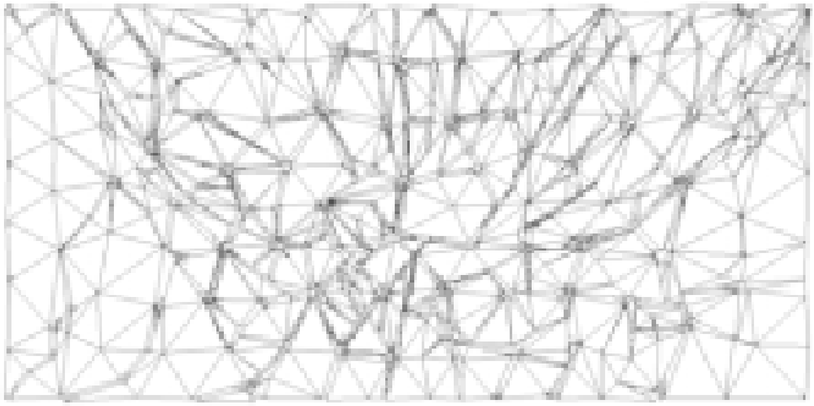
Wejchert&Haumann, '91

Fracture

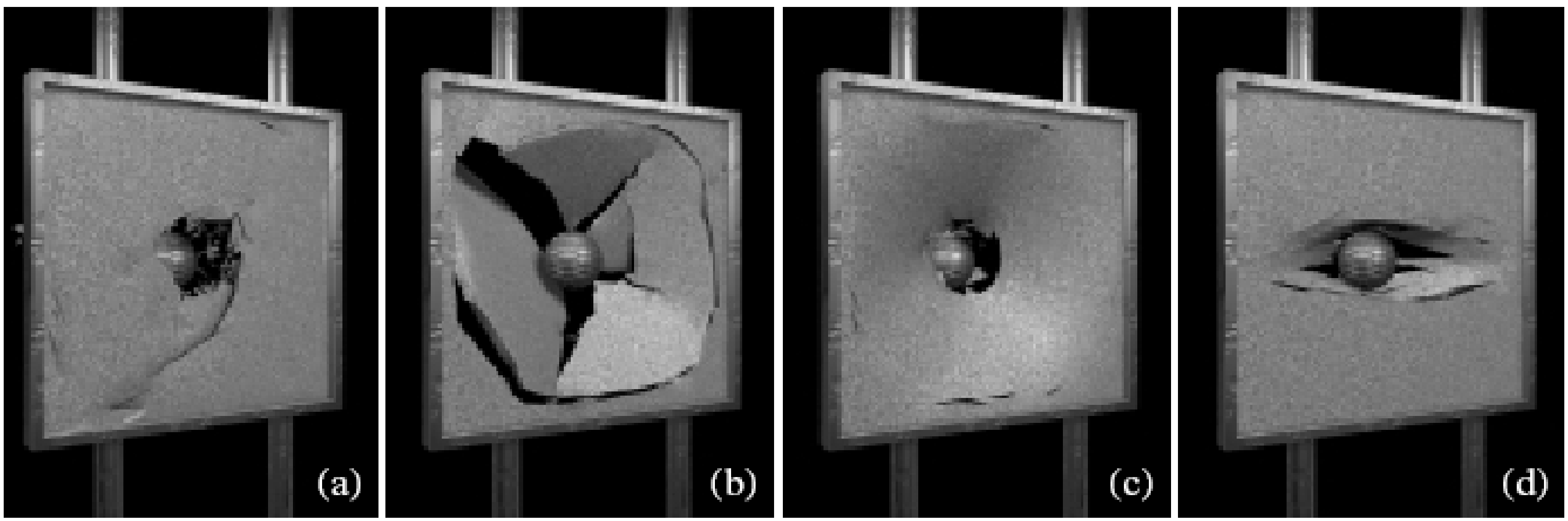
O'Brien, J. F., Hodgins, J. K., (1999) Graphical Modeling and Animation of Brittle Fracture. The proceedings of ACM SIGGRAPH 99, Los Angeles, California.



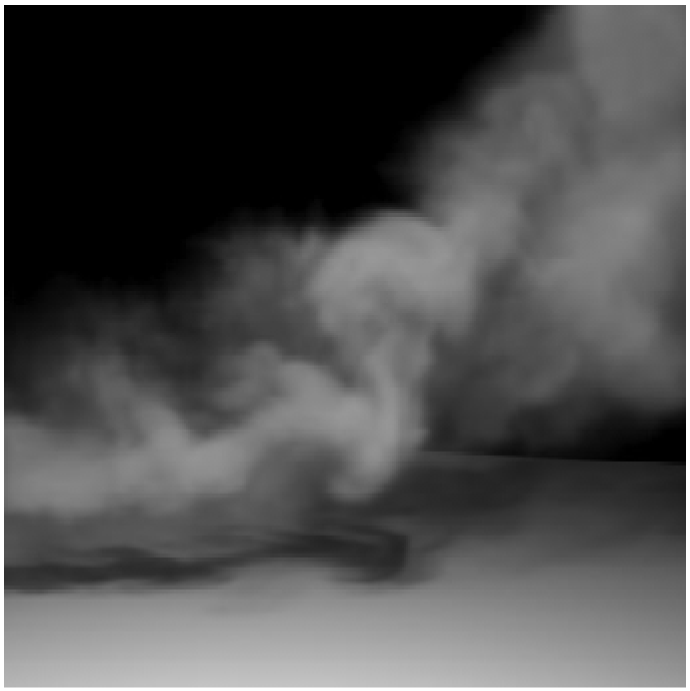
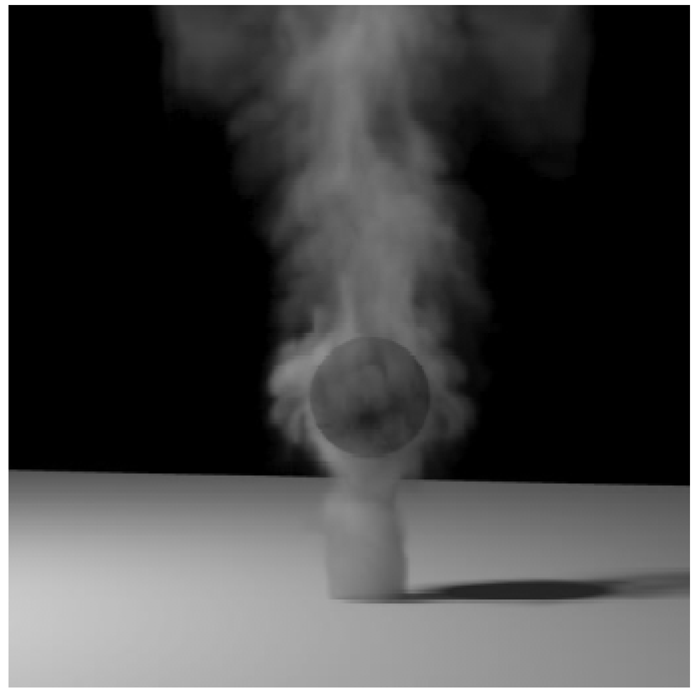




