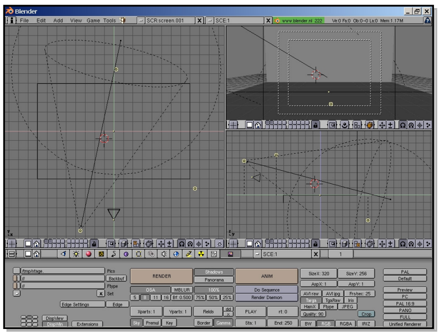
Computer Animation

Adam Finkelstein
Princeton University
C0S 426, Fall 2001

Advertisement

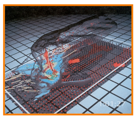


Computer Animation

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

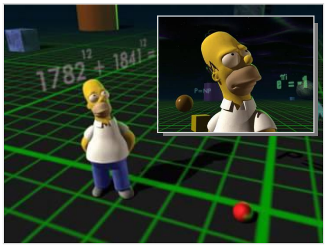
Pixar

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



University of Illinois

3-D and 2-D animation

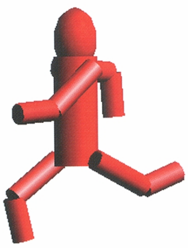


Homer 3-D

Homer 2-D

Outline

- Principles of animation
- Keyframe animation
- Articulated figures
- Kinematics
- Dynamics



Angel Plate 1

Principles of Traditional Animation

- Squash and stretch
- Slow In and out
- Anticipation
- Exaggeration
- Follow through and overlapping action
- Timing
- Staging
- Straight ahead action and pose-to-pose action
- Arcs
- Secondary action
- Appeal

Disney

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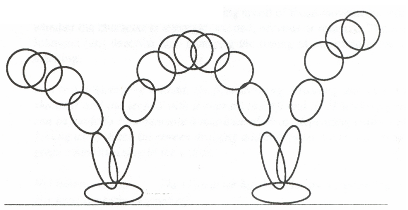
Principles of Traditional Animation

- Squash and stretch



Lasseter `87

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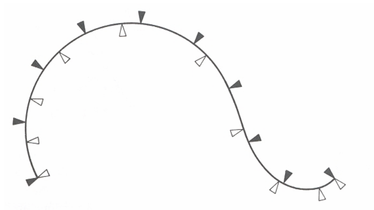
Principles of Traditional Animation

- Slow In and Out



Watt Figure 13.5

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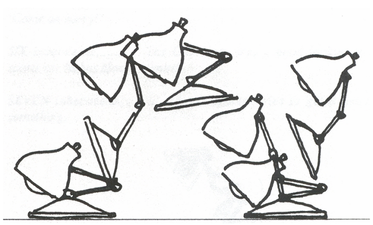
Principles of Traditional Animation

- Anticipation (and squash & stretch)



Lasseter `87

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Principles of Traditional Animation

- Squash and stretch
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Disney

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Computer Animation

- Animation pipeline
  - 3D modeling
  - Motion specification
  - Motion simulation
  - Shading, lighting, & rendering
  - Postprocessing

Pixar

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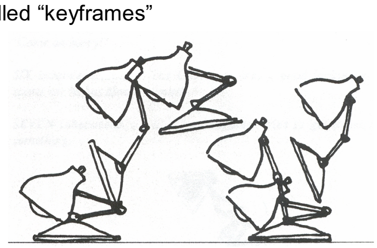
Keyframe Animation

- Define character poses at specific time steps called “keyframes”



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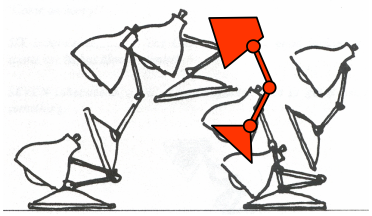
Keyframe Animation

- Interpolate variables describing keyframes to determine poses for character “in-between”



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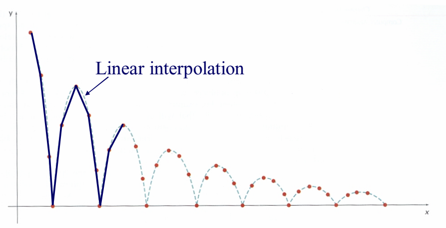
Keyframe Animation

