Character Animation

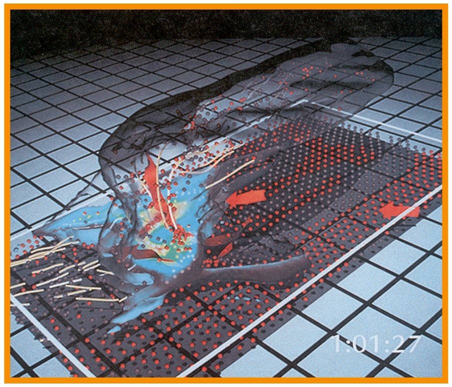
COS 426, Spring 2015
Princeton University

Computer Animation

- Animation ←
  - Make objects change over time according to scripted actions

Pixar

- Simulation / dynamics
  - Predict how objects change over time according to physical laws



University of Illinois

Computer Animation

- Describing how 3D objects (& cameras) move over time

Pixar

Computer Animation

- Challenge is balancing between …
  - Animator control
  - Physical realism

AVATAR
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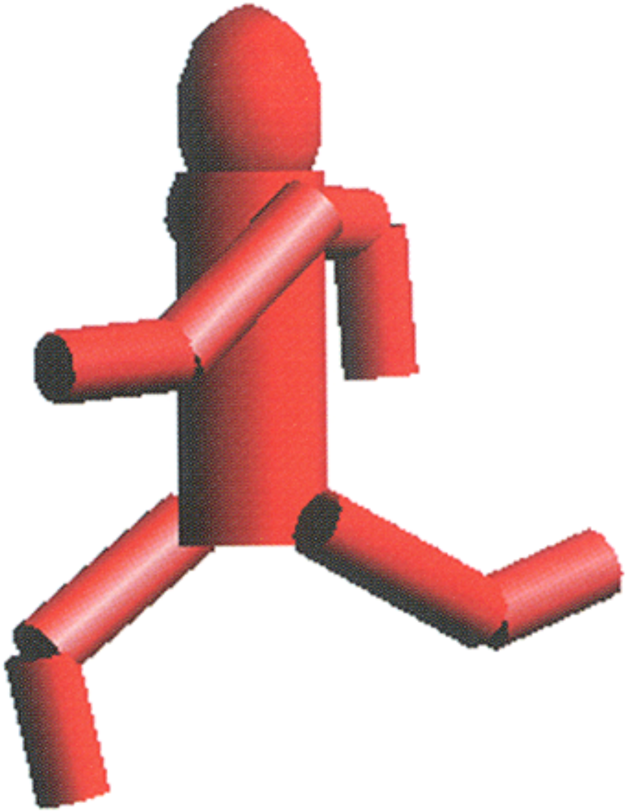
Character Animation Methods

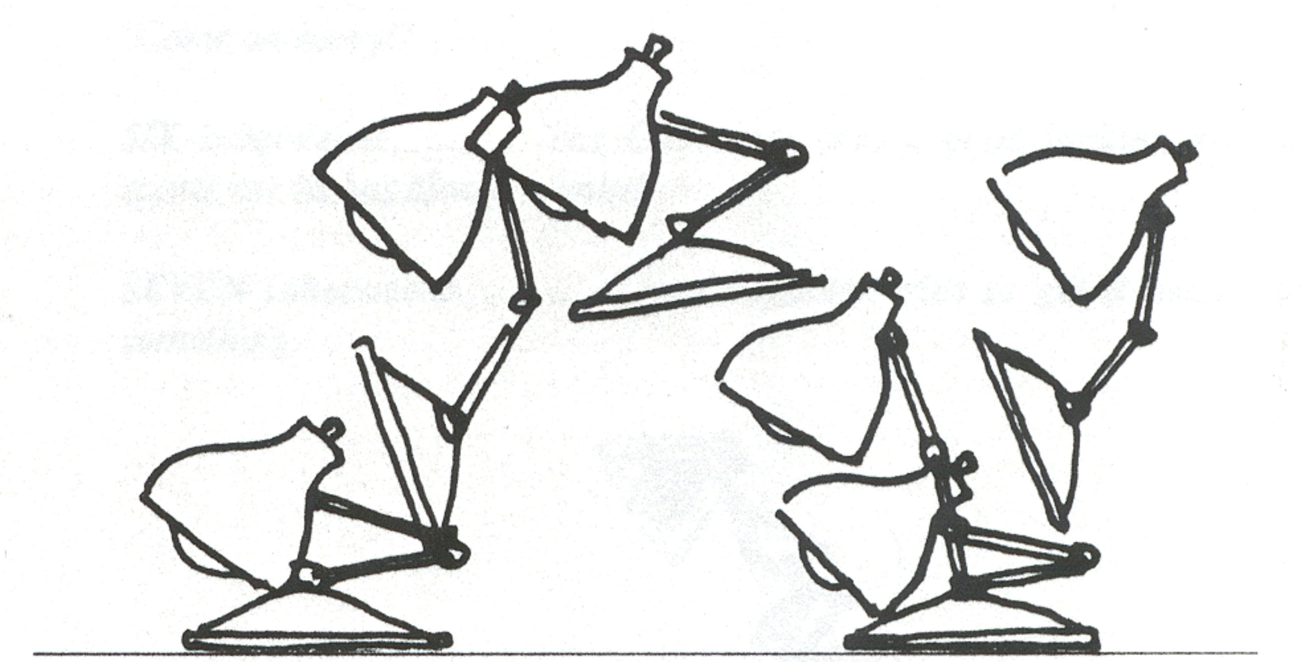
- Keyframing / Forward Kinematics
- Inverse Kinematics
- Dynamics
- Motion capture