Fracture

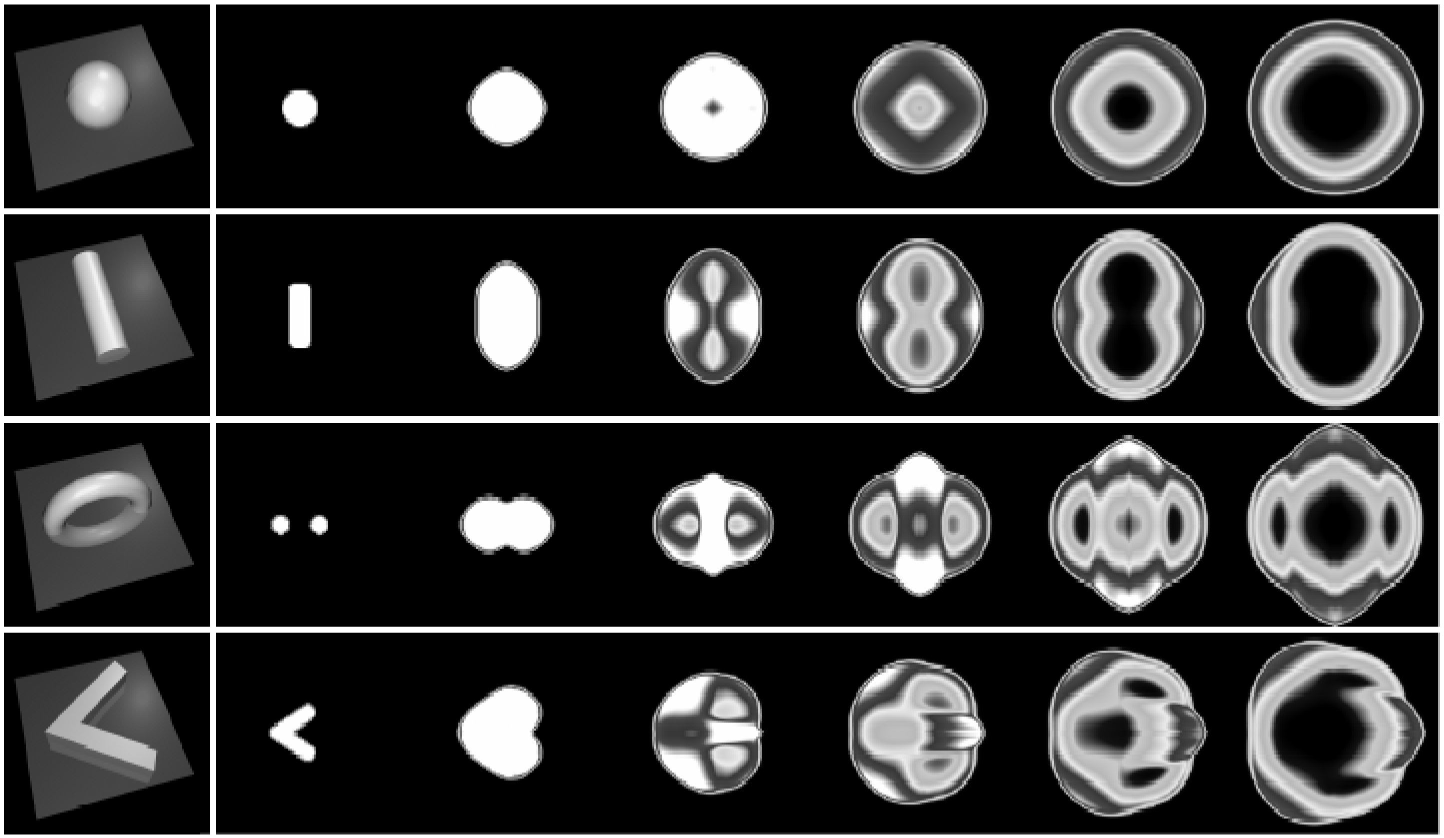


Smoke

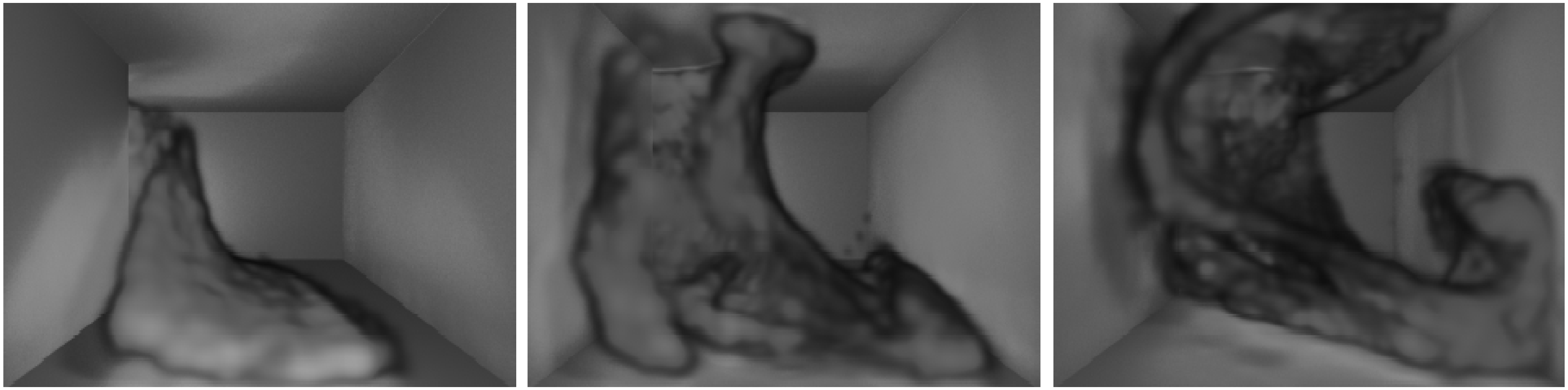
Visual Simulation of Smoke, Ronald Fedkiw Jos Stam Henrik Wann Jensen
SIGGRAPH 2001, Computer Graphics Proceedings

Explosions



Explosions

Yngve, G. D., O'Brien, J. F., Hodgins, J. K., 2000, Animating Explosions. The proceedings of ACM SIGGRAPH 2000.



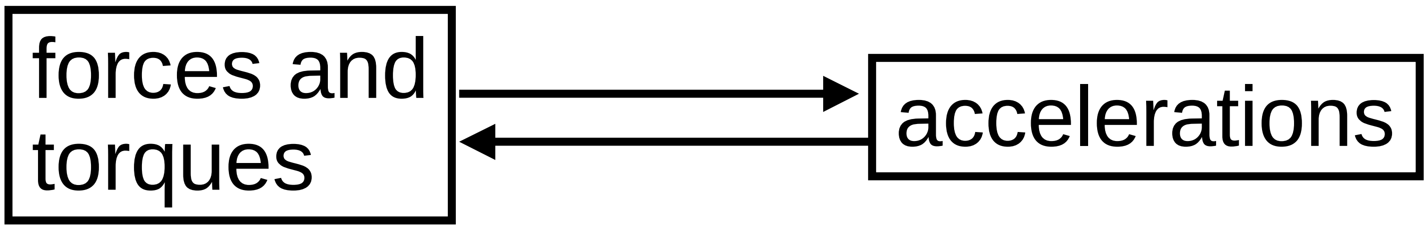
The Challenges of Passive Simulation

- Accurate for the situation
- What pieces of the physics are necessary for appearance?
- How to give the animator control?