- Inbetweening:
  - Linear interpolation - usually not enough continuity



H&B Figure 16.16

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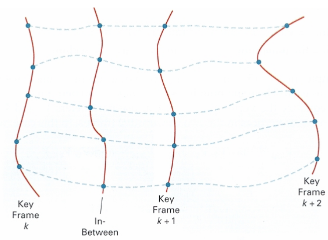
Keyframe Animation

- Inbetweening:
  - Spline interpolation - maybe good enough



H&B Figure 16.11

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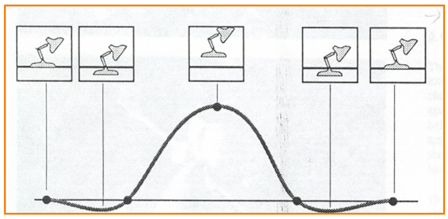
Keyframe Animation

- Inbetweening:
  - Cubic spline interpolation - maybe good enough
    - » May not follow physical laws



Lasseter `87

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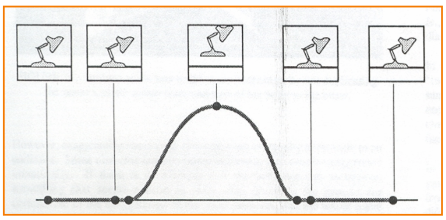
Keyframe Animation

- Inbetweening:
  - Cubic spline interpolation - maybe good enough
    - » May not follow physical laws



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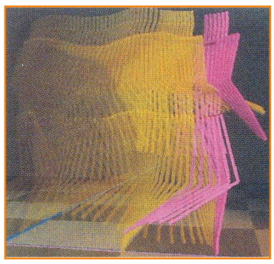
Keyframe Animation

- Inbetweening:
  - Inverse kinematics or dynamics



Rose et al. `96

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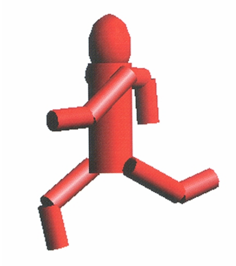
Outline

- Principles of animation
- Keyframe animation
- Articulated figures
- Kinematics
- Dynamics



Angel Plate 1

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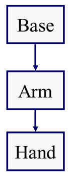
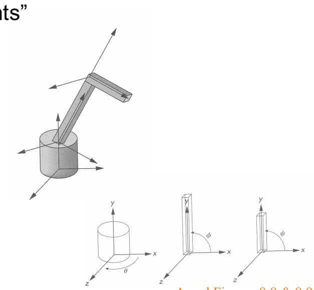
Articulated Figures

- Character poses described by set of rigid bodies connected by "joints"



Scene Graph



Angel Figures 8.8 & 8.9

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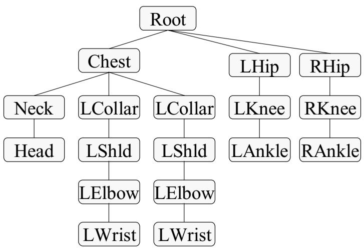
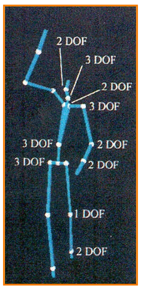
Articulated Figures

- Well-suited for humanoid characters





Rose et al. `96

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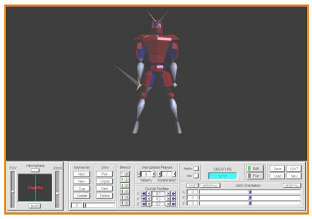
Articulated Figures

- Joints provide handles for moving articulated figure



Mike Marr, COS 426, Princeton University, 1995

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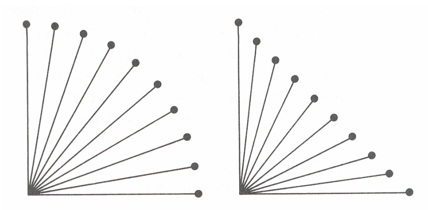
Articulated Figures

- Inbetweening
  - Compute joint angles between keyframes



Watt & Watt

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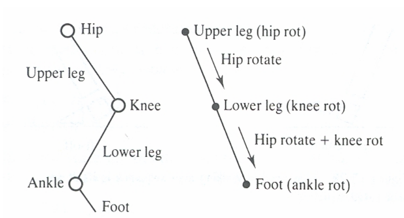
Example: Walk Cycle

- Articulated figure:



Watt & Watt

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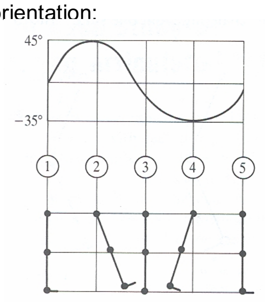
Example: Walk Cycle

