Announcements

Ray tracer is due in five days – you should have started by now or you're going to have a bad week…

Missing file posted on the web page

I'm sorry for canceling class on Tuesday...

Animation—Simulation

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

COMPUTER GRAPHICS

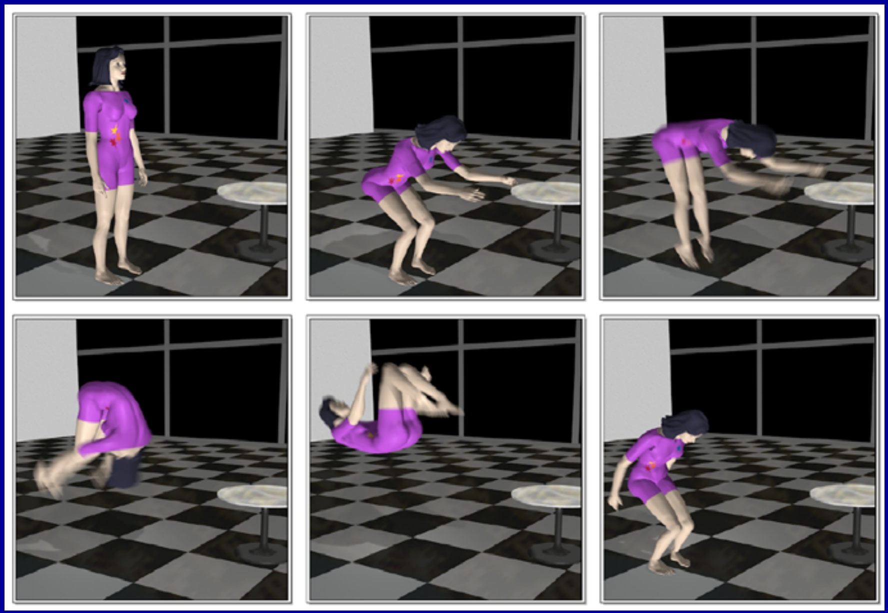
15-462

Overview

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

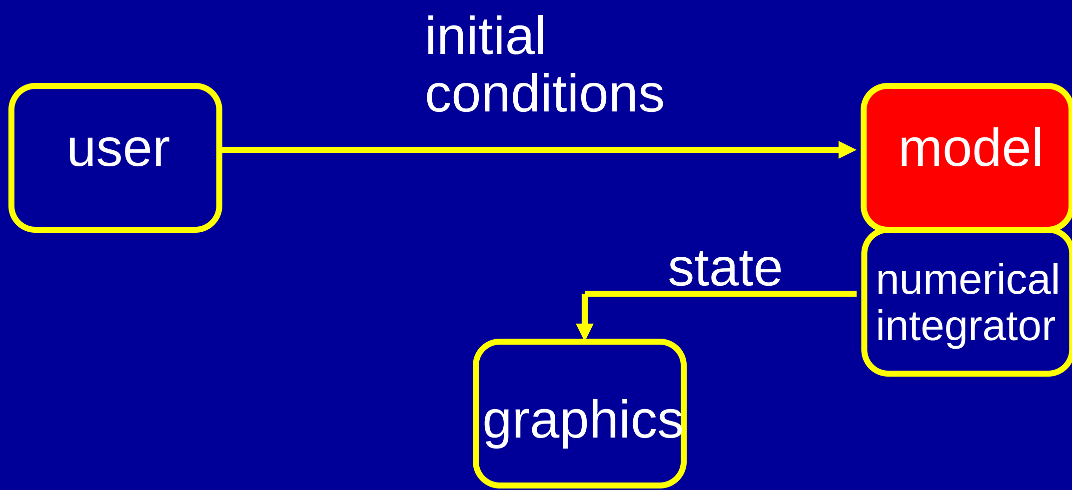
Dynamic Simulation

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



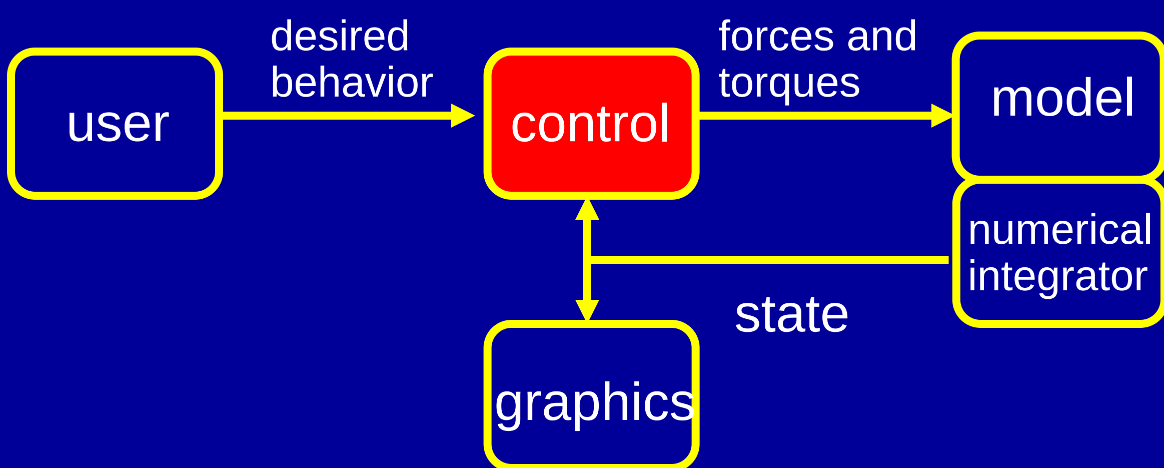
Antz, PDI/Dreamworks

Passive—no muscles or motors



Particle systems
Leaves
Water
Smoke
Clothing

Active—internal sources of energy

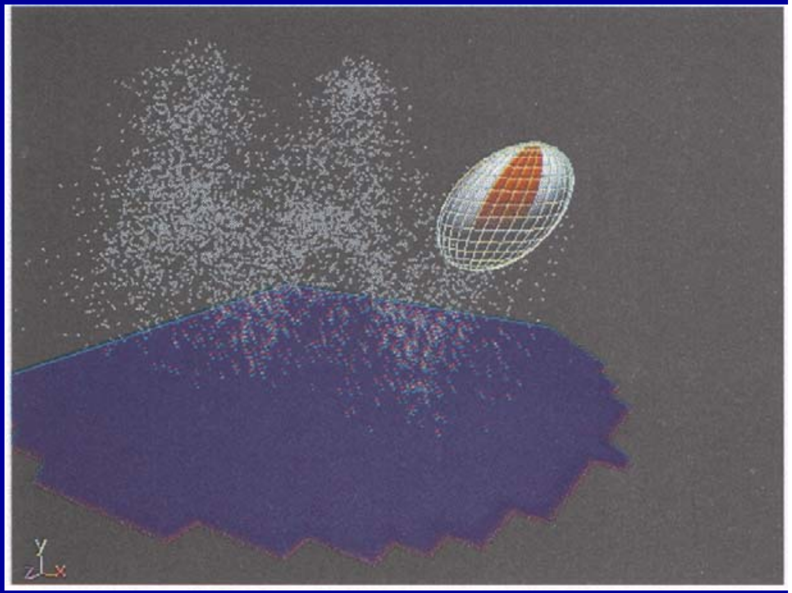


Running human
Trotting dog
Swimming fish

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

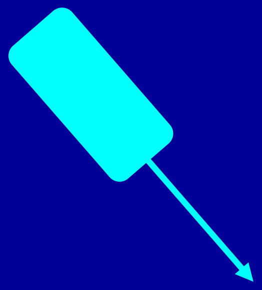
Creation—number, initial condiions
- position/velocity
  - randomly
  - surface of shape
  - vertex of polygonal object
- size
- color
- transparency
- shape
- lifetime

Deletion

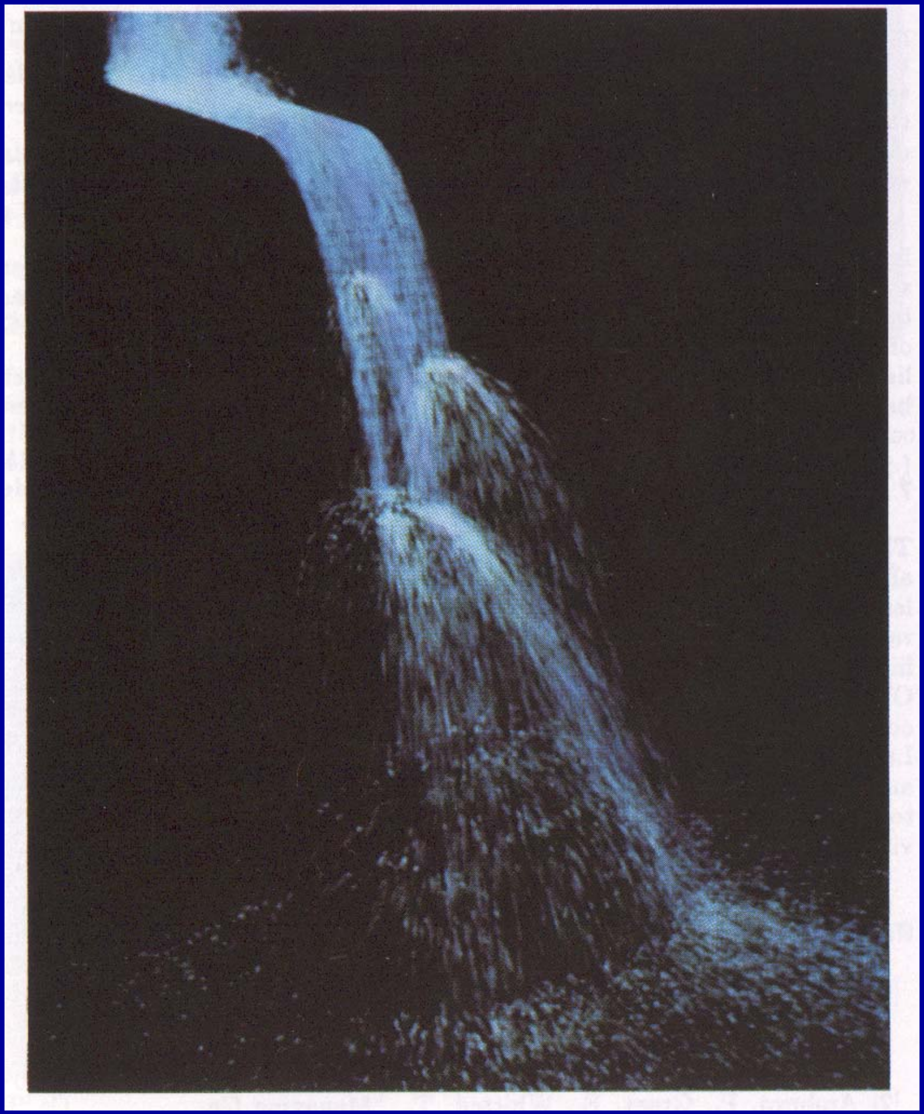
Update of position/velocity
- translation
- vortex

Rendering style – motion blur, compositing

What control handles do we want/need?