Dynamics, more generally

- Point mass
- Spring/mass systems
- Linkages of rigid bodies
- Other physical phenomena
  - Aerodynamics
  - Fluids
  - Fracture
  - Explosions

Forward and Inverse Dynamics

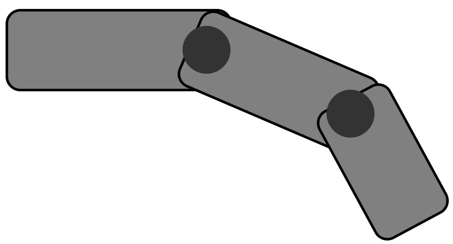


Forward: given forces and torques what is the motion?

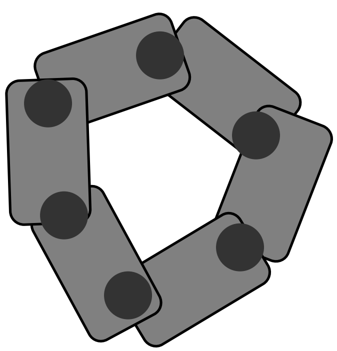
Inverse: given prescribed motion what are the forces and torques?

What can we simulate?

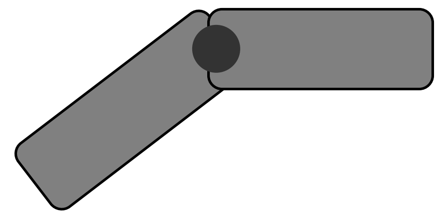
Open loop



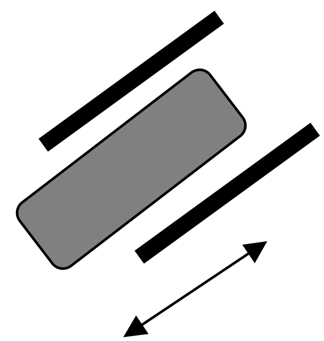
Closed loop



Joints
Rotary (1,2,3d)



Telescoping joints

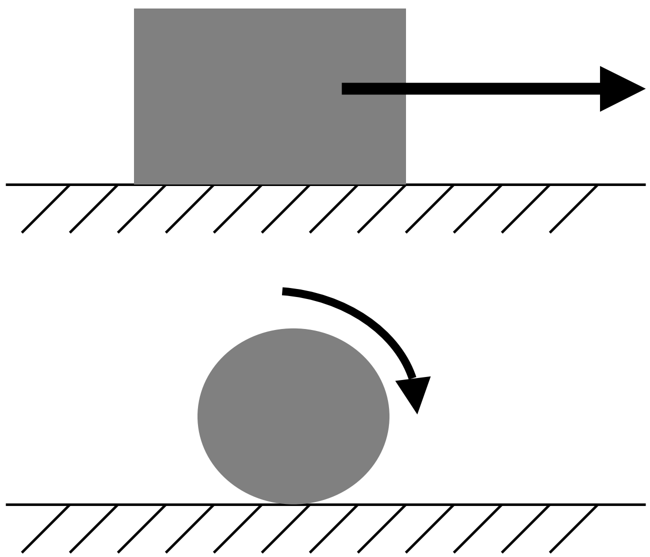


Forces/Torques

Gravity
Wind
Collisions/contact

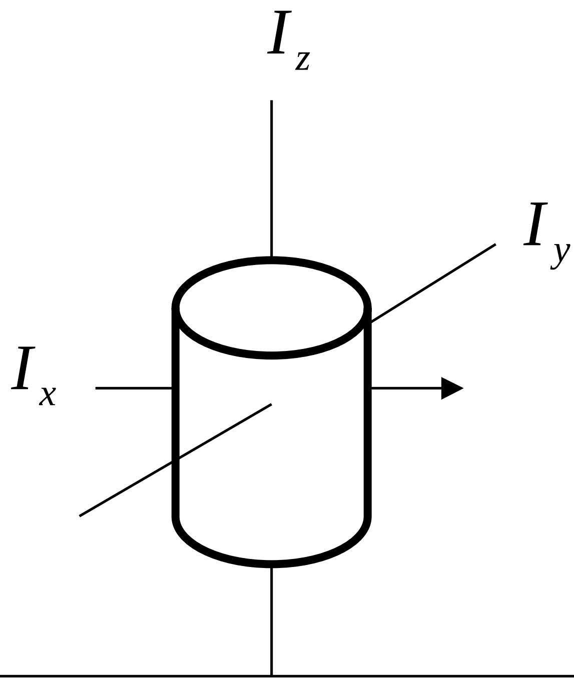
sliding

rolling



System Description

Mass
Center of mass
Moment of inertia: formula for simple objects



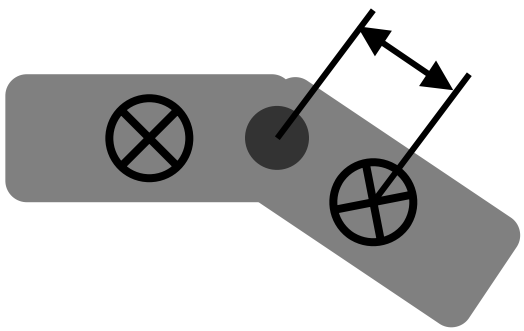
$$I_x = I_y = \frac{1}{12} m(3r^2 + L^2)$$

$$I_z = \frac{mr^2}{2}$$

Calculate from polygonal model (closed) for more complicated shapes

Commercially Available Simulation Code

Link: mass, moment of inertia
Joints: degrees of freedom
distance from center of mass of links



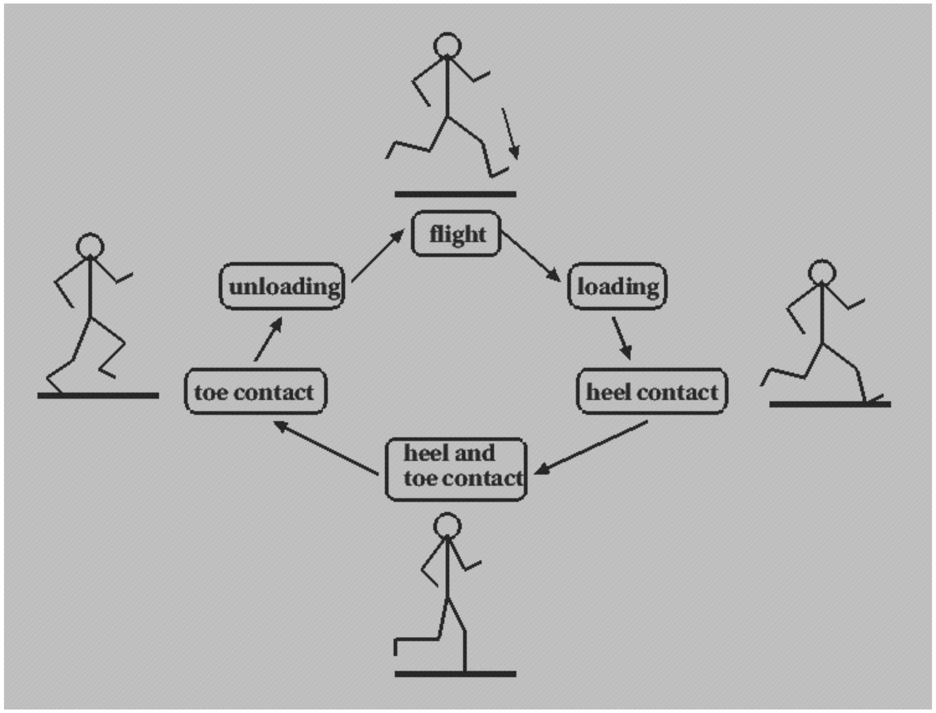
Code for equations of motion
Hooks for applying forces, torques