- Hip joint orientation:



Watt & Watt

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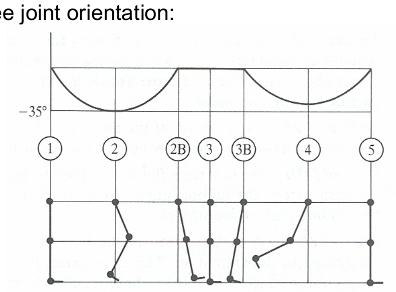
Example: Walk Cycle

- Knee joint orientation:



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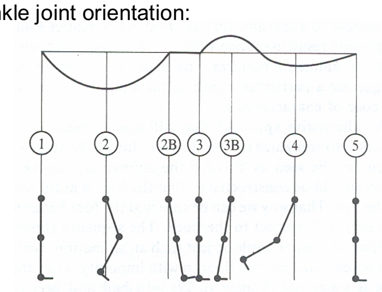
Example: Walk Cycle

- Ankle joint orientation:



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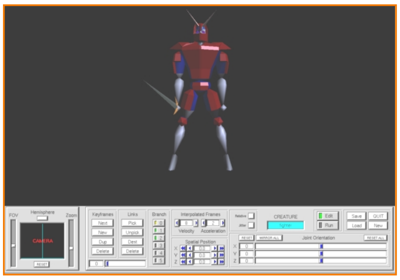
Example: Run Cycle



Mike Marr, COS 426, Princeton University, 1995

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Example: Ice Skating

(Mao Chen, Zaijin Guan, Zhiyan Liu, Xiaohu Qie, CS426, Fall98, Princeton University)

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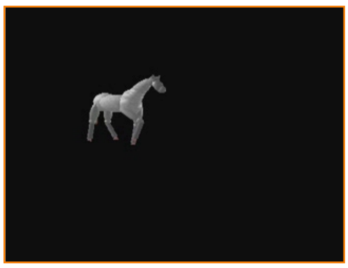
Example: Horse



(Casey McTaggart, CS426, Fall99)

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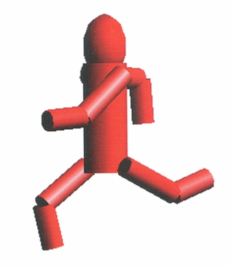
Outline

- Principles of animation
- Keyframe animation
- Articulated figures
- Kinematics
- Dynamics



Angel Plate 1

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Kinematics and Dynamics

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

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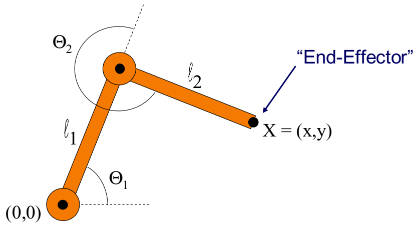
Example: 2-Link Structure

- Two links connected by rotational joints



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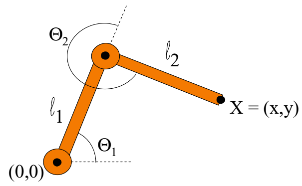
Forward Kinematics

- Animator specifies joint angles: Θ_1 and Θ_2
- Computer finds positions of end-effector: X



$$X = (l_1 \cos\Theta_1 + l_2 \cos(\Theta_1 + \Theta_2), l_1 \sin\Theta_1 + l_2 \sin(\Theta_1 + \Theta_2))$$

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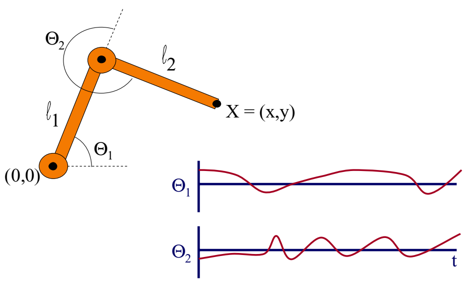
Forward Kinematics

- Joint motions can be specified by spline curves



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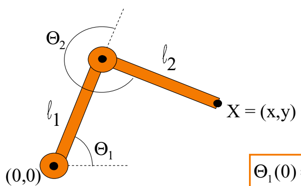
Forward Kinematics