Karl Sims, Particle Dreams

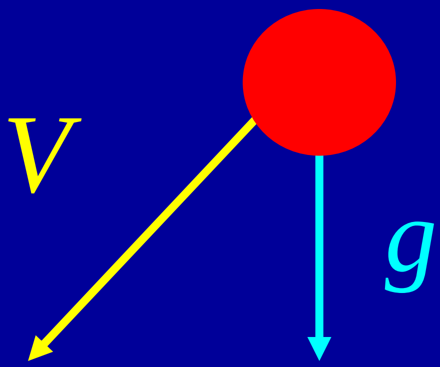


Behavioral Animation

- 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

$$P = (x, y, z)$$

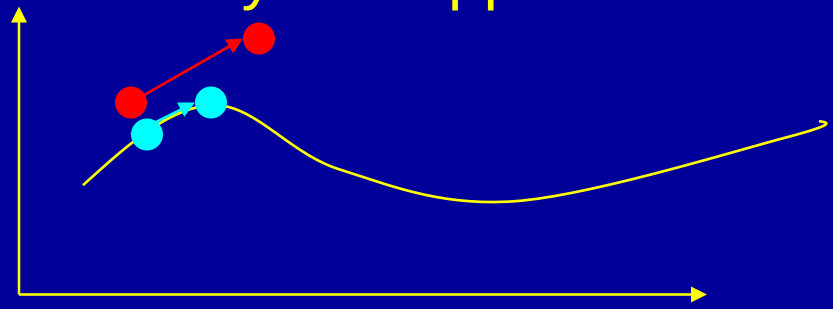


$$A = g$$

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

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

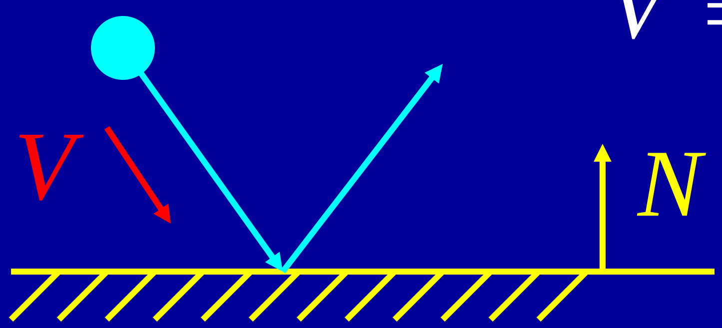
Integration: accuracy improves as step size decreases but always an approximation



More generally have other forces

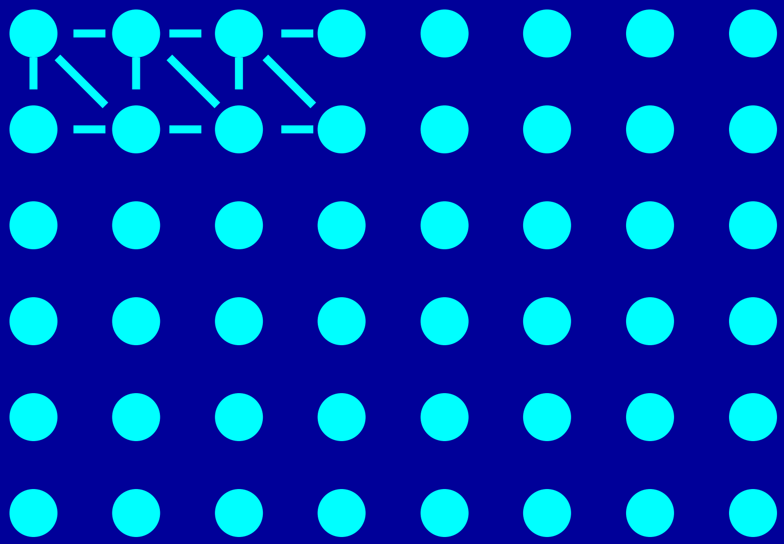
- Forces on the particle
  - Gravity f = mg
  - Viscous drag: f=-kv
- Forces between particles
  - Spring: f=ke e is distance between two points
- Interaction forces
  - Collisions with objects in the environment

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

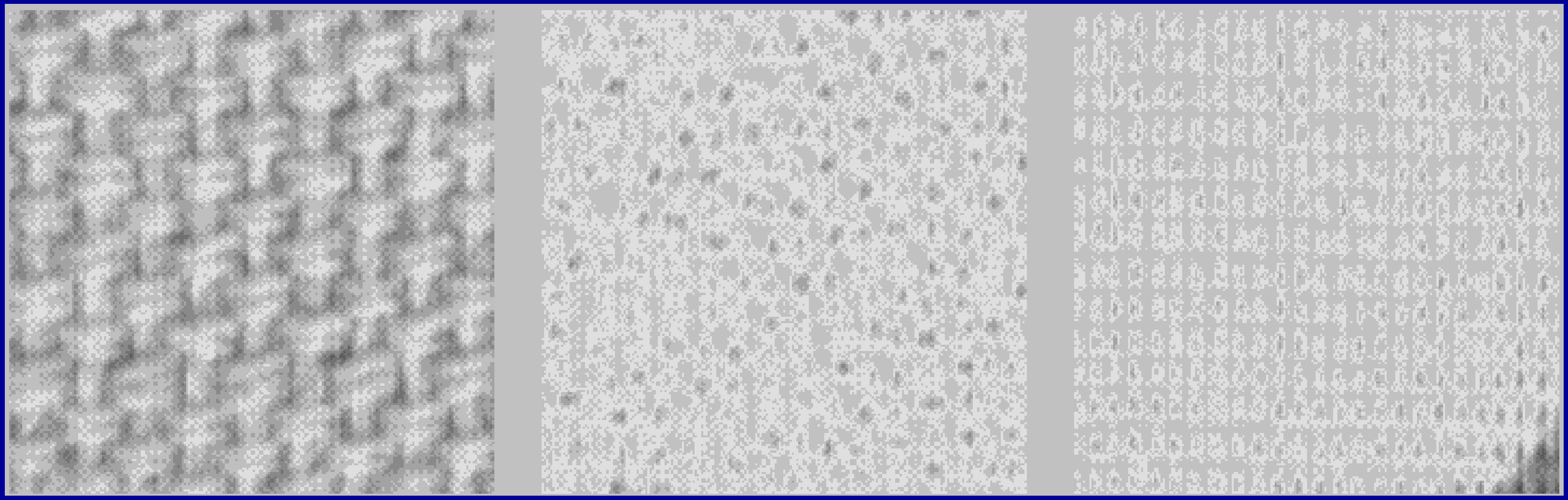


Spring-Mass Systems

Cloth in 2D
Jello in 3D



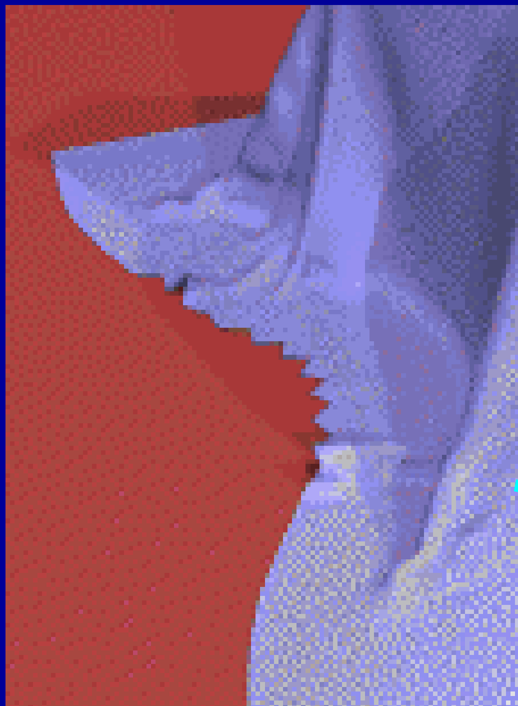
Cloth

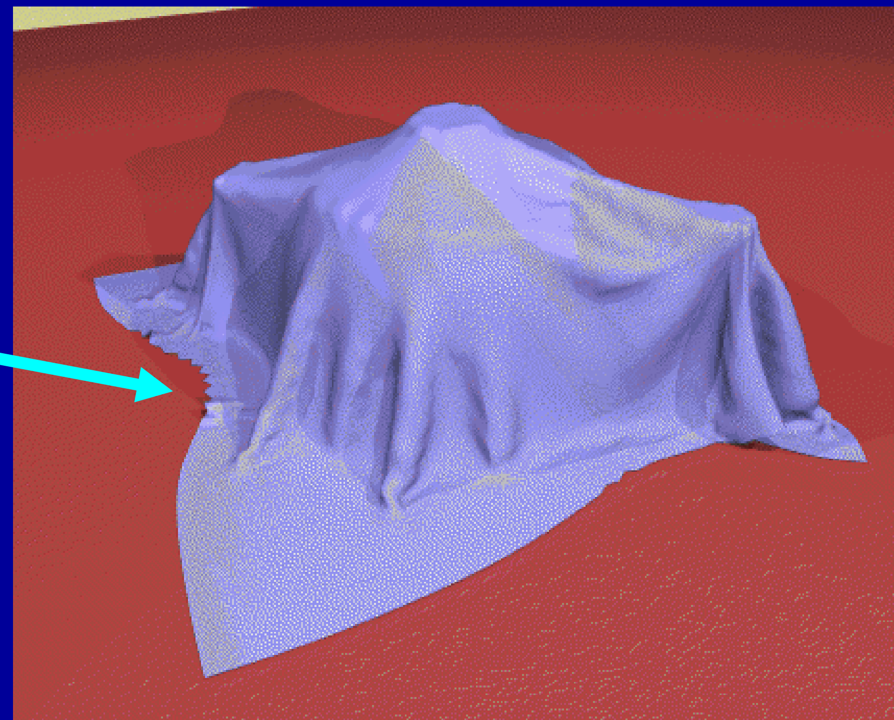


- Many types of cloth
- Very different properties
- Not a simple elastic surface
- Woven fabrics tend to be very stiff
- Anisotropic

Breen '95

Cloth

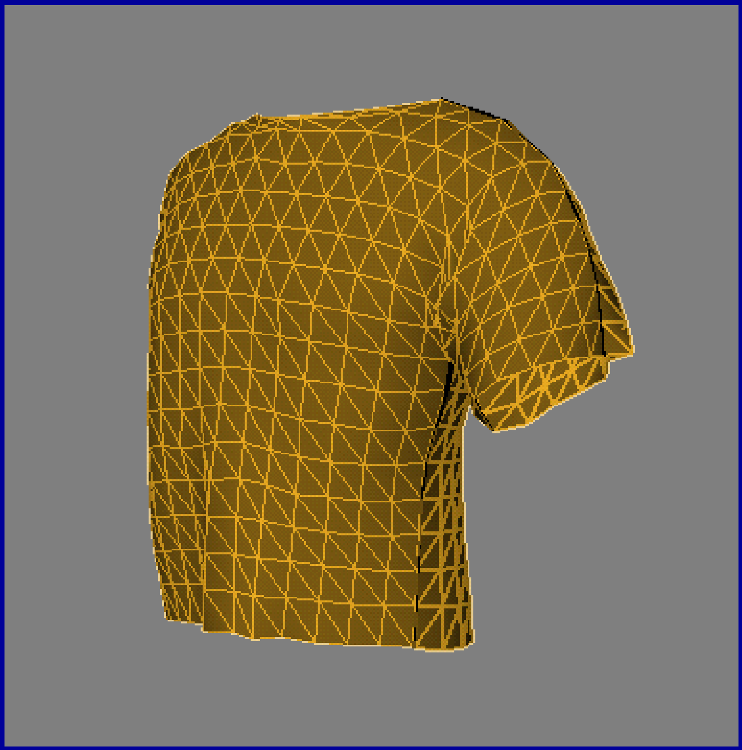


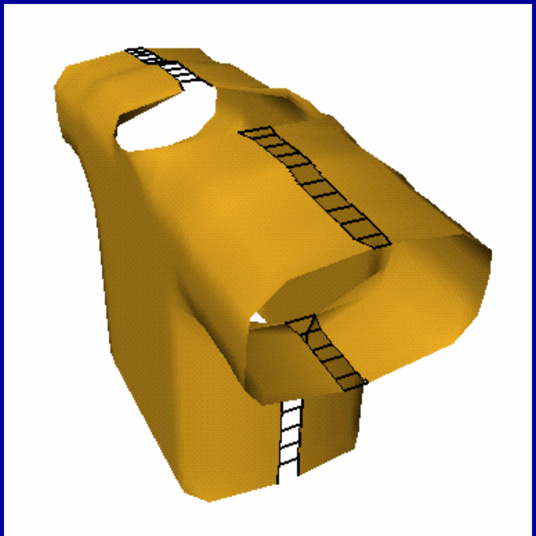


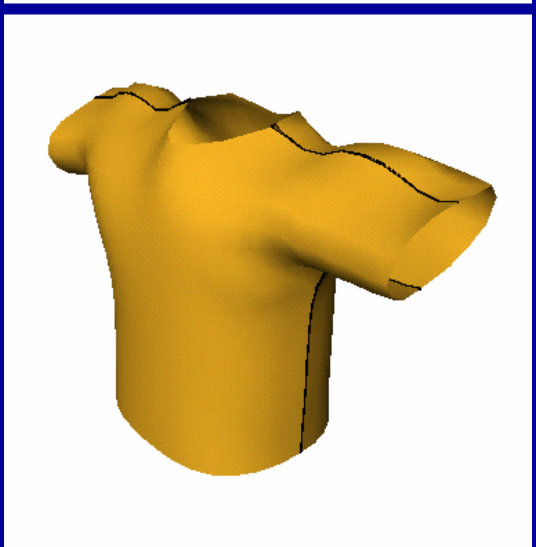
Resolution of Mesh is critical
Computation of collisions is expensive

