Keyframe Animation

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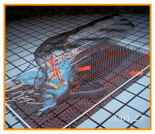
Princeton University
COS 426, Spring 2008

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



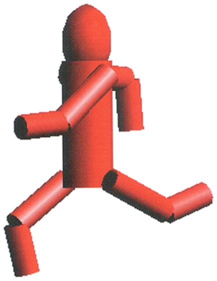
University of Illinois

Computer Animation

Pixar

Outline

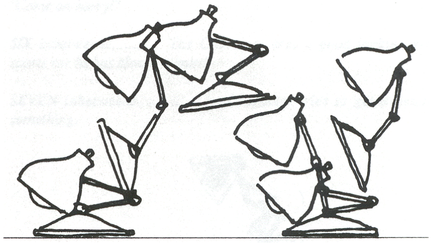
- ➤ Keyframe animation
- Adding inverse kinematics
- Adding dynamics



Angel Plate 1

Keyframe Animation

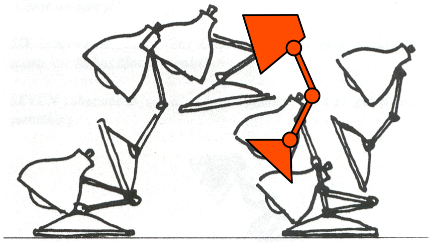
- Define character poses at specific time steps called “keyframes”



Lasseter ’87

Keyframe Animation

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



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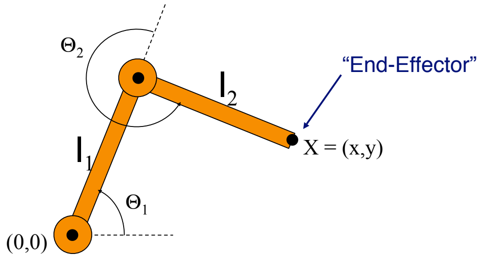
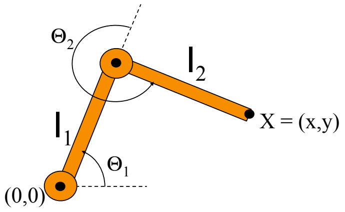
Example: 2-Link Structure

- Two links connected by rotational joints



Forward Kinematics

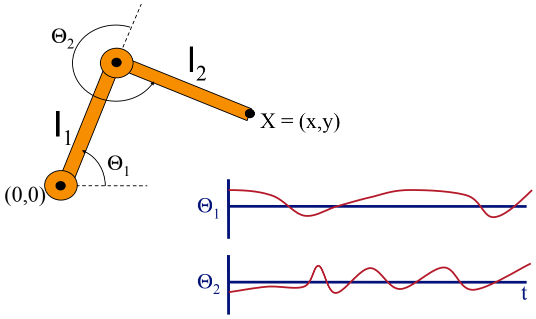
- Animator specifies joint angles: Θ_1 and Θ_2
- Computer finds positions of end-effector: X



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

Forward Kinematics

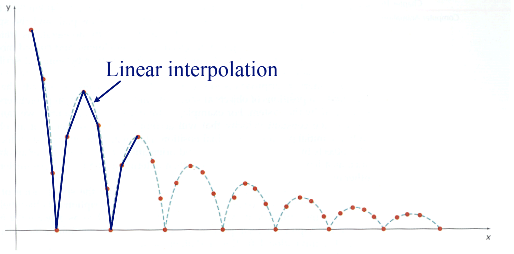
- Joint motions can be specified by spline curves



Example (online)

Keyframe Animation

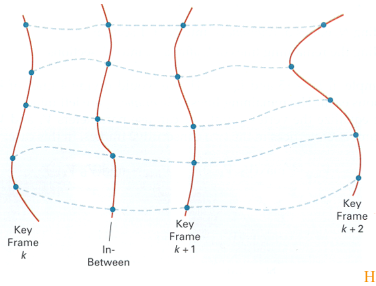
- Inbetweening:
  - Linear interpolation - usually not enough continuity



H&B Figure 16.16

Keyframe Animation

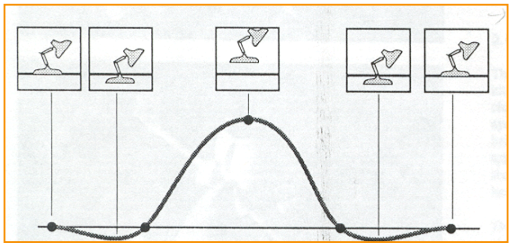
- Inbetweening:
  - Spline interpolation - maybe good enough