- Joint motions can be specified by initial conditions and velocities



$$\Theta_1(0) = 60^\circ \qquad \Theta_2(0) = 250^\circ$$

$$\frac{d\Theta_1}{dt} = 1.2 \qquad \frac{d\Theta_2}{dt} = -0.1$$

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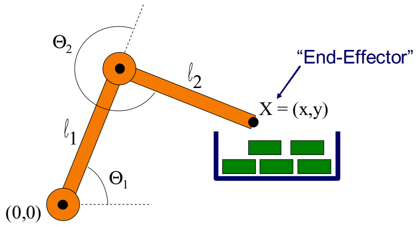
Example: 2-Link Structure

- What if animator knows position of “end-effector”



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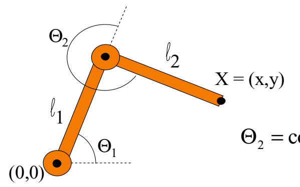
Inverse Kinematics

- Animator specifies end-effector positions: X
- Computer finds joint angles: Θ_1 and Θ_2:



$$\Theta_2 = \cos^{-1}\left(\frac{x^2 + x^2 - l_1^2 - l_2^2}{2 l_1 l_2}\right)$$

$$\Theta_1 = \frac{-(l_2 \sin(\Theta_2))x + (l_1 + l_2 \cos(\Theta_2))y}{(l_2 \sin(\Theta_2))y + (l_1 + l_2 \cos(\Theta_2))x}$$

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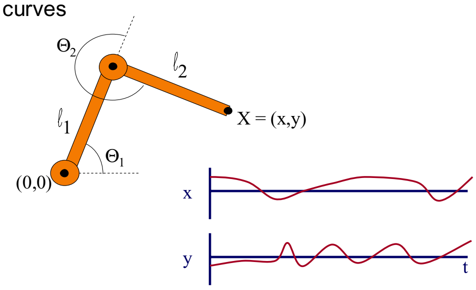
Inverse Kinematics

- End-effector postions can be specified by spline curves



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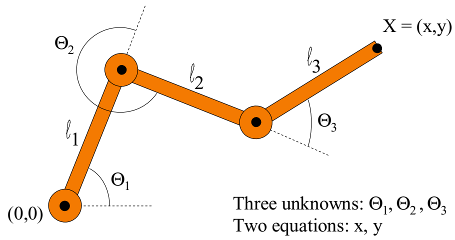
Inverse Kinematics

- Problem for more complex structures
  - System of equations is usually under-defined
  - Multiple solutions



Three unknowns: $\Theta_1, \Theta_2, \Theta_3$
Two equations: x, y

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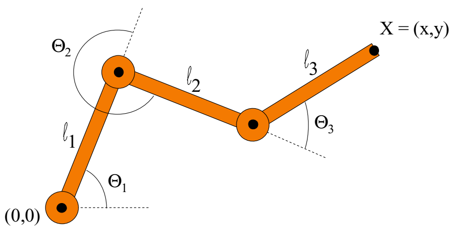
Inverse Kinematics

- Solution for more complex structures:
  - Find best solution (e.g., minimize energy in motion)
  - Non-linear optimization



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Inverse Kinematics

“Ballboy”

Fujito, Milliron, Ngan, & Sanocki
Princeton University

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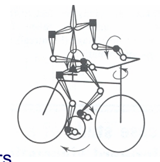
Summary of Kinematics

- Forward kinematics
  - Specify conditions (joint angles)
  - Compute positions of end-effectors
- Inverse kinematics
  - “Goal-directed” motion
  - Specify goal positions of end effectors
  - Compute conditions required to achieve goals



Inverse kinematics provides easier specification for many animation tasks, but it is computationally more difficult

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Overview

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

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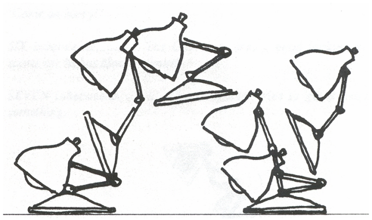
Dynamics

- Simulation of physics insures realism of motion



Lasseter `87

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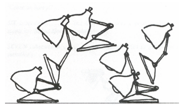
Spacetime Constraints

- Animator specifies constraints:
  - What the character’s physical structure is
    - » e.g., articulated figure
  - What the character has to do
    - » e.g., jump from here to there within time t
  - What other physical structures are present
    - » e.g., floor to push off and land
  - How the motion should be performed
    - » e.g., minimize energy



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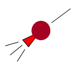
Spacetime Constraints