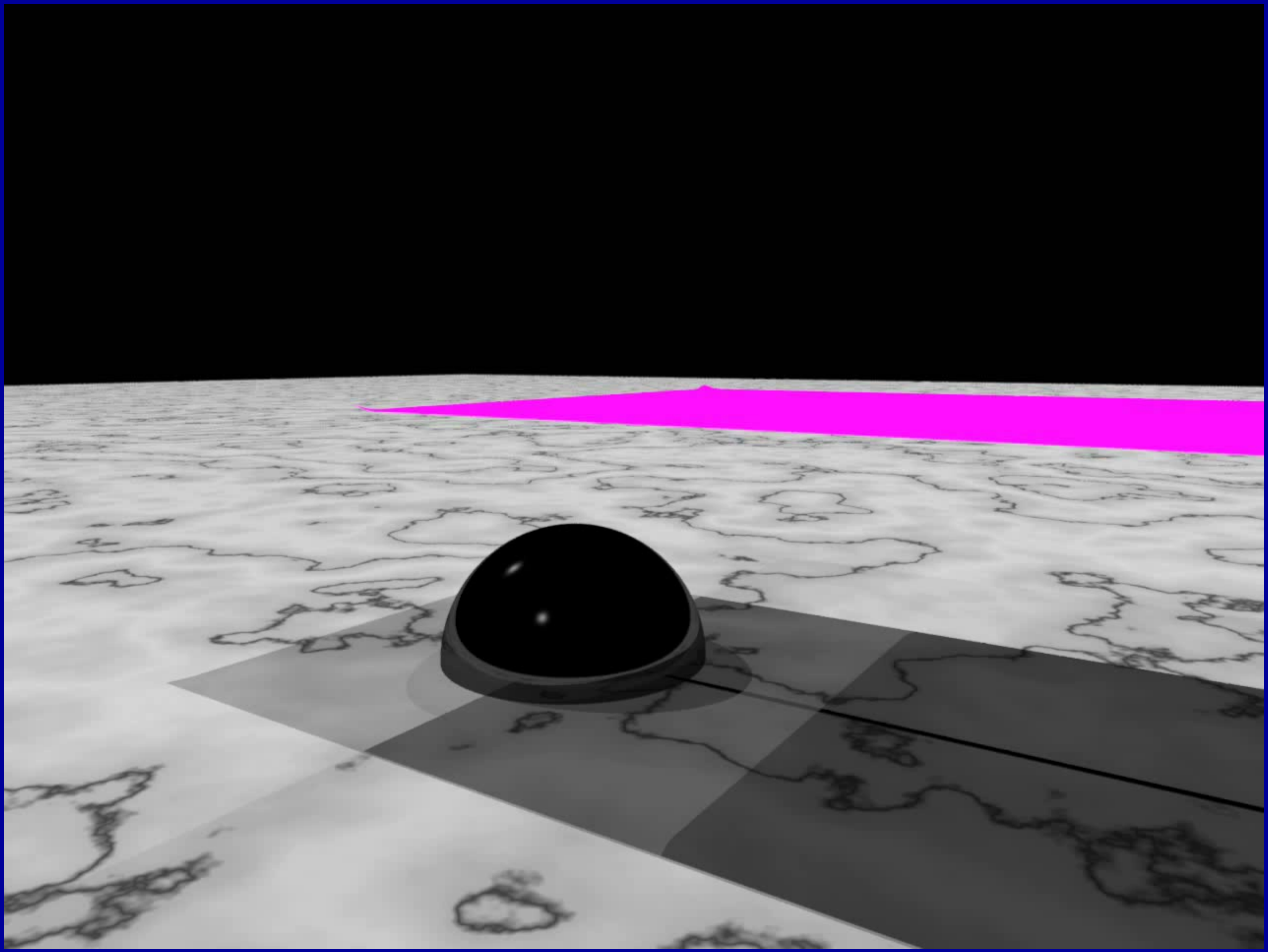
Breen ‘95

Modeling for Clothing

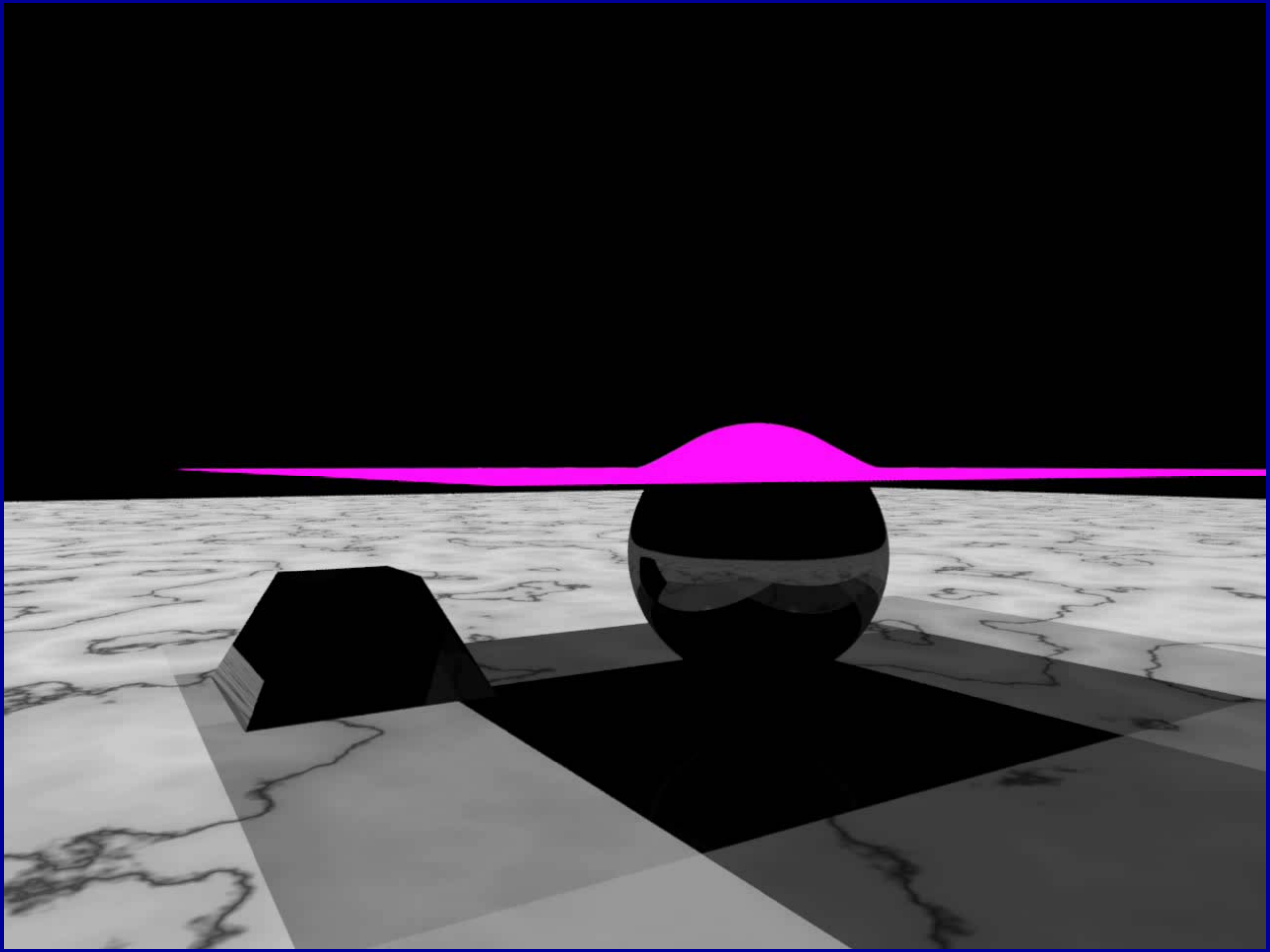








http://graphics.stanford.edu/~fedkiw/



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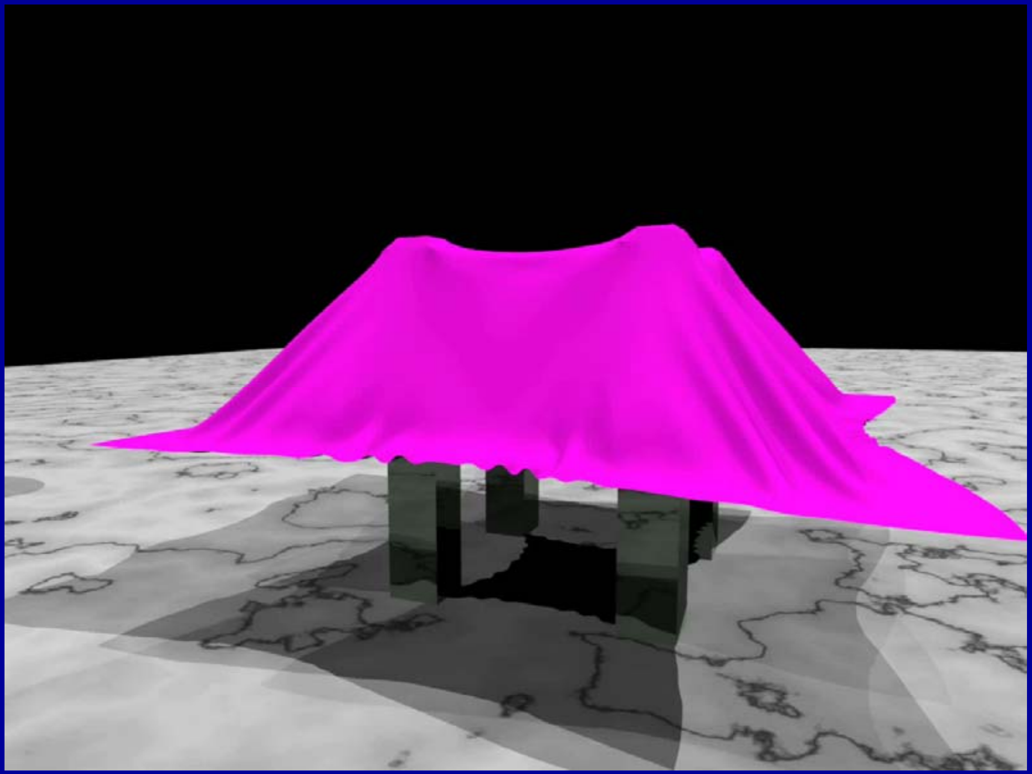