Angel Plate 1

Keyframe Animation

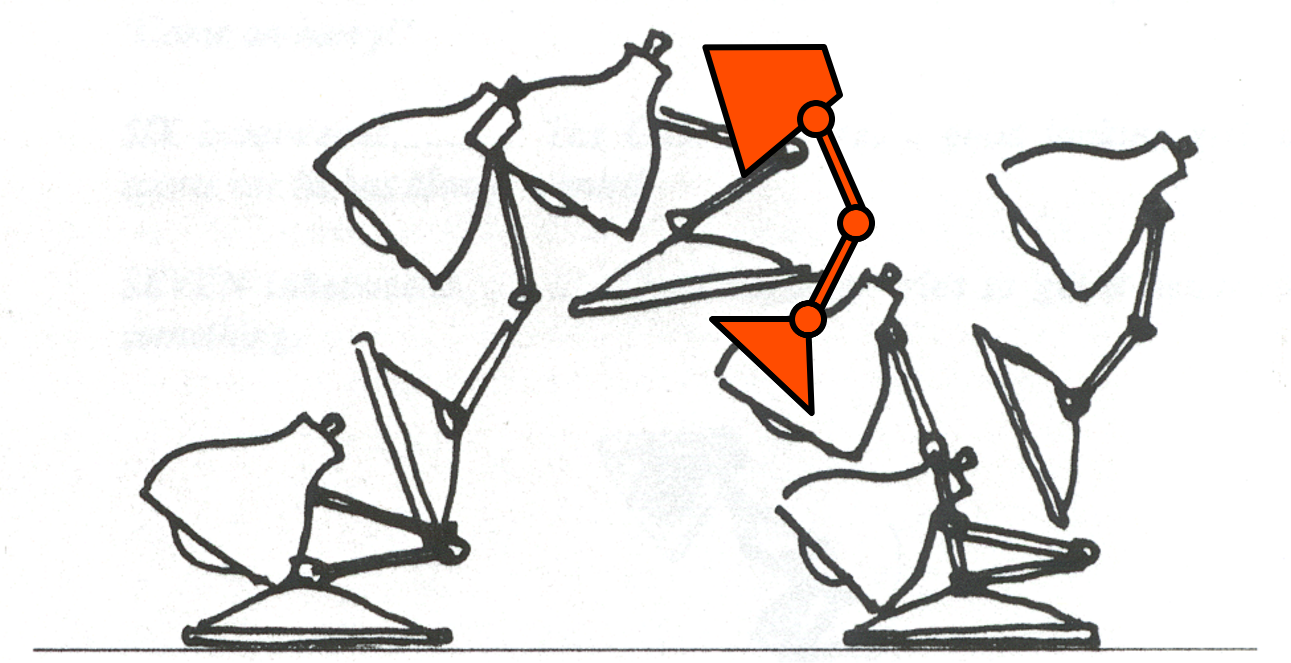
- Define character poses at specific time steps called "keyframes"