H&B Figure 16.11

Keyframe Animation

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



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Keyframe Animation

- Inbetweening:
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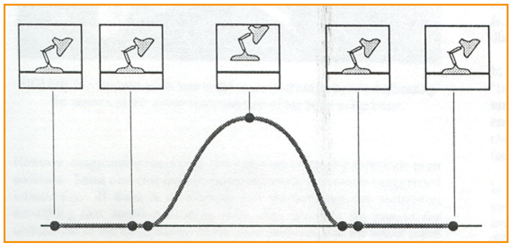

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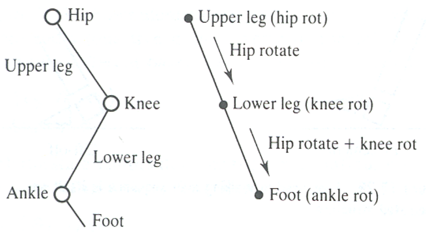
Example: Walk Cycle

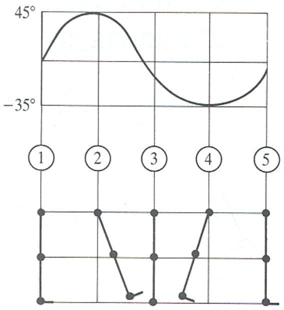
- Articulated figure:



Watt & Watt

Example: Walk Cycle

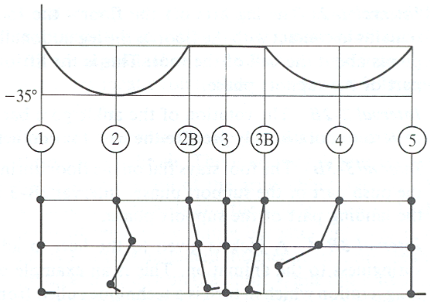
- Hip joint orientation:



Watt & Watt

Example: Walk Cycle

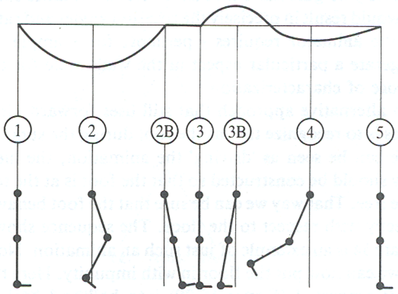
- Knee joint orientation:



Watt & Watt

Example: Walk Cycle

- Ankle joint orientation:



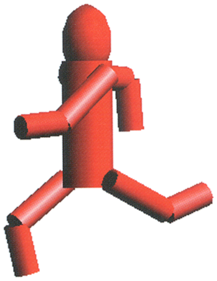
Watt & Watt

Example: Ice Skating

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

Outline

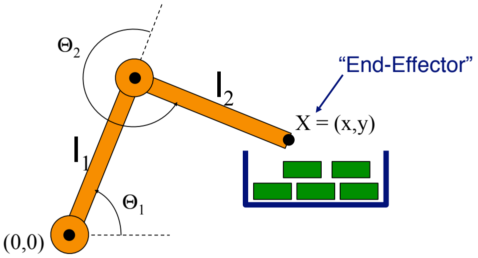
- Keyframe animation
- Adding inverse kinematics
- Adding dynamics



Angel Plate 1

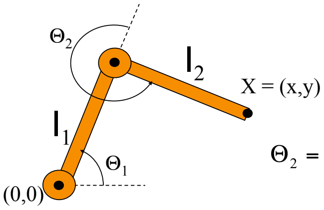
Example: 2-Link Structure

- What if animator knows position of "end-effector"



Inverse Kinematics

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

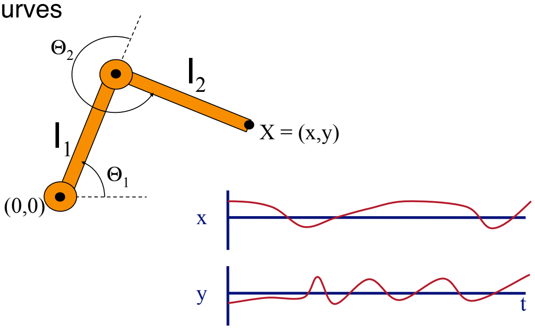


$$\Theta_2 = \cos^{-1}\left(\frac{x^2 + x^2 - l_1^2 - l_2^2}{\mathbf{2}l_1 l_2}\right)$$