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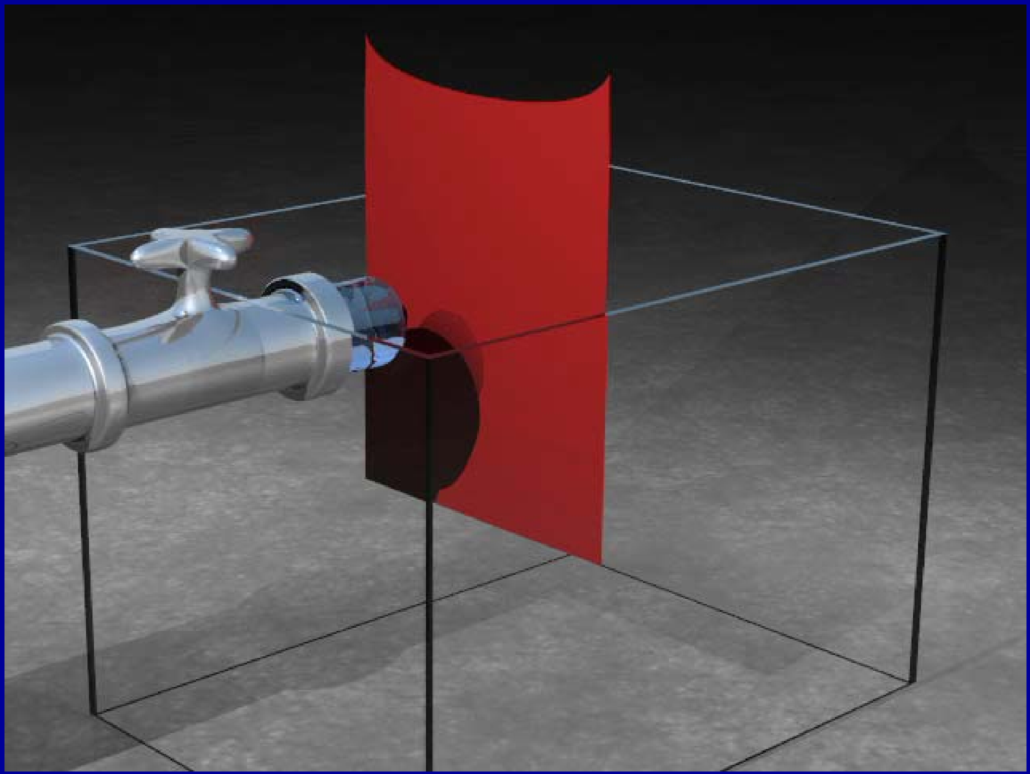

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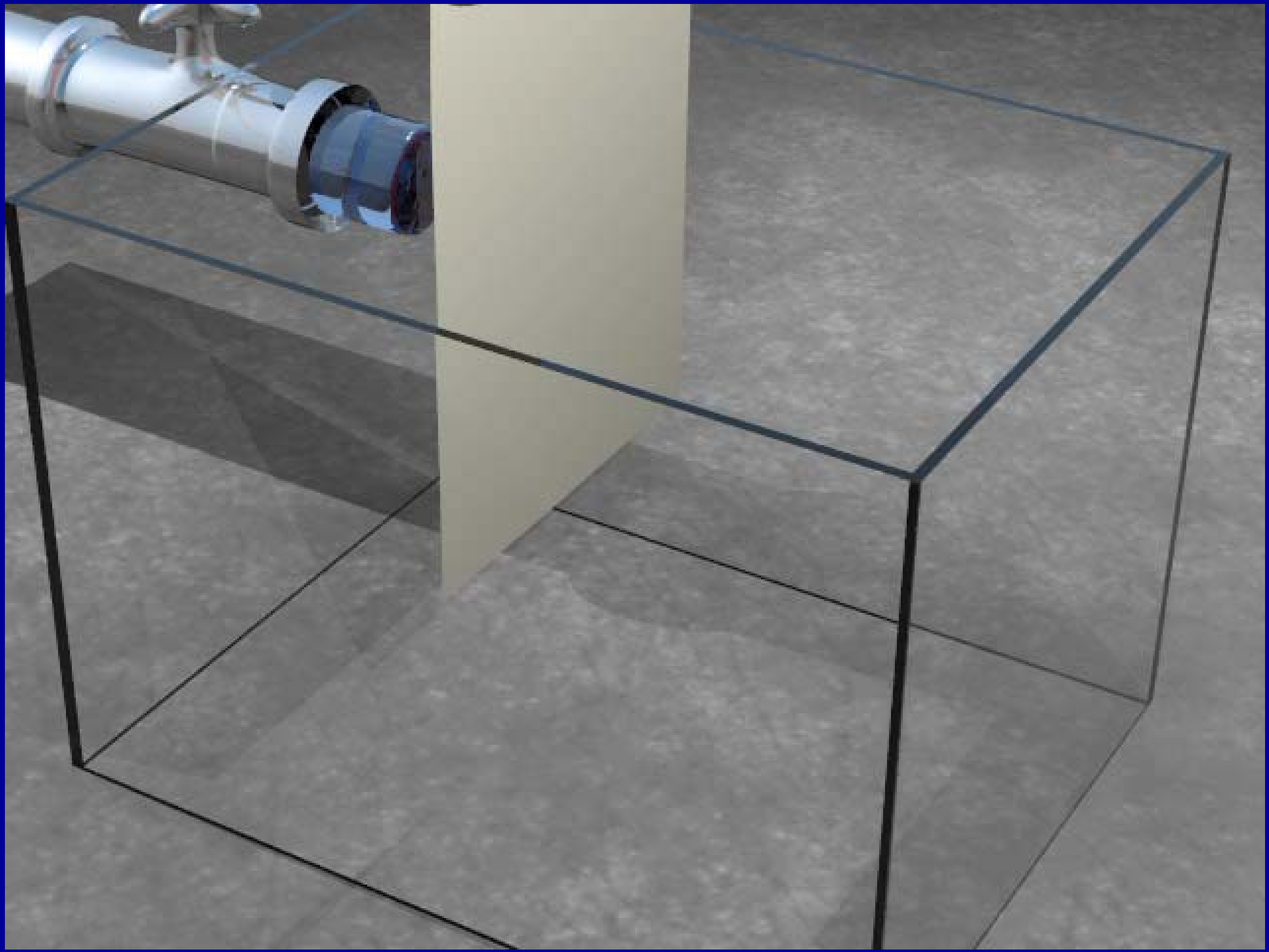
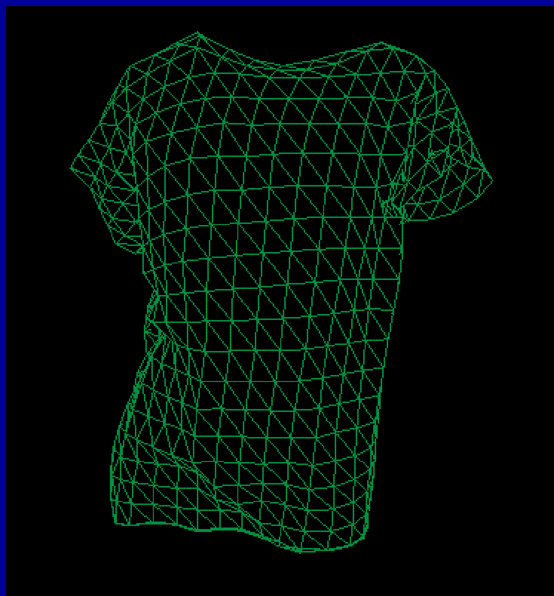
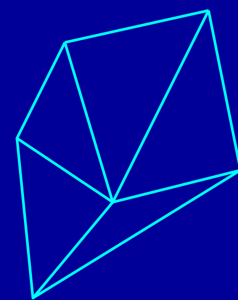


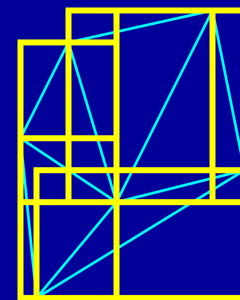
http://graphics.stanford.edu/~fedkiw/

Collisions for Clothing

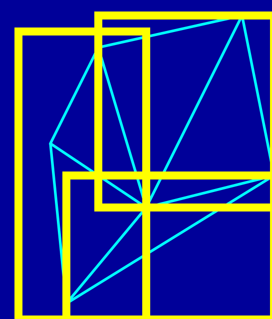




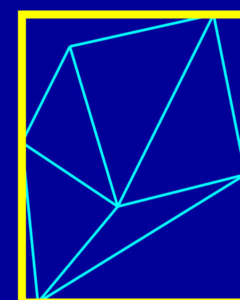
Polygons



Primitive Level



Intermediate
Level(s)



Top Level

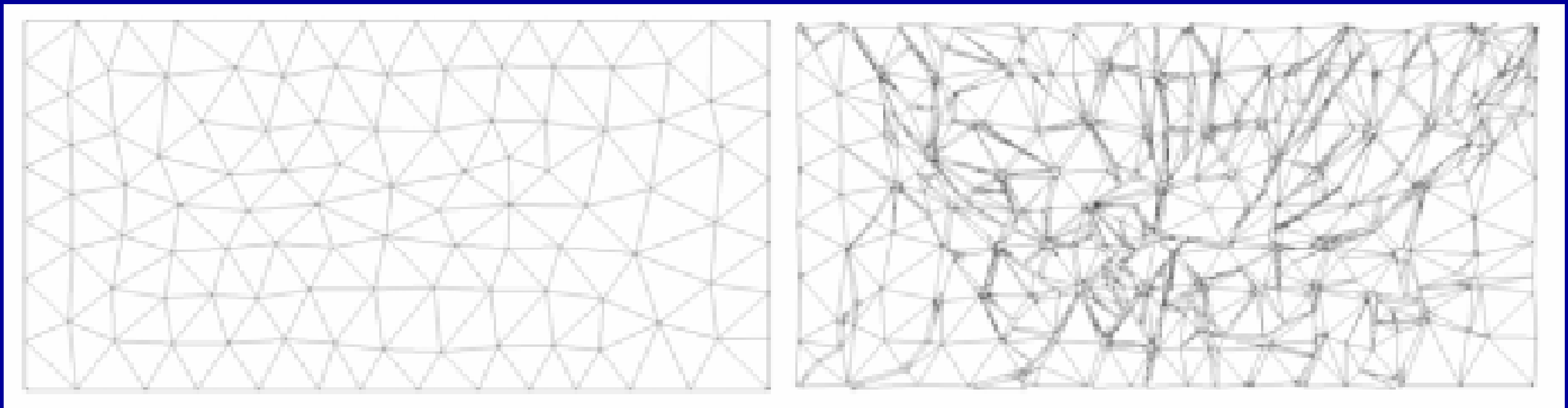
Potentially VERY expensive

Bounding Box Hierarchy

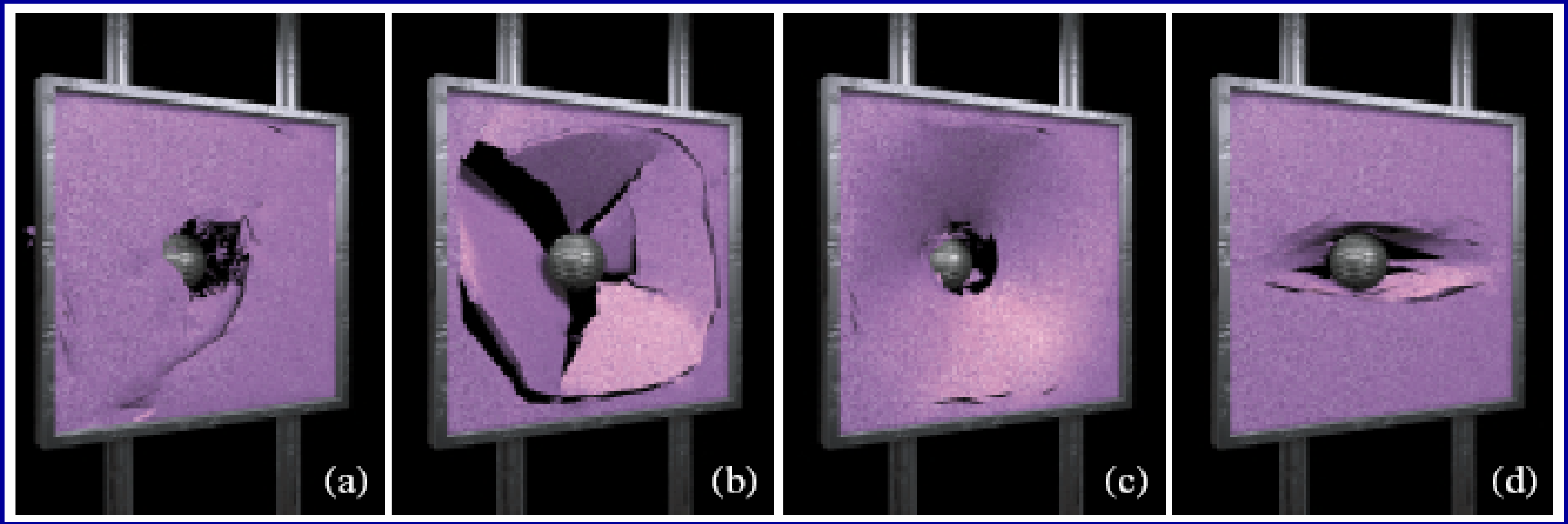
- Partition space or objects
- Avoid expensive primitive tests