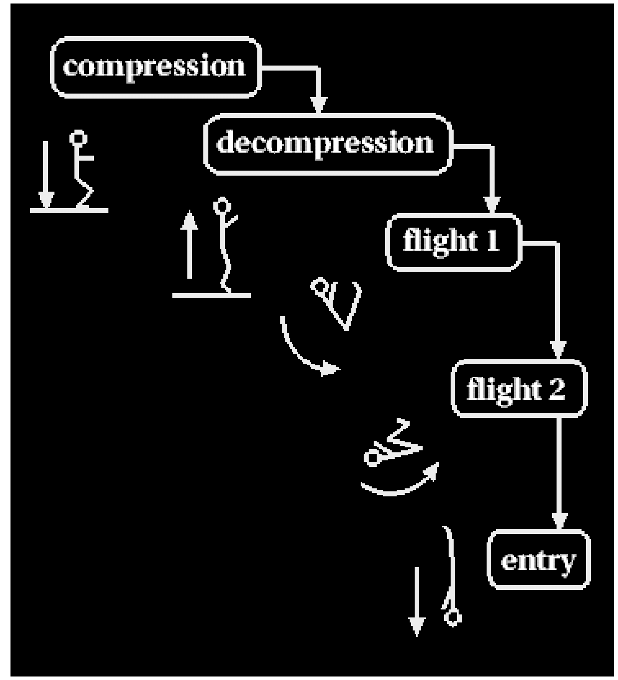
Control Systems—how do we do something with these mechanisms ?

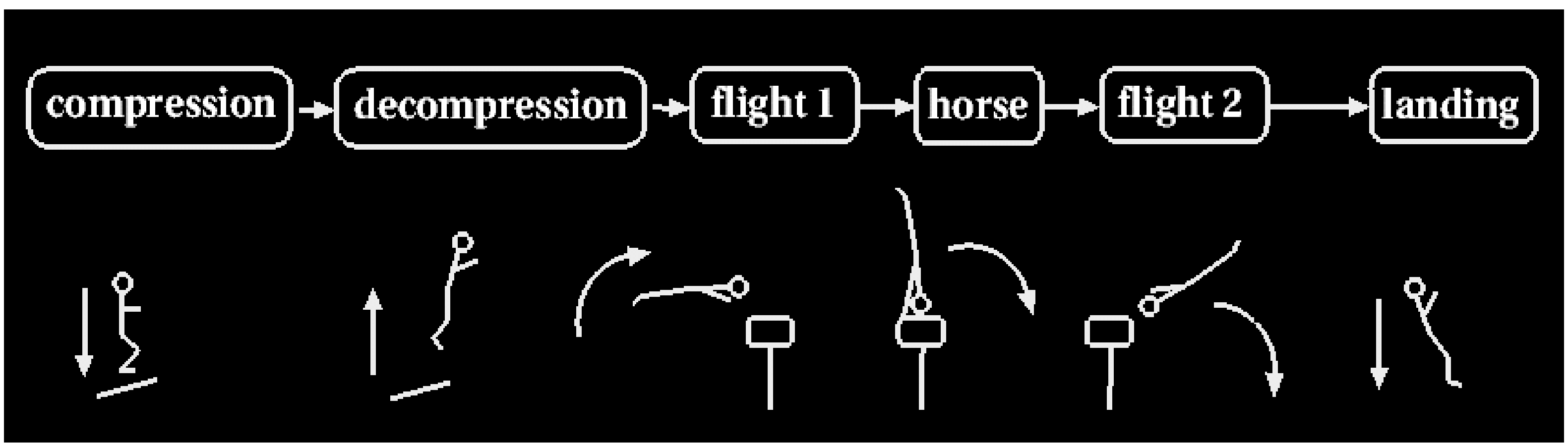
Hierarchy of control:

- State machines
- Control actions
- Low-level servos

State Machines

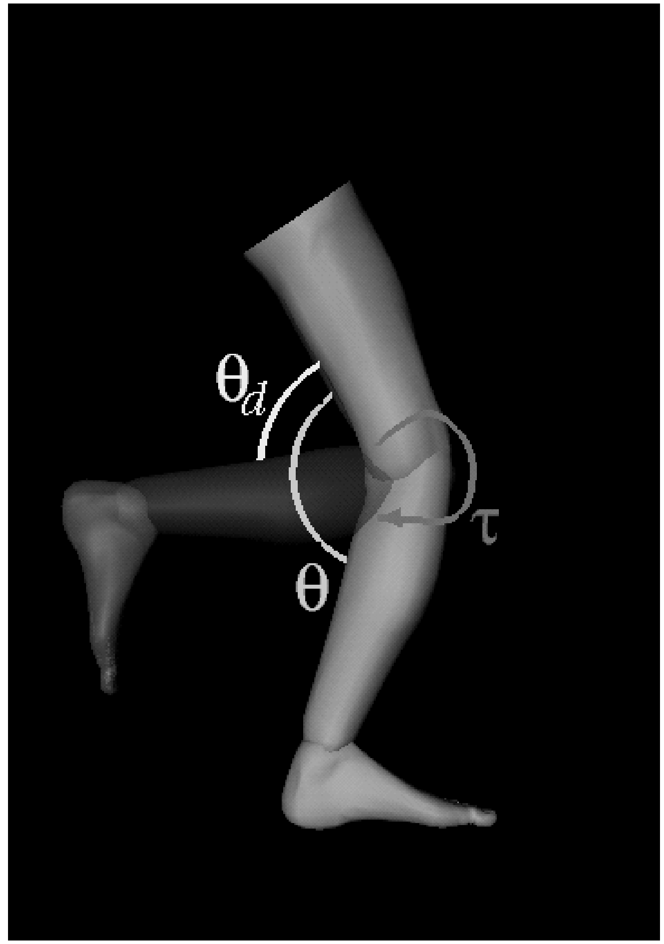






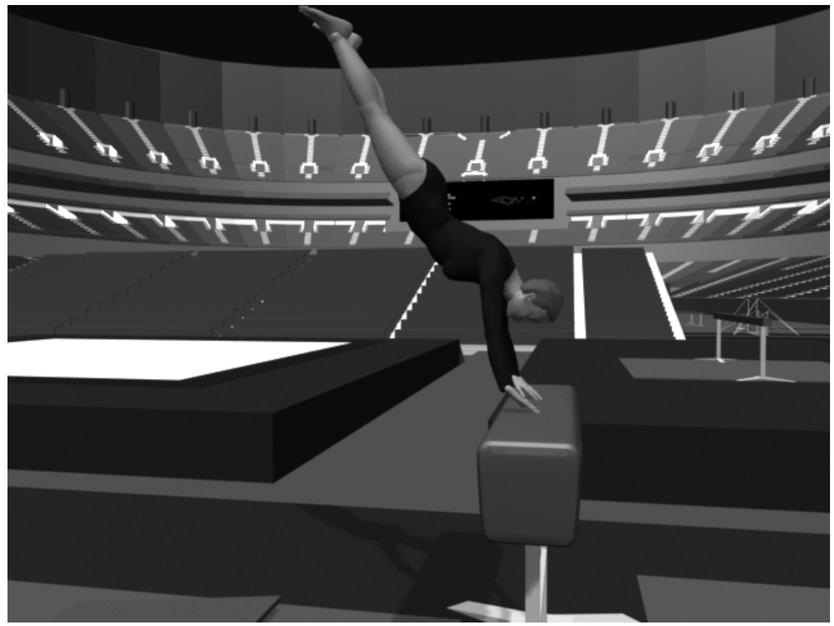
Low-level Control

$$\tau = k_p(\theta_d - \theta) - k_v\,\dot{\theta}$$



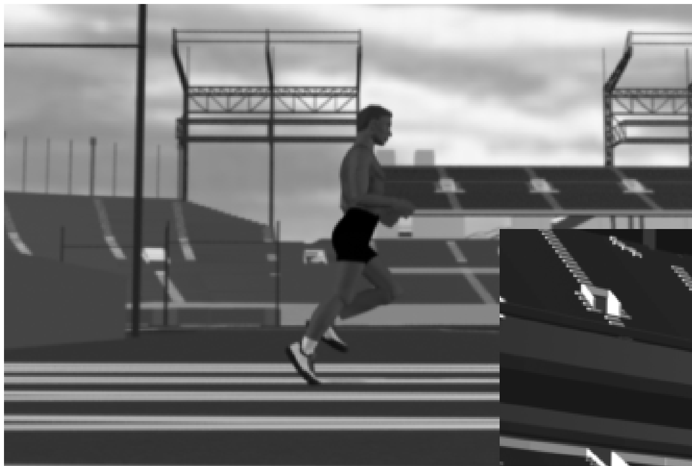
Control Actions

Passive strategies where possible



Control Actions

Synergistic use of joints

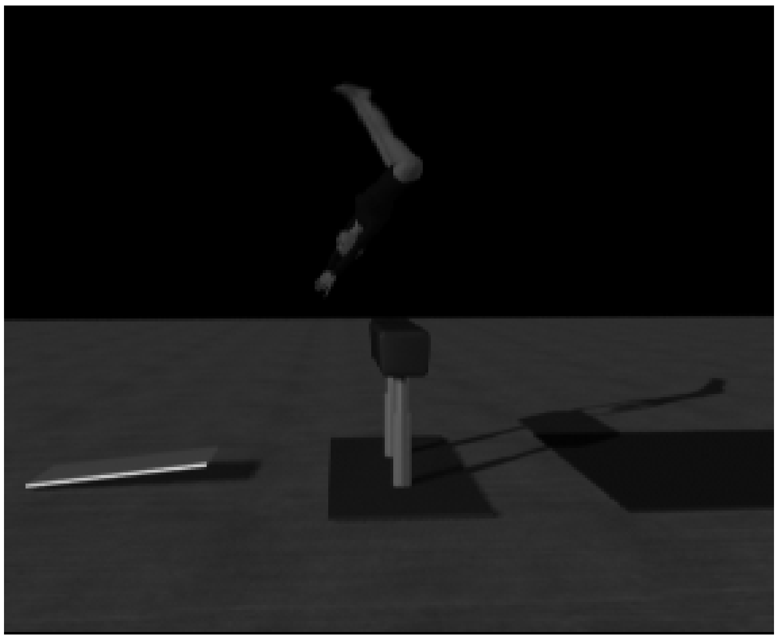


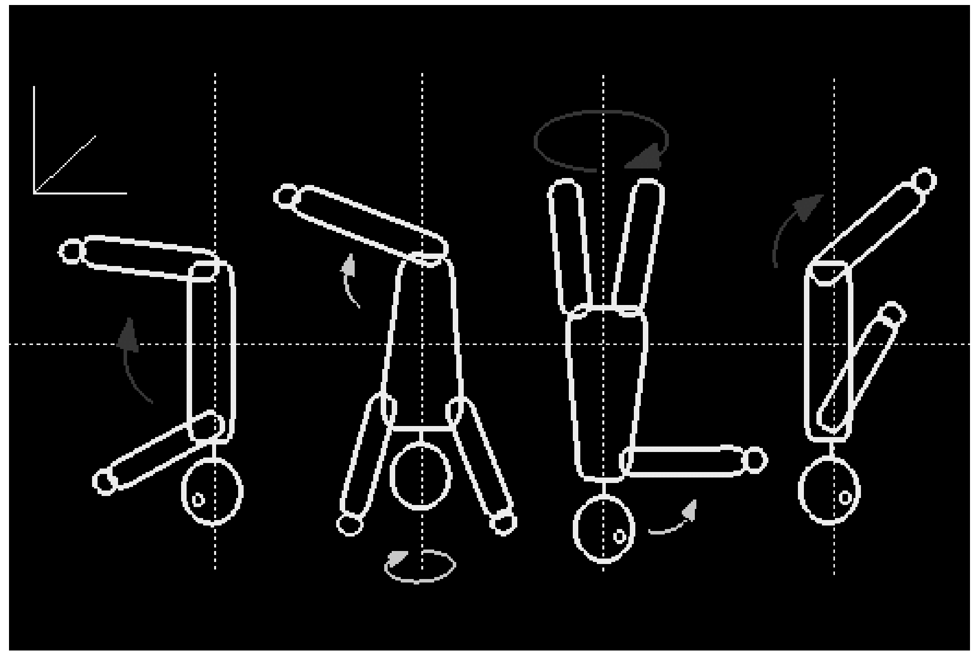
Control Actions

Reduce disturbances

Control Actions

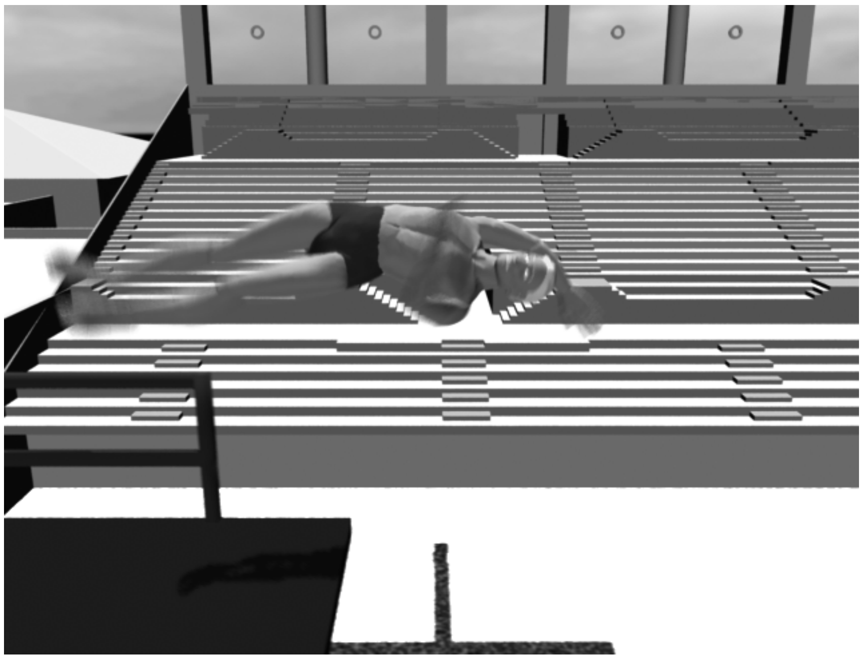