- Computer finds the “best” physical motion satisfying constraints
- Example: particle with jet propulsion
  - **x**(t) is position of particle at time t
  - **f**(t) is force of jet propulsion at time t
  - Particle’s equation of motion is:



$$mx'' - f - mg = 0$$

  - Suppose we want to move from a to b within t_0 to t_1 with minimum jet fuel:

$$\text{Minimize } \int_{t_0}^{t_1} \left| f(t)^2 \right| dt \quad \text{subject to } x(t_0)=a \text{ and } x(t_1)=b$$

Witkin & Kass `88

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Spacetime Constraints

- Discretize time steps:

$$x'_i = \frac{x_i - x_{i-1}}{h}$$

$$x''_i = \frac{x_{i+1} - 2x_i + x_{i-1}}{h^2}$$

$$m\left(x''_i = \frac{x_{i+1} - 2x_i + x_{i-1}}{h^2}\right) - f_i - mg = 0$$

$$\text{Minimize } h\sum_i \left| f_i \right|^2 \quad \text{subject to } x_0=a \text{ and } x_1=b$$

Witkin & Kass `88

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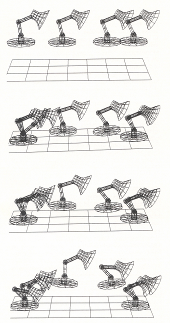
Spacetime Constraints

- Solve with iterative optimization methods



Witkin & Kass `88

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Spacetime Constraints

- Advantages:
  - Free animator from having to specify details of physically realistic motion with spline curves
  - Easy to vary motions due to new parameters and/or new constraints
- Challenges:
  - Specifying constraints and objective functions
  - Avoiding local minima during optimization

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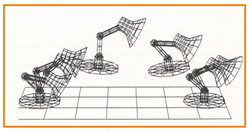
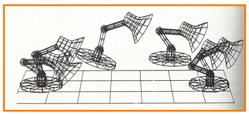
Spacetime Constraints

- Adapting motion:



Original Jump



Heavier Base

Witkin & Kass `88

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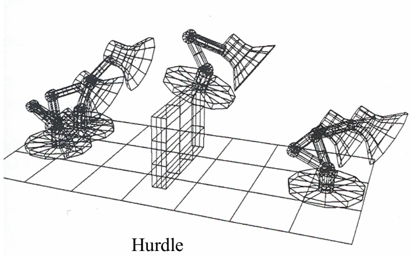
Spacetime Constraints

- Adapting motion:



Hurdle

Witkin & Kass `88

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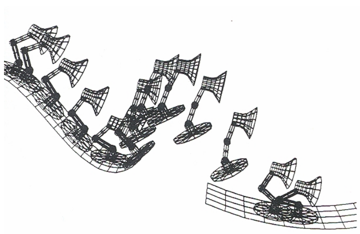
Spacetime Constraints

- Adapting motion:



Ski Jump

Witkin & Kass `88

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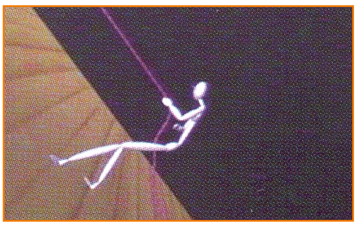
Spacetime Constraints

- Editing motion:



Li et al. `99

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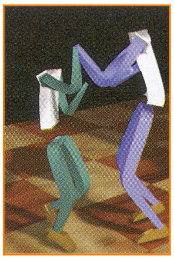
Spacetime Constraints

- Morphing motion:



Gleicher '98

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Spacetime Constraints

- Advantages:
  - Free animator from having to specify details of physically realistic motion with spline curves
  - Easy to vary motions due to new parameters and/or new constraints
- Challenges:
  - Specifying constraints and objective functions
  - Avoiding local minima during optimization

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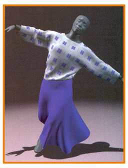
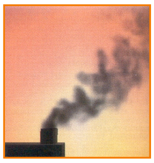
Dynamics

- Other physical simulations:
  - Rigid bodies
  - Soft bodies
  - Cloth
  - Liquids
  - Gases
  - etc.



Cloth
(Baraff & Witkin '98)



Hot Gases
(Foster & Metaxas '97)

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Summary

- Principles of animation
- Keyframe animation
- Articulated figures
- Kinematics
  - Forward kinematics
  - Inverse kinematics
- Dynamics
  - Space-time constraints
  - Also other physical simulations