Fracture

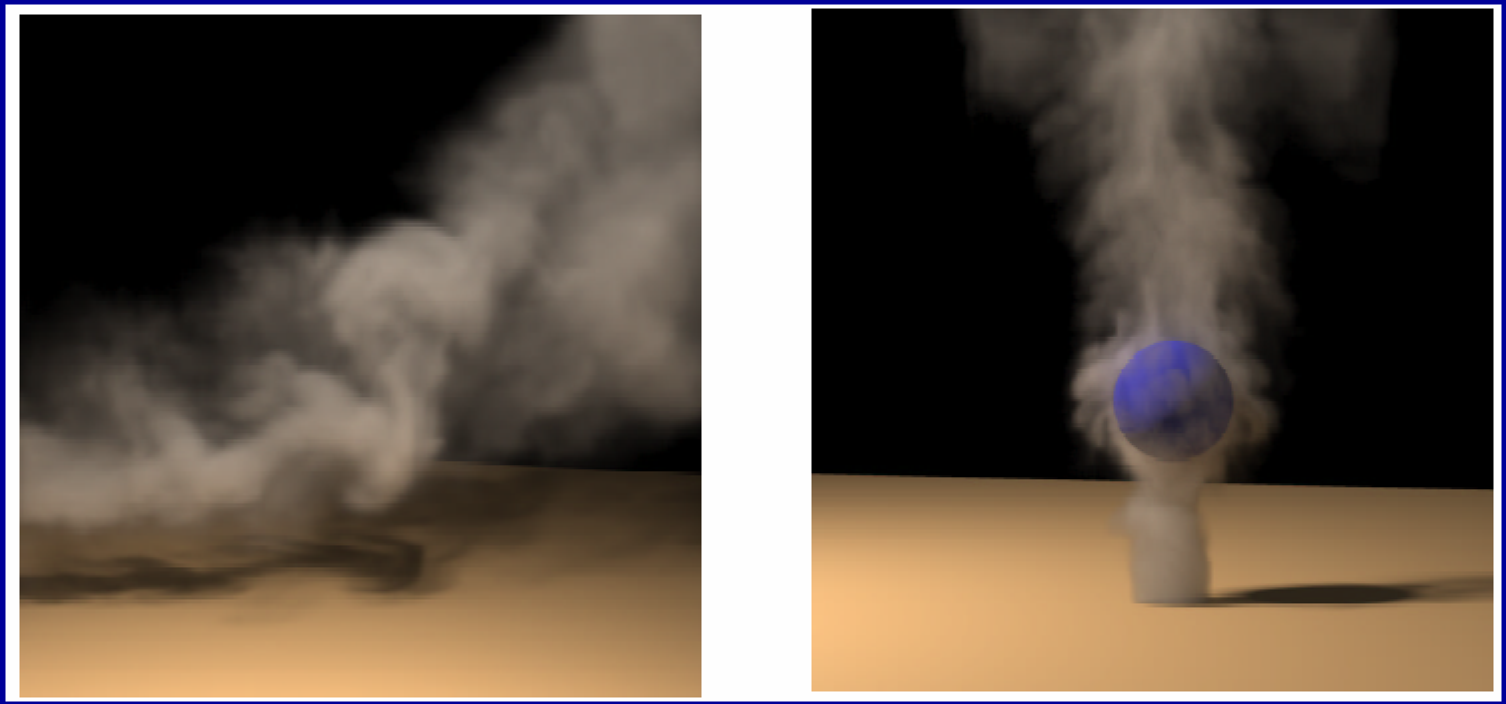
O'Brien, J. F., Hodgins, J. K., (1999) Graphical Modeling and Animation of Brittle Fracture. The proceedings of ACM SIGGRAPH 99, Los Angeles, California.



Fracture

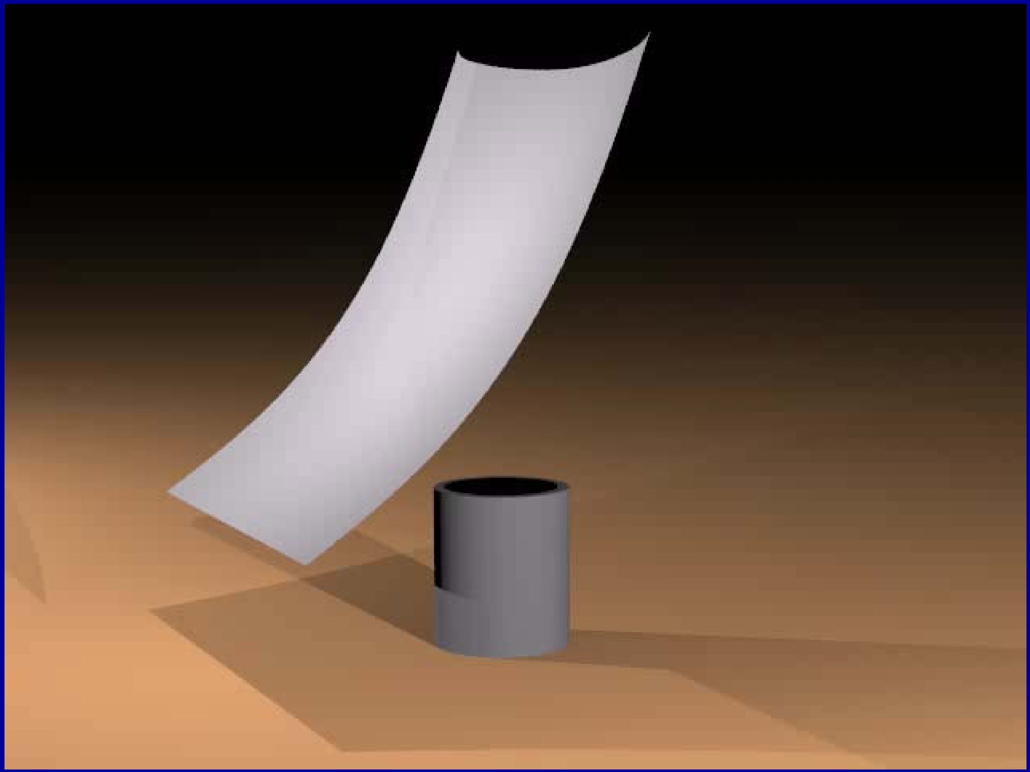


Smoke

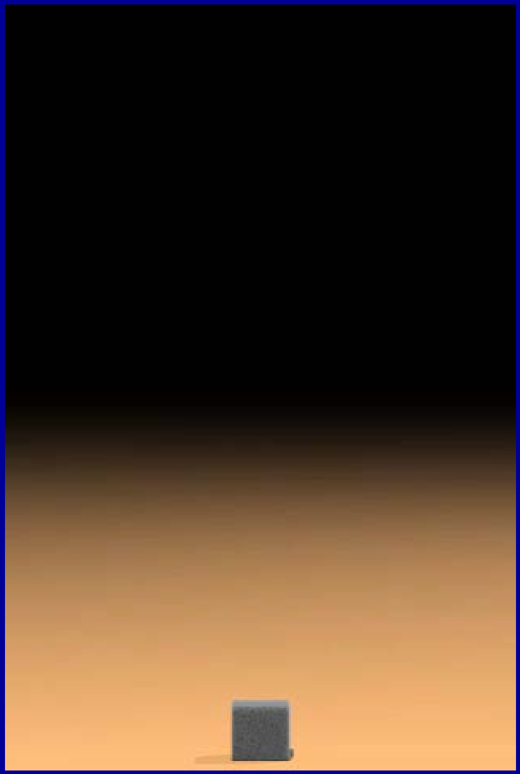


Visual Simulation of Smoke, Ronald Fedkiw Jos Stam Henrik Wann Jensen
SIGGRAPH 2001, Computer Graphics Proceedings

Smoke



Smoke



http://graphics.stanford.edu/~fedkiw/

Control for the animator

http://grail.cs.washington.edu/projects/control/

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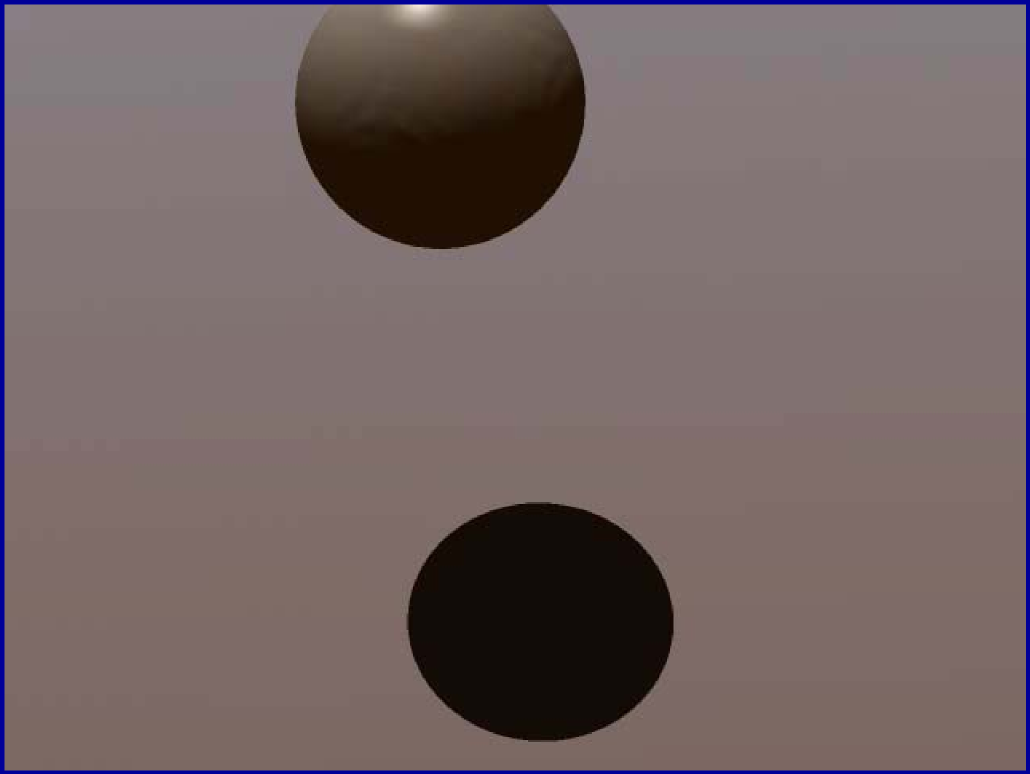


http://grail.cs.washington.edu/projects/control/

The Challenges of Passive Simulation

Accurate enough for the situation

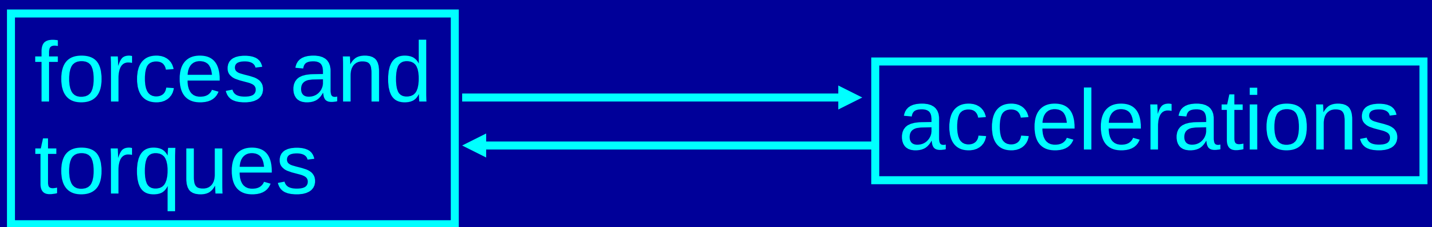
What pieces of the physics are necessary for appearance?

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

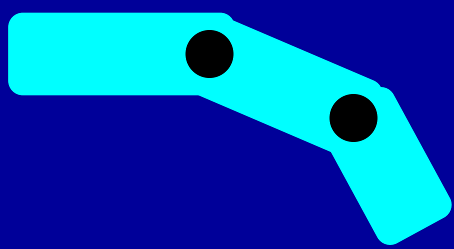


Forward: given forces and torques what is the motion?