Physical intuition

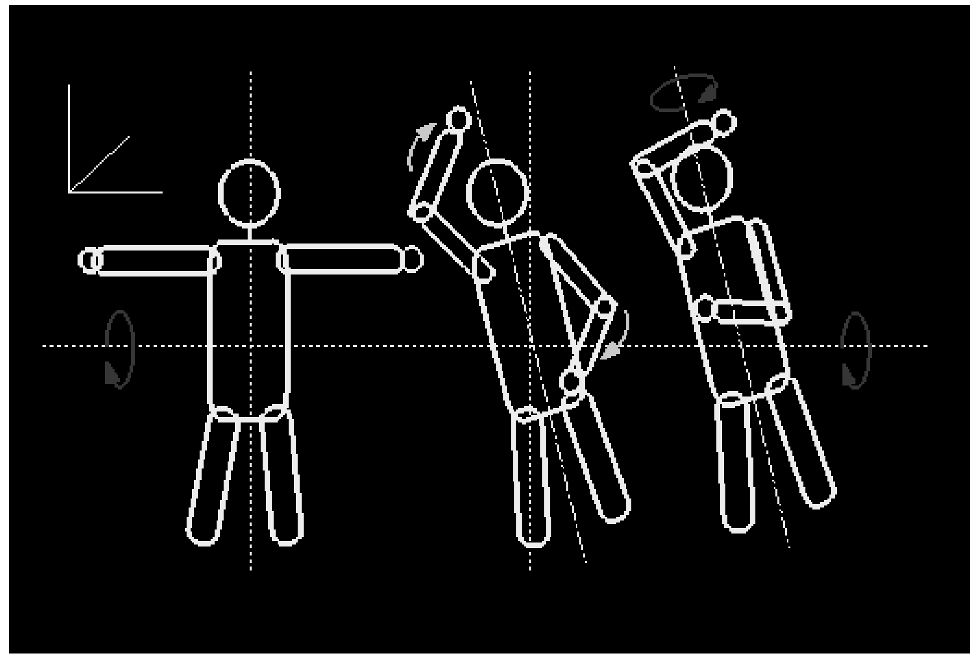


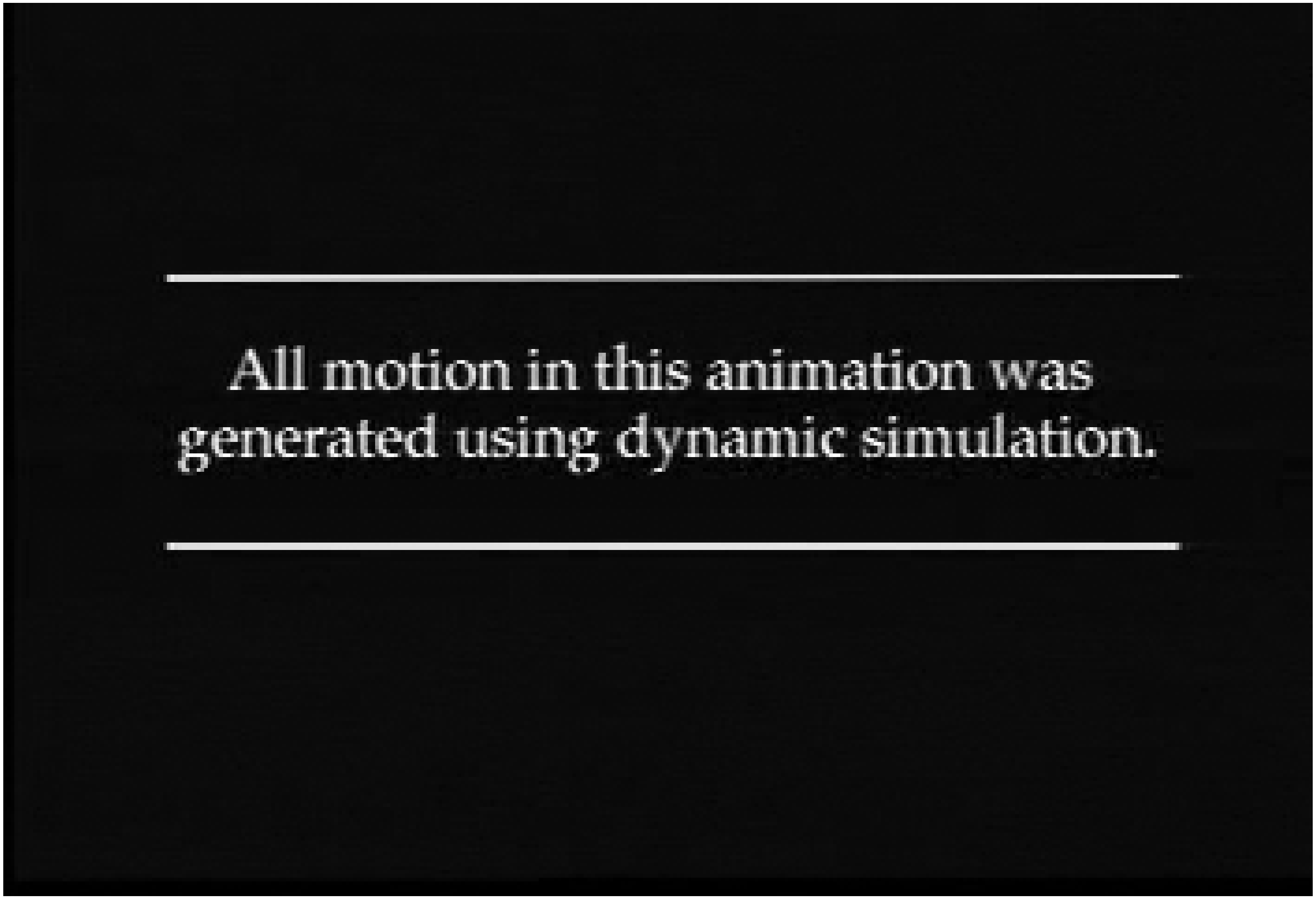


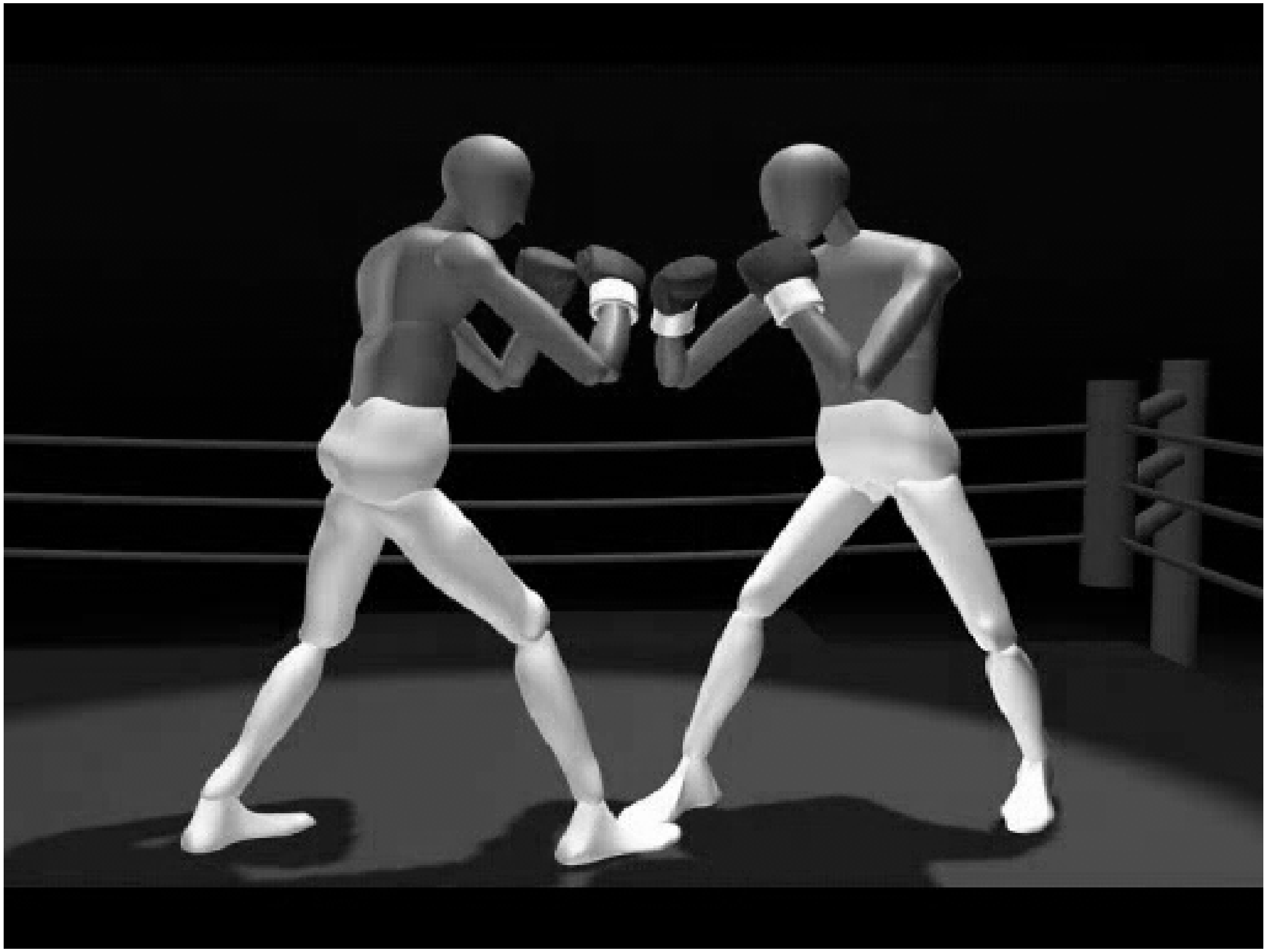
Control Actions

Physical intuition

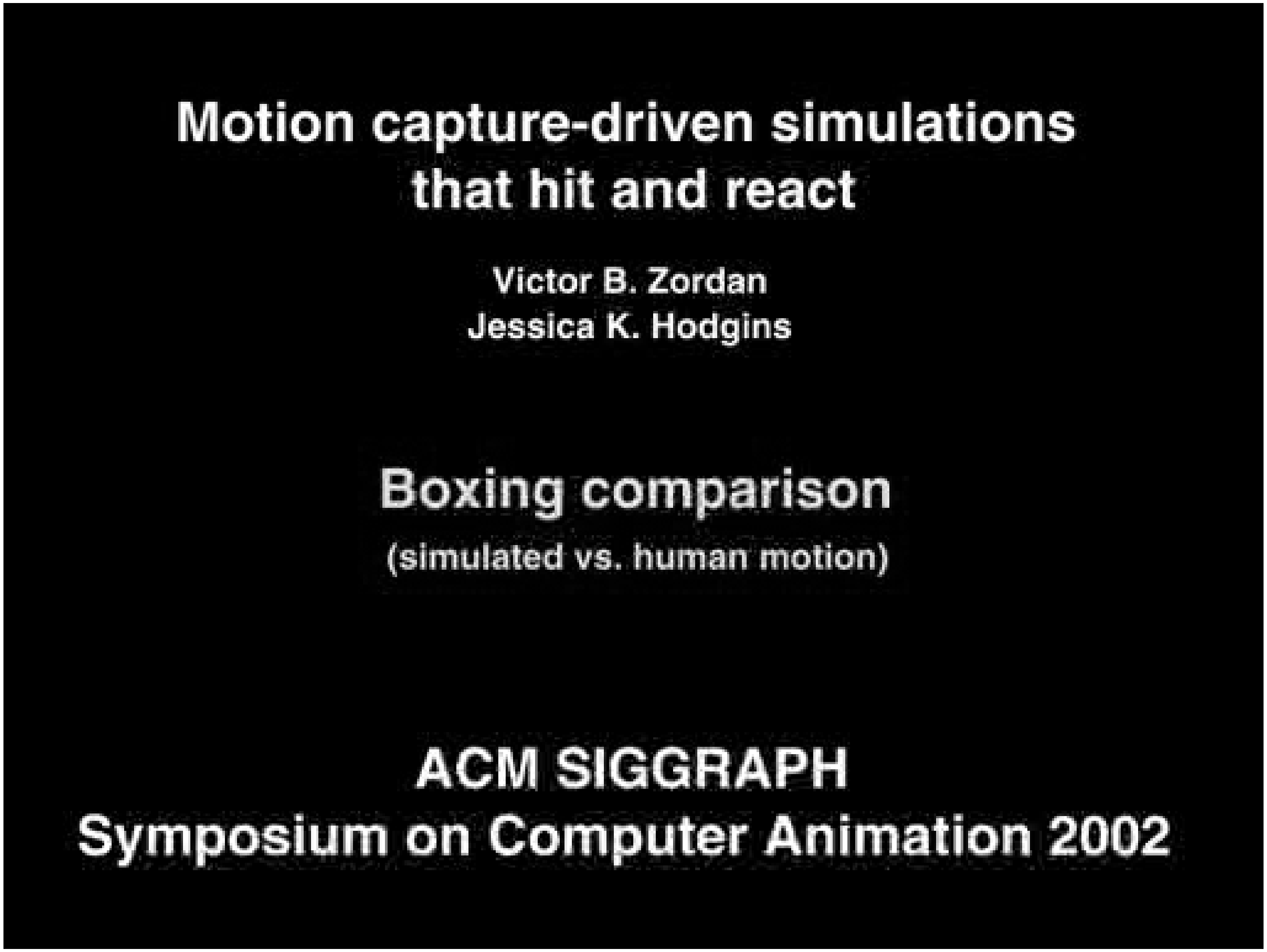


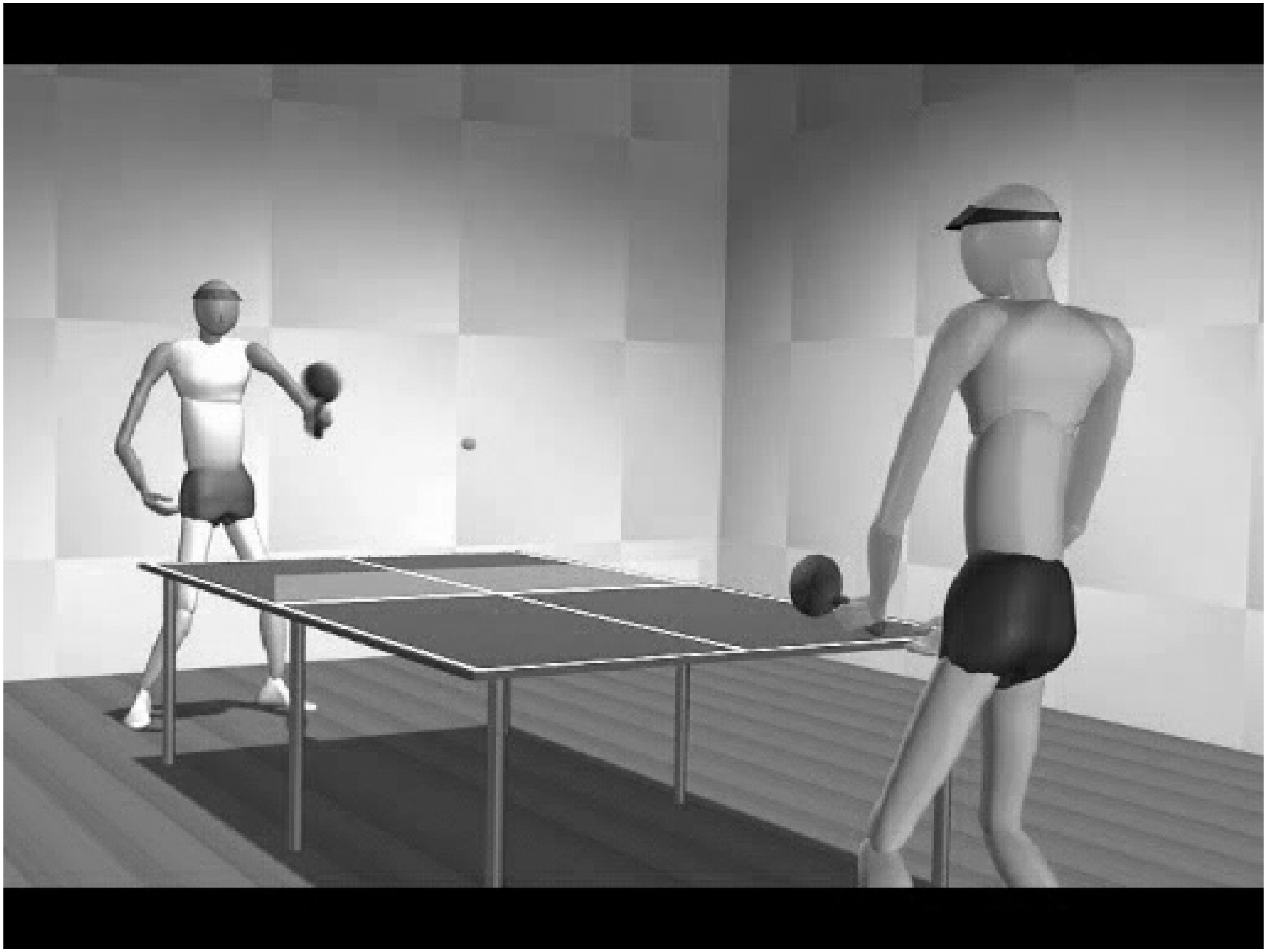



All motion in this animation was
generated using dynamic simulation.



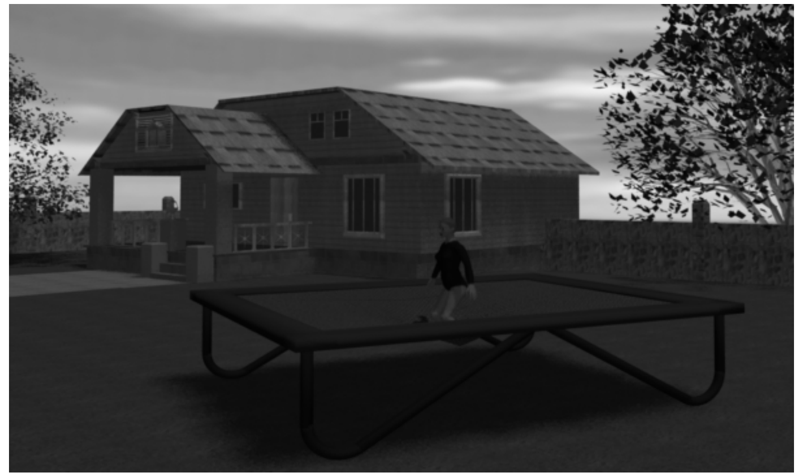
Zordan, V. B., Hodgins, J. K., Motion capture-driven simulations that hit and react, Symposium on Computer Animation, 2002.