Lasseter `87

Keyframe Animation

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



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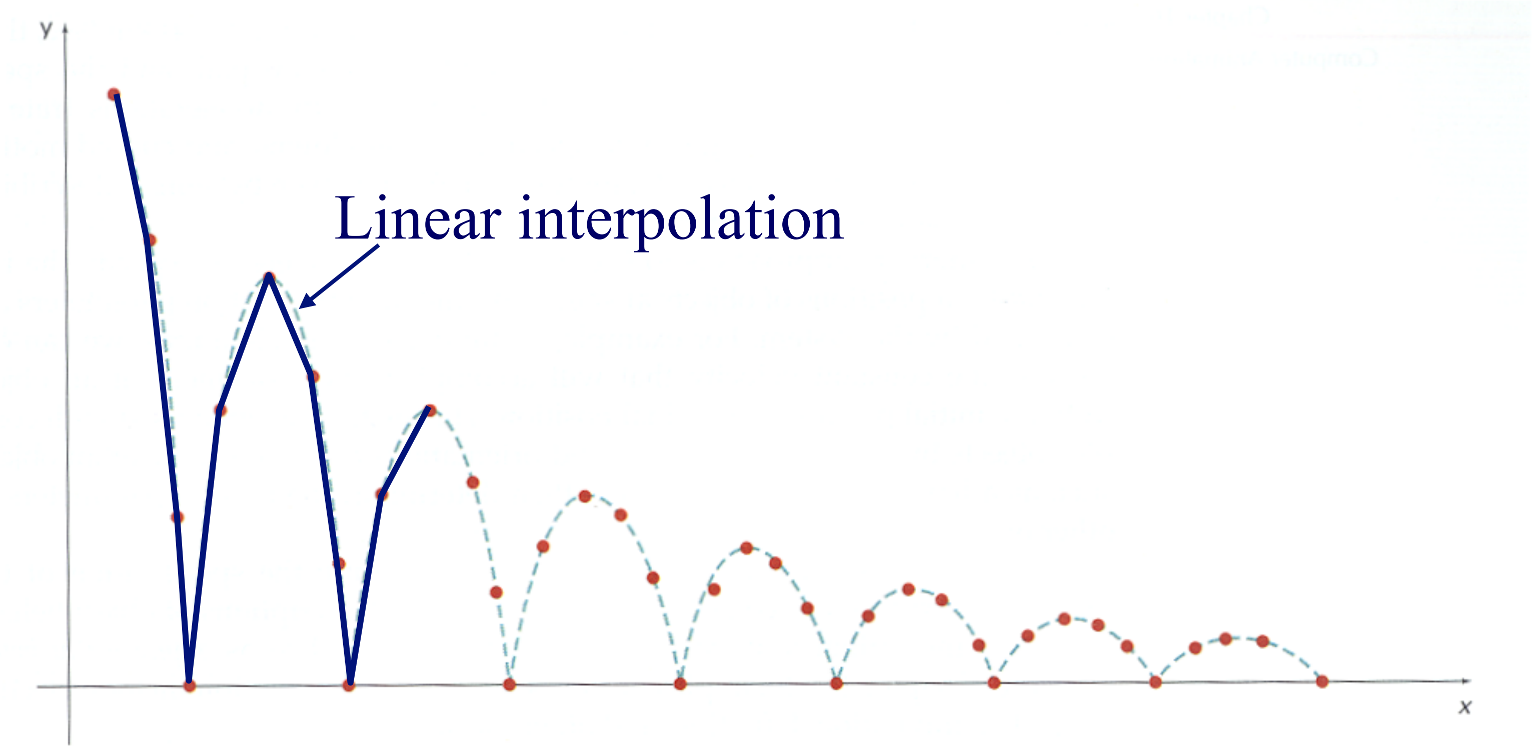
Keyframe Animation

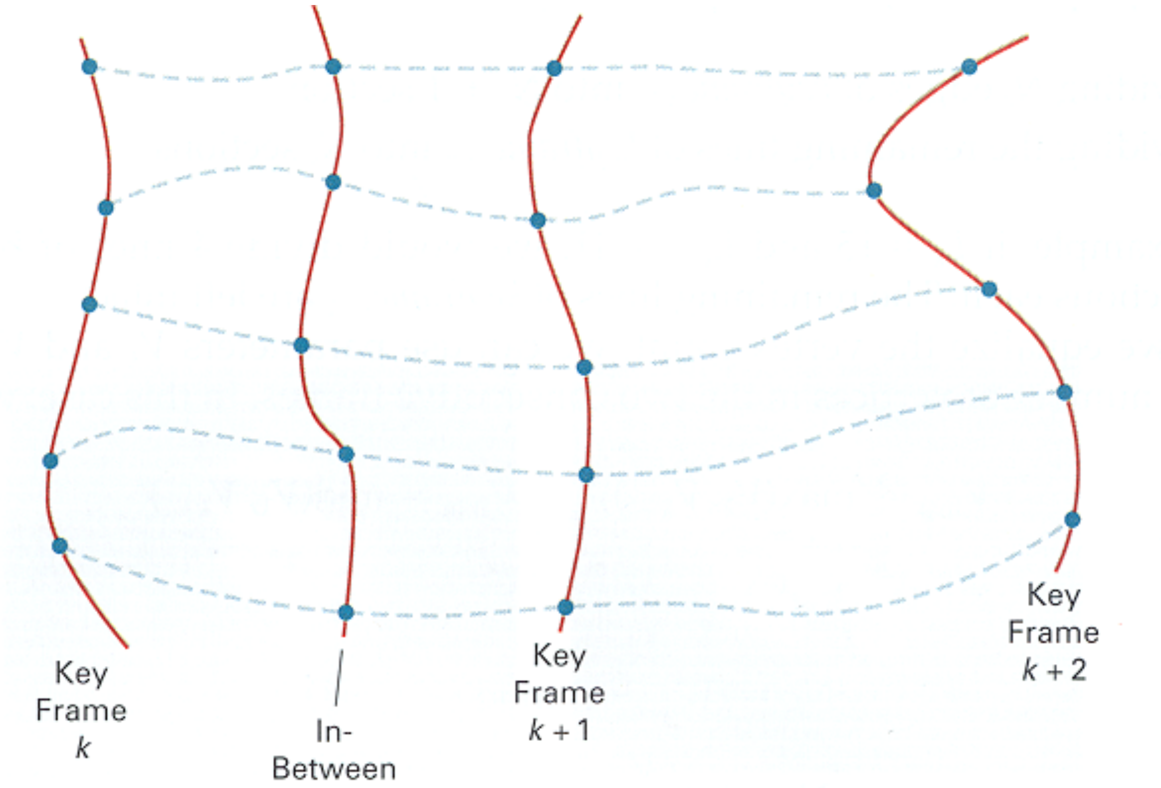
- Inbetweening:
  - Linear interpolation - usually not enough continuity