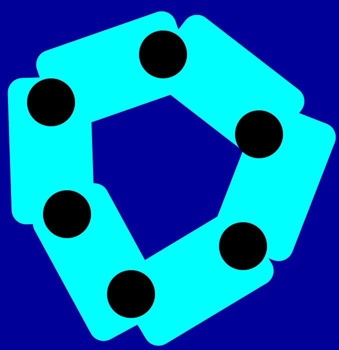
Inverse: given prescribed motion what are the forces and torques?

What can we simulate?

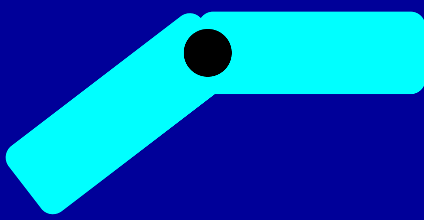
Open loop



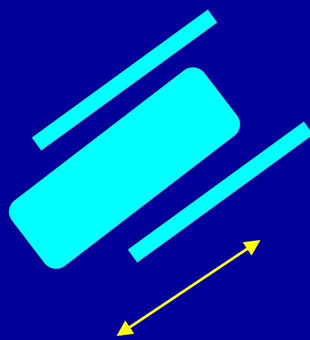
Closed loop



Joints
Rotary (1,2,3d)

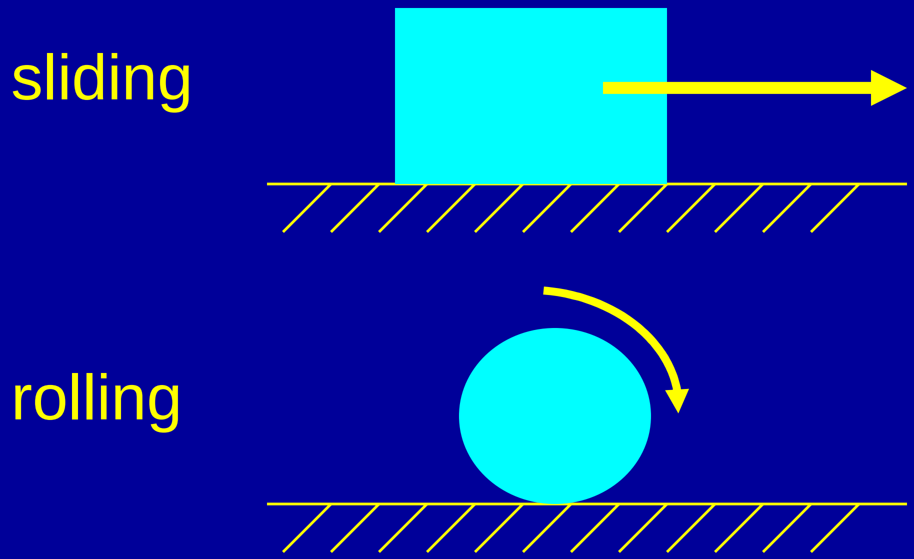


Telescoping joints



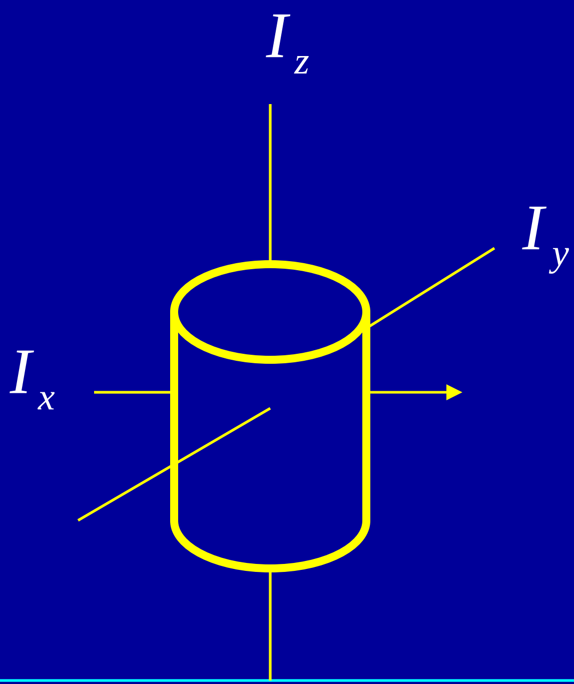
Forces/Torques

Gravity
Wind
Collisions/contact



System Description

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



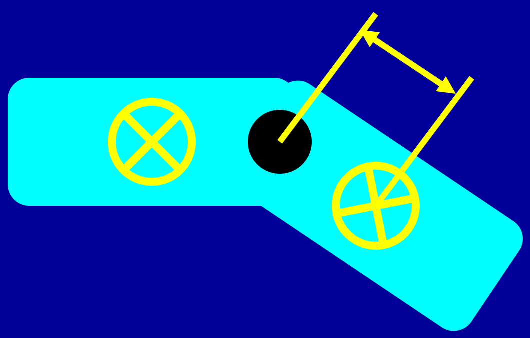
$$I_x = I_y = \frac{1}{12} m(3r^2 + L^2)$$

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

Calculate from polygonal model (closed) for more complicated shapes

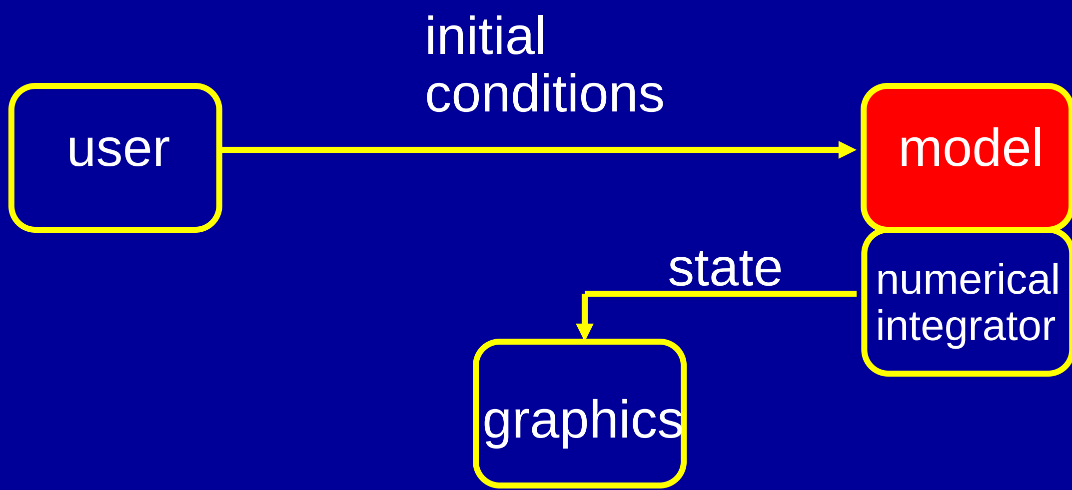
Commercially Available Simulation Code

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
Rigid body simulator also contained within Maya

Passive—no muscles or motors



Particle systems
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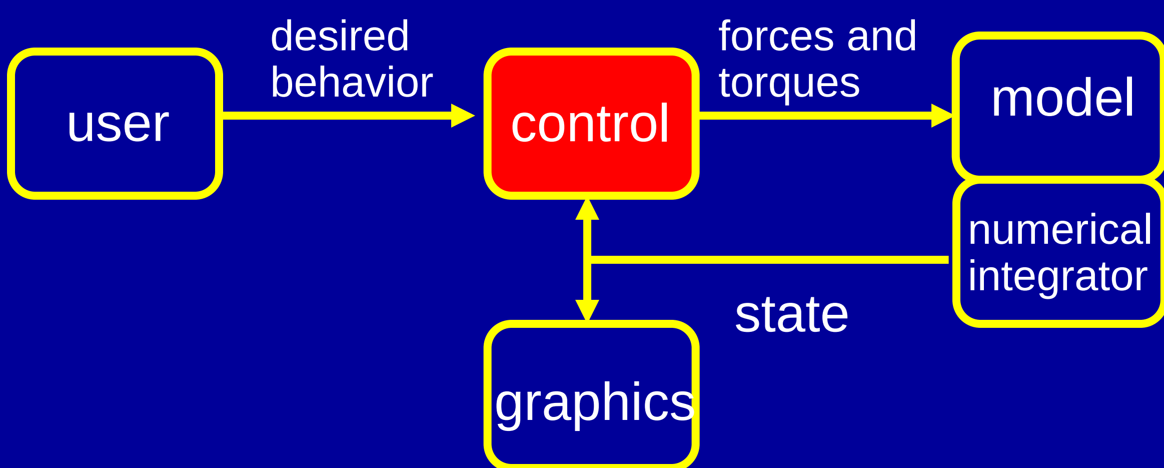
Active—internal sources of energy

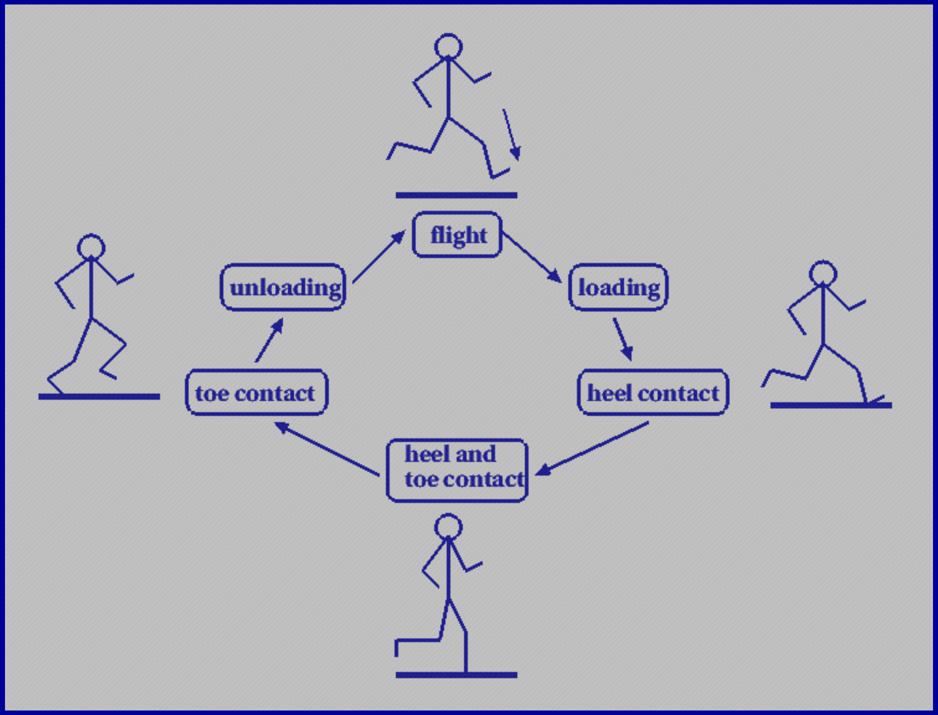


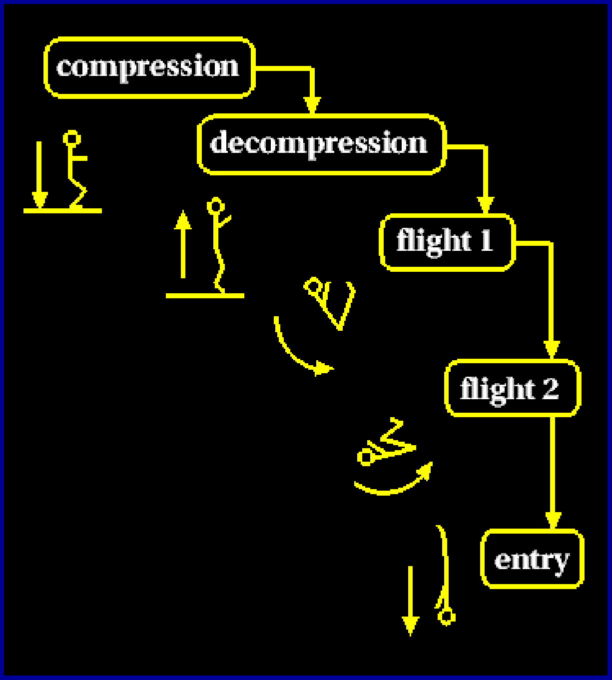
Running human
Trotting dog
Swimming fish