Motion capture-driven simulations
that hit and react
Victor B. Zordan
Jessica K. Hodgins
Boxing comparison
(simulated vs. human motion)
ACM SIGGRAPH
Symposium on Computer Animation 2002



Secondary Motion: Coupling Passive and Active Simulations

One-way coupled



Fully coupled

Partially coupled

The Challenges of Active Simulation

- Control laws are hard to design
- Automatic design hasn't worked for complex systems (yet)
- Need a larger variety of behaviors
- Need to be able to handle new characters easily
- Higher-level behaviors
- Realtime performance

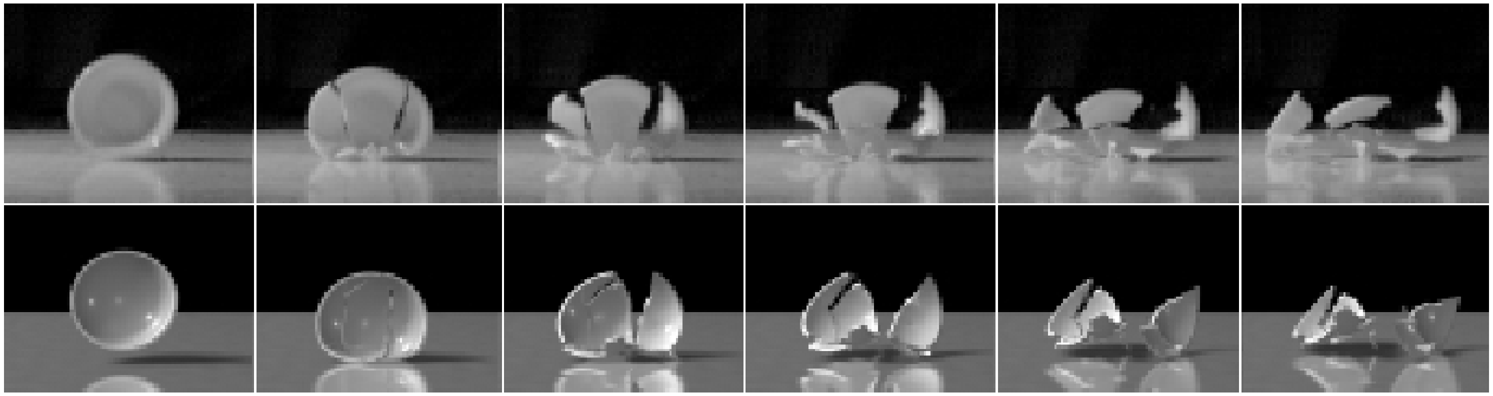
Perceptual Hacks

- How good a job do you have to do?
  - Objects don't go through walls
- Viewers can be pretty oblivious of things like incorrect bounces
- And we can't predict exactly how something should break

This shift of emphasis from accuracy to fast-and-looks-good is what distinguishes physically based CG from "real" engineering.

Evaluat

- Side-by-side comparisons
- Biomech or engineering data
- Turing test?



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