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

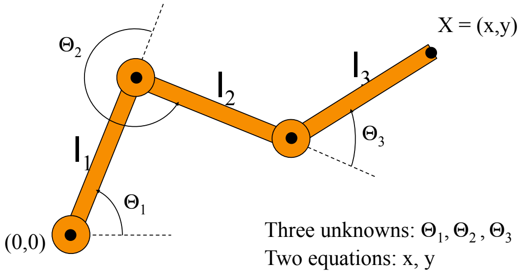
Inverse Kinematics

- End-effector postions can be specified by spline curves



Inverse Kinematics

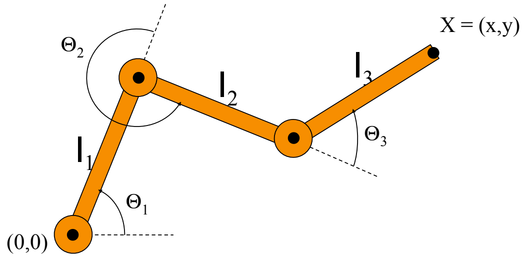
- Problem for more complex structures
  - System of equations is usually under-defined
  - Multiple solutions



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

Inverse Kinematics

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



Example: Ball Boy

"Ballboy"

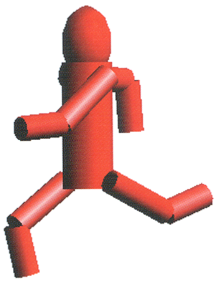
Fujito, Milliron, Ngan, & Sanocki
Princeton University

More examples: online

Pixar

Outline

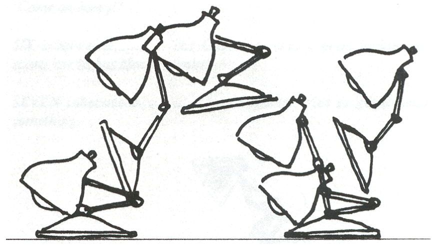
- Keyframe animation
- Adding inverse kinematics
- Adding dynamics



Angel Plate 1

Dynamics

- Simulation of physics insures realism of motion



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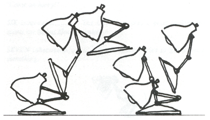
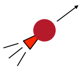
Spacetime Constraints

- Animator specifies constraints:
  - What the character's physical structure is
    - » e.g., articulated figure
  - What the character has to do (keyframes)
    - » 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



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:

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

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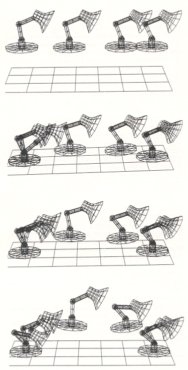
Spacetime Constraints

- Solve with iterative optimization methods



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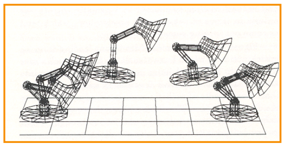
Spacetime Constraints

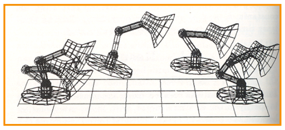
- Advantages:
  - Free animator from having to specify details of physically realistic motion with spline curves
  - Easy to vary motions due to new parameters and/or new constraints
- Challenges:
  - Specifying constraints and objective functions
  - Avoiding local minima during optimization

Spacetime Constraints

- Adapting motion:



Original Jump



Heavier Base

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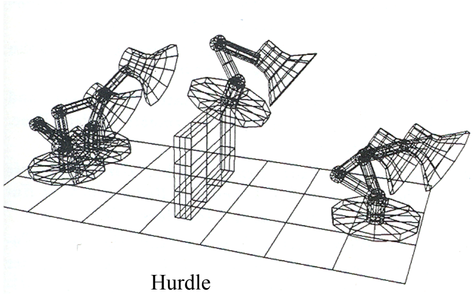
Spacetime Constraints

- Adapting motion:



Hurdle

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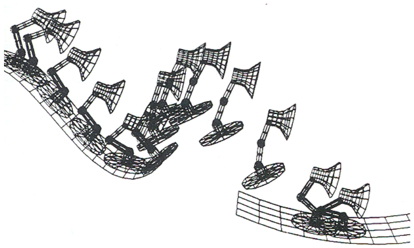
Spacetime Constraints

- Adapting motion:



Ski Jump

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Spacetime Constraints

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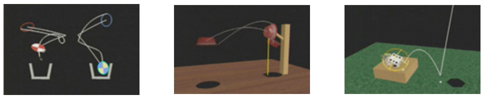
Example: Manipulation of Sims.



Interactive Manipulation of Rigid Body Simulations.
Popovic et al Siggraph 2000.

Popovic

Summary

- Keyframe animation
  - Poses specified at key times
  - In-betweening to fill in the rest
- Incorporating inverse kinematics
  - Makes keyframes easier to specify
- Incorporating dynamics
  - Makes animation easier to adapt