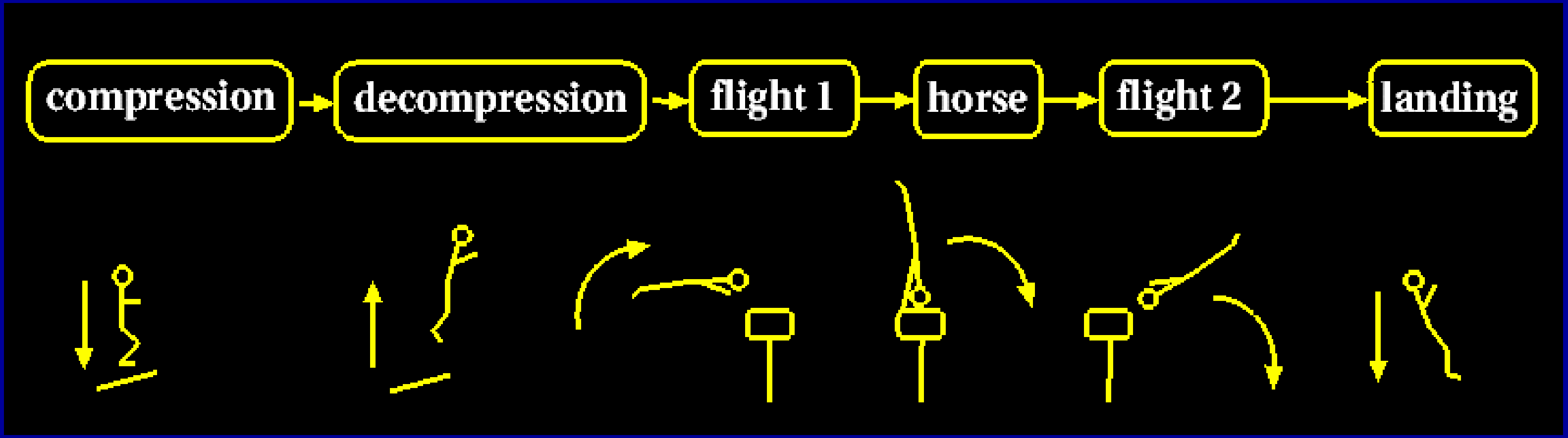
Control Systems—how do we do something with these mechanisms ?

Hierarchy of control:
- State machines
- Control actions
- Low-level servos

State Machines

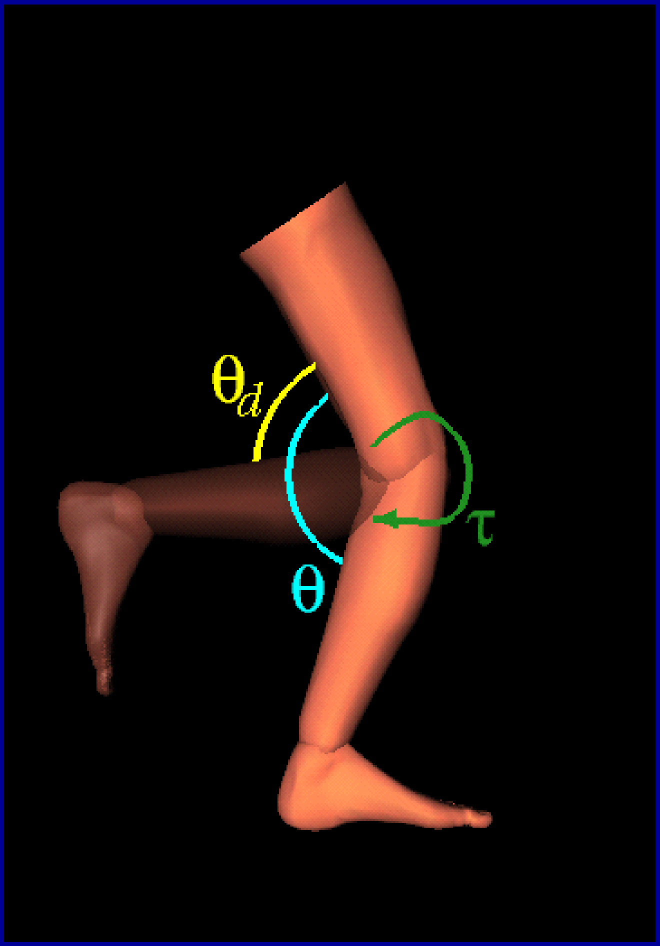






Low-level Control

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



Control Actions

Passive strategies where possible

Control Actions

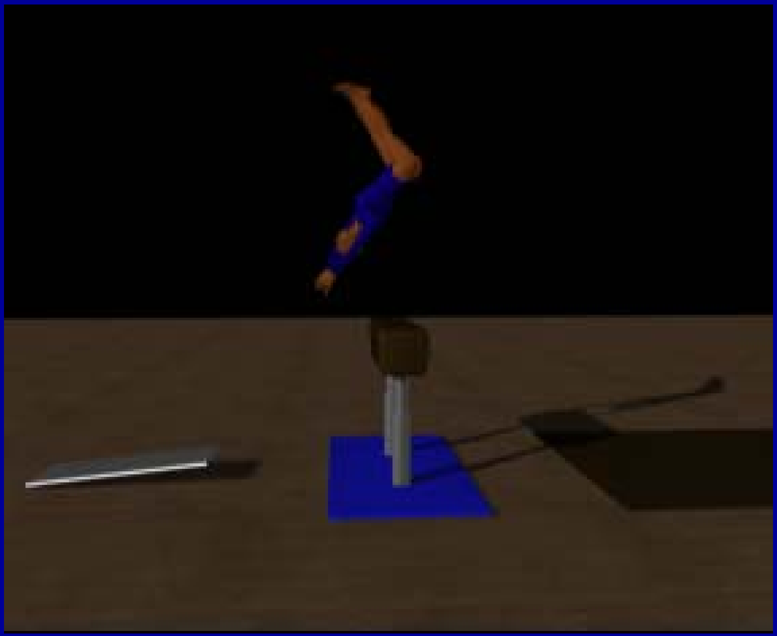
Synergistic use of joints

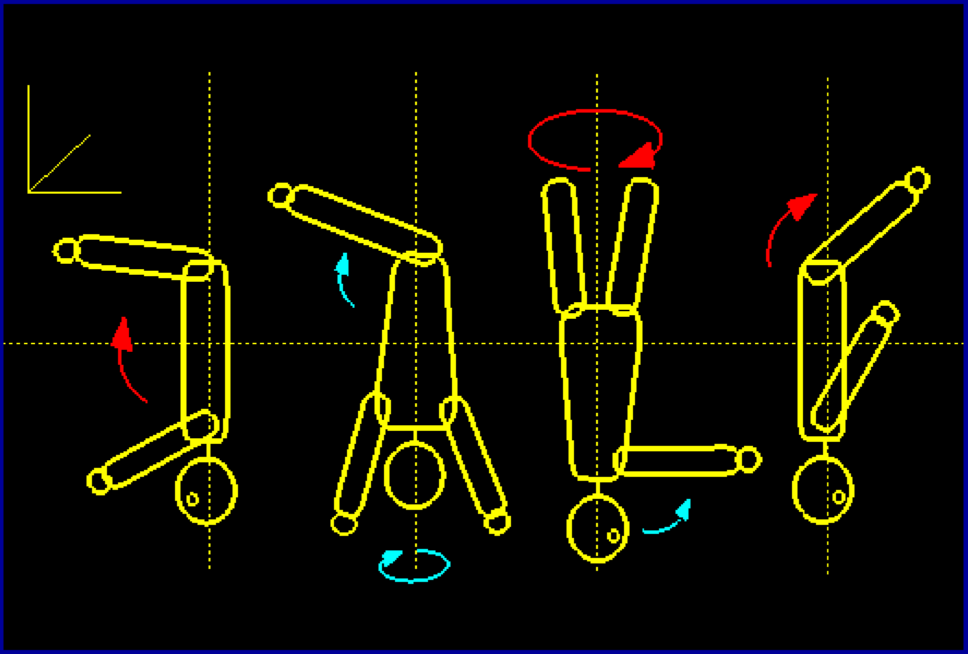
Control Actions

Reduce disturbances

Control Actions

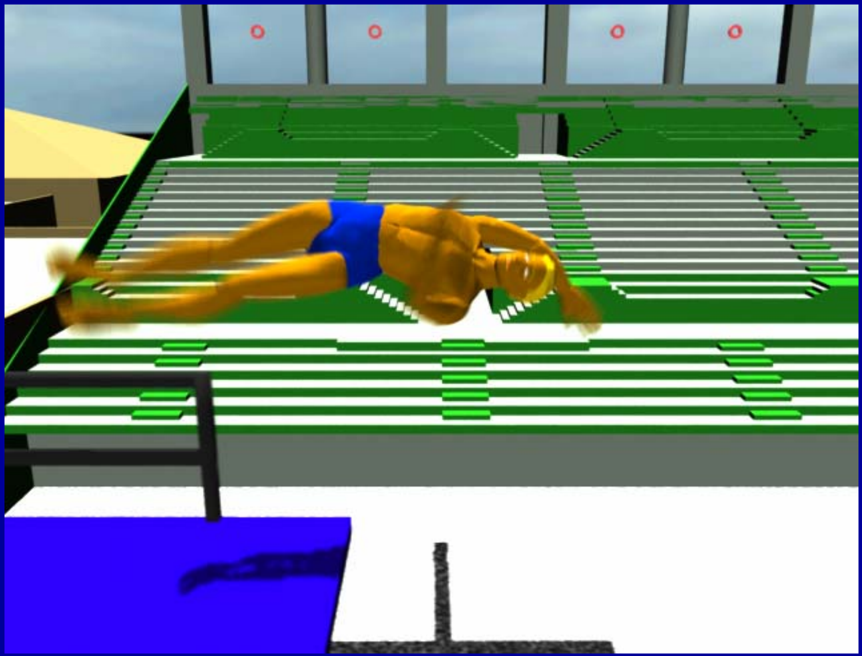
Physical intuition

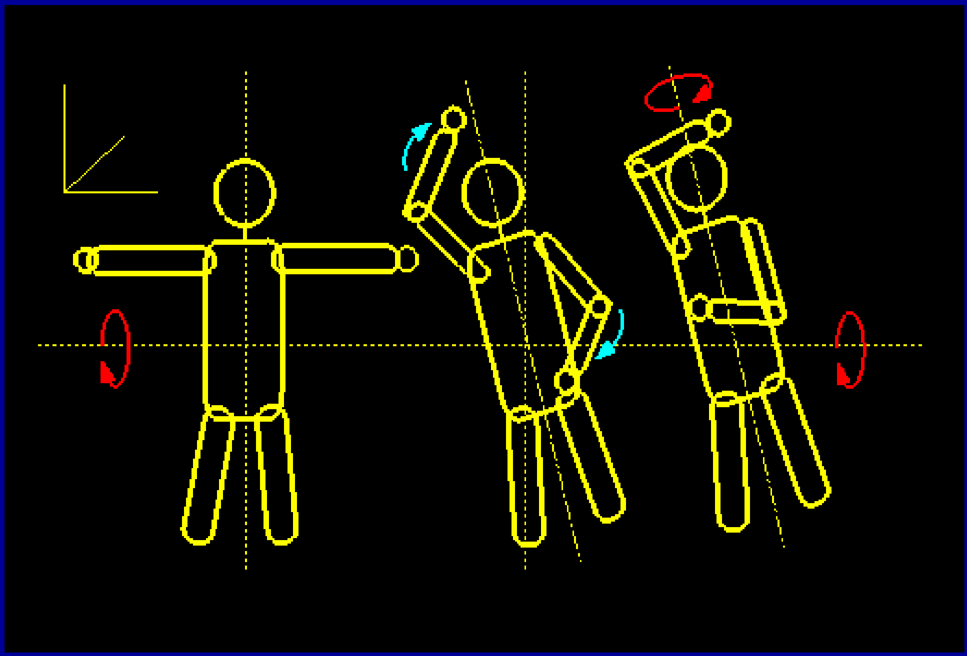


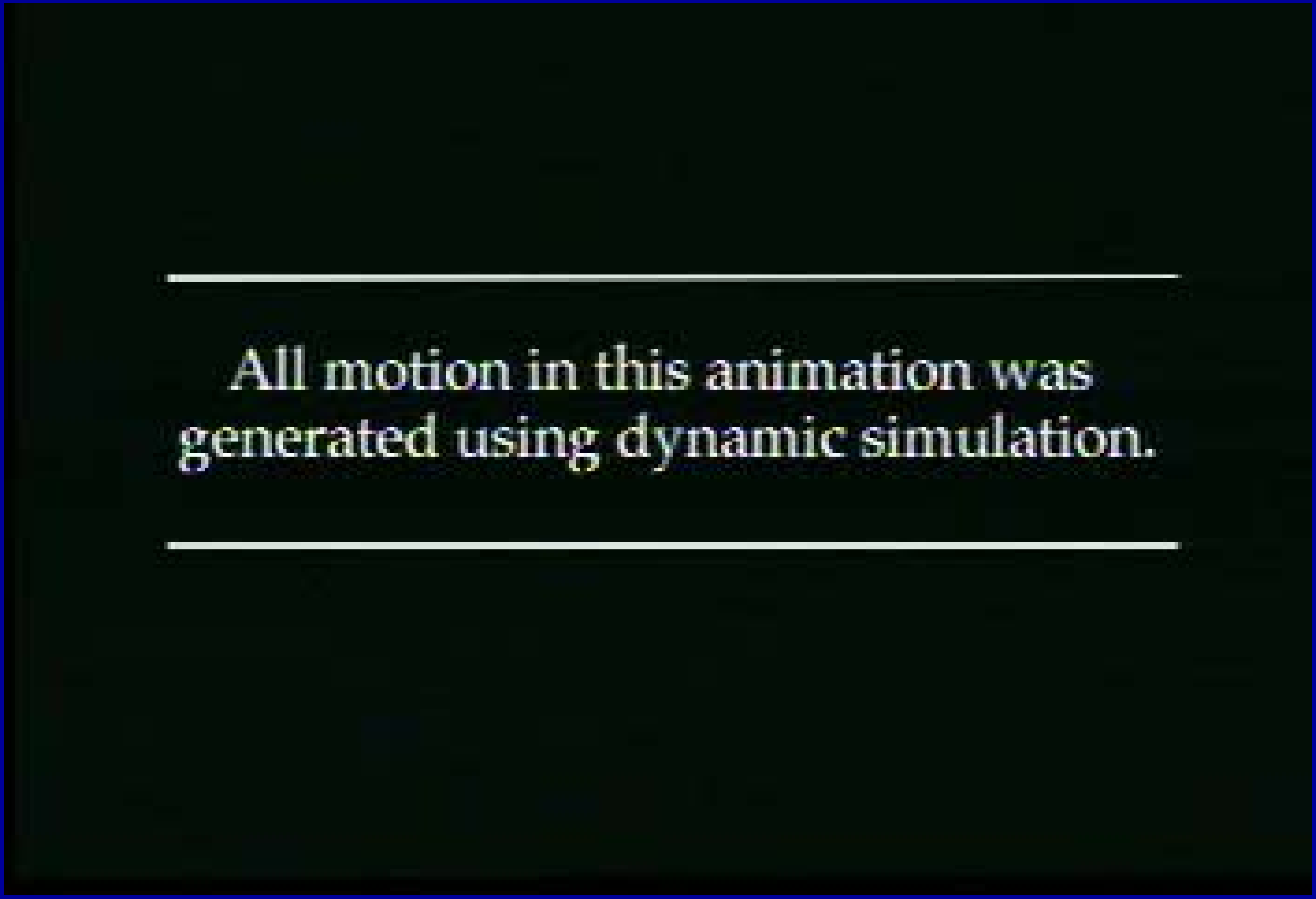


Control Actions

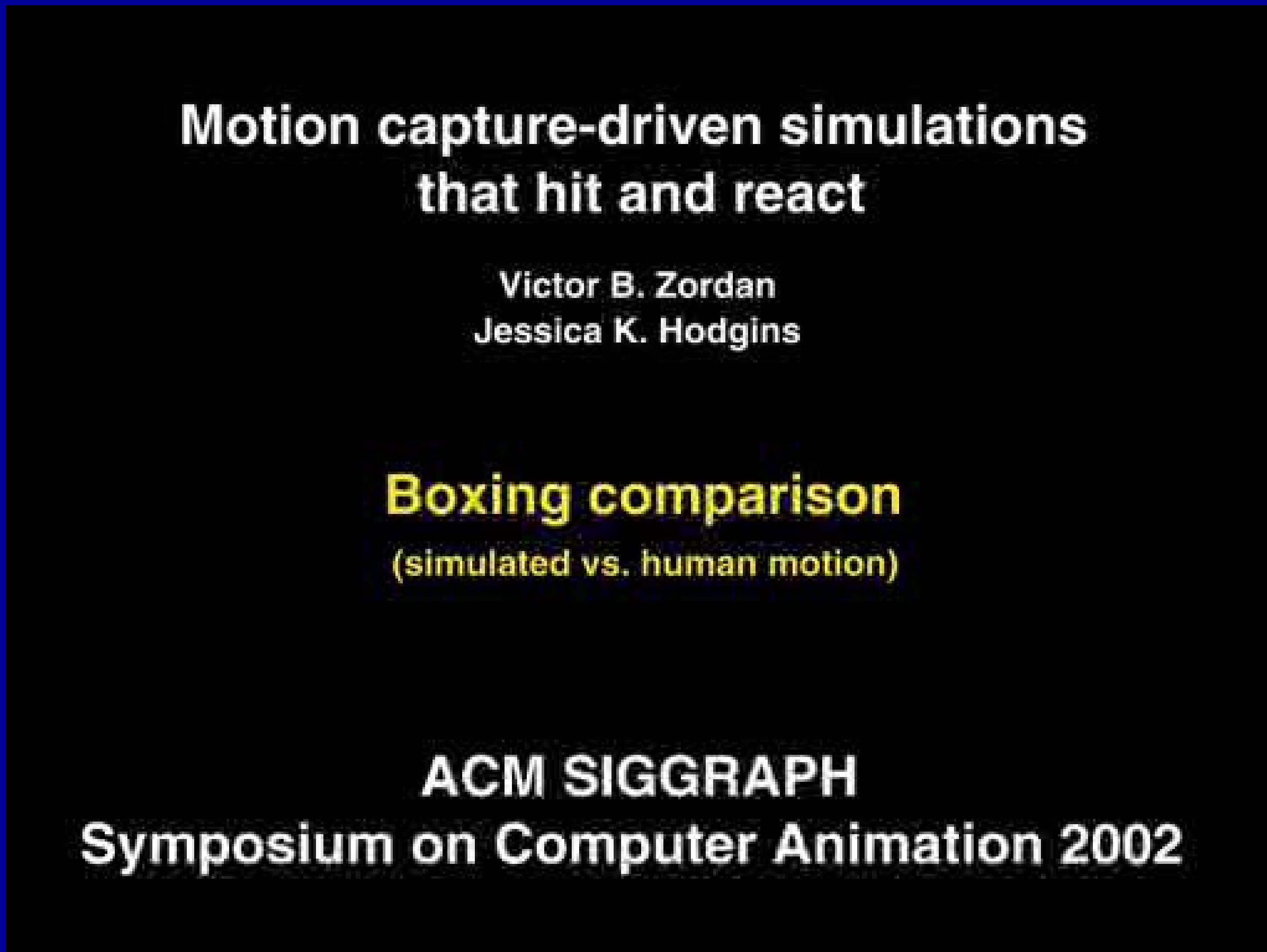
Physical intuition






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

Several papers on control this year in SIGGRAPH after a multi-year drought

Perceptual Hacks

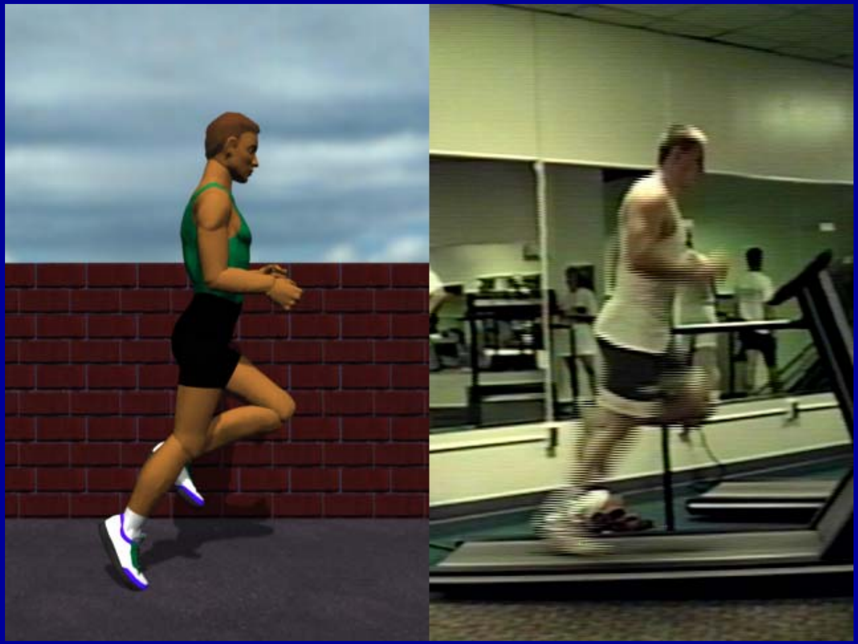
- How good a job do you have to do?
  - Objects don't go through walls
- Viewers can be pretty oblivious of things like incorrect bounces
- And we can't predict exactly how something should break

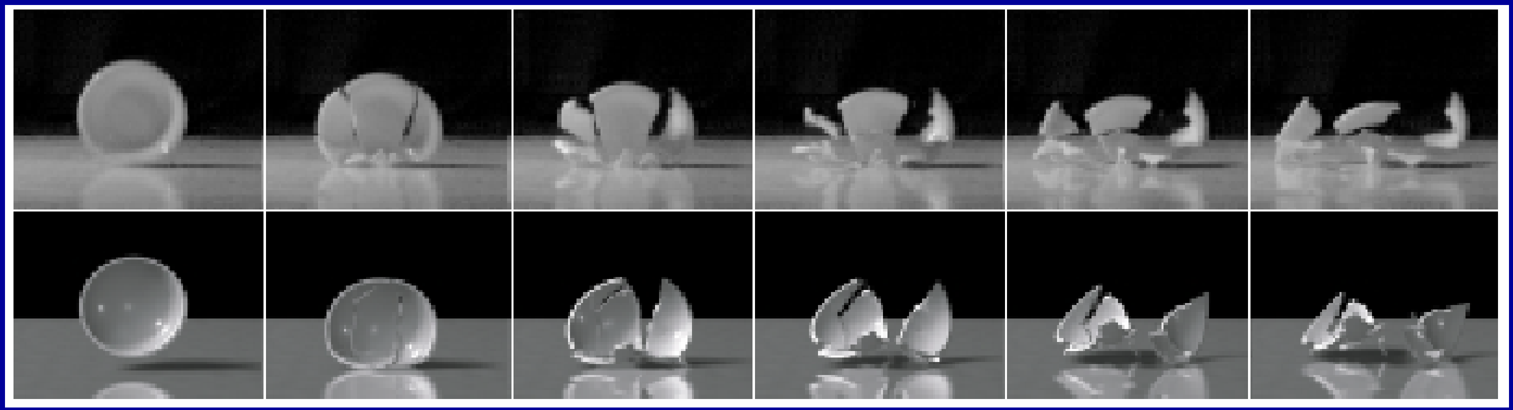
This shift of emphasis from accuracy to fast-and-looks-good is what distinguishes physically based CG from "real" engineering.

Tuesday's lecture will be on perception

Evaluation

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





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Missing file posted on the web page

I'm sorry for canceling class on Tuesday...