H&B Figure 16.16

Keyframe Animation

- Inbetweening:
  - Spline interpolation - maybe good enough



H&B Figure 16.11

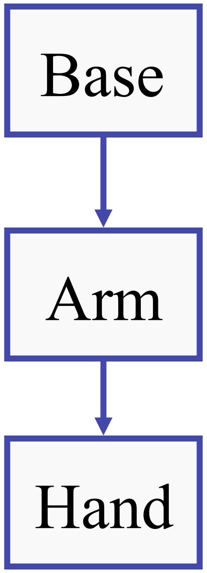
Example: Ball Boy

"Ballboy"

Fujito, Milliron, Ngan, & Sanocki
Princeton University

Articulated Figures

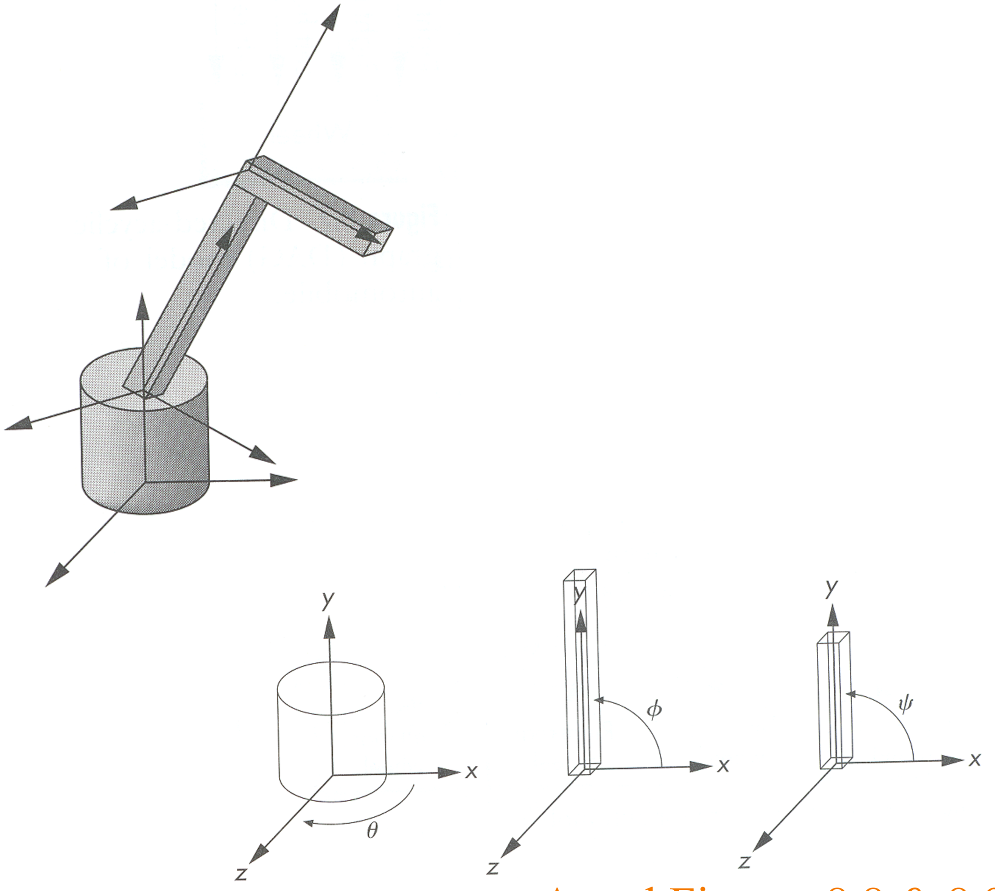
- Character poses described by set of rigid bodies connected by “joints”


Base

Arm

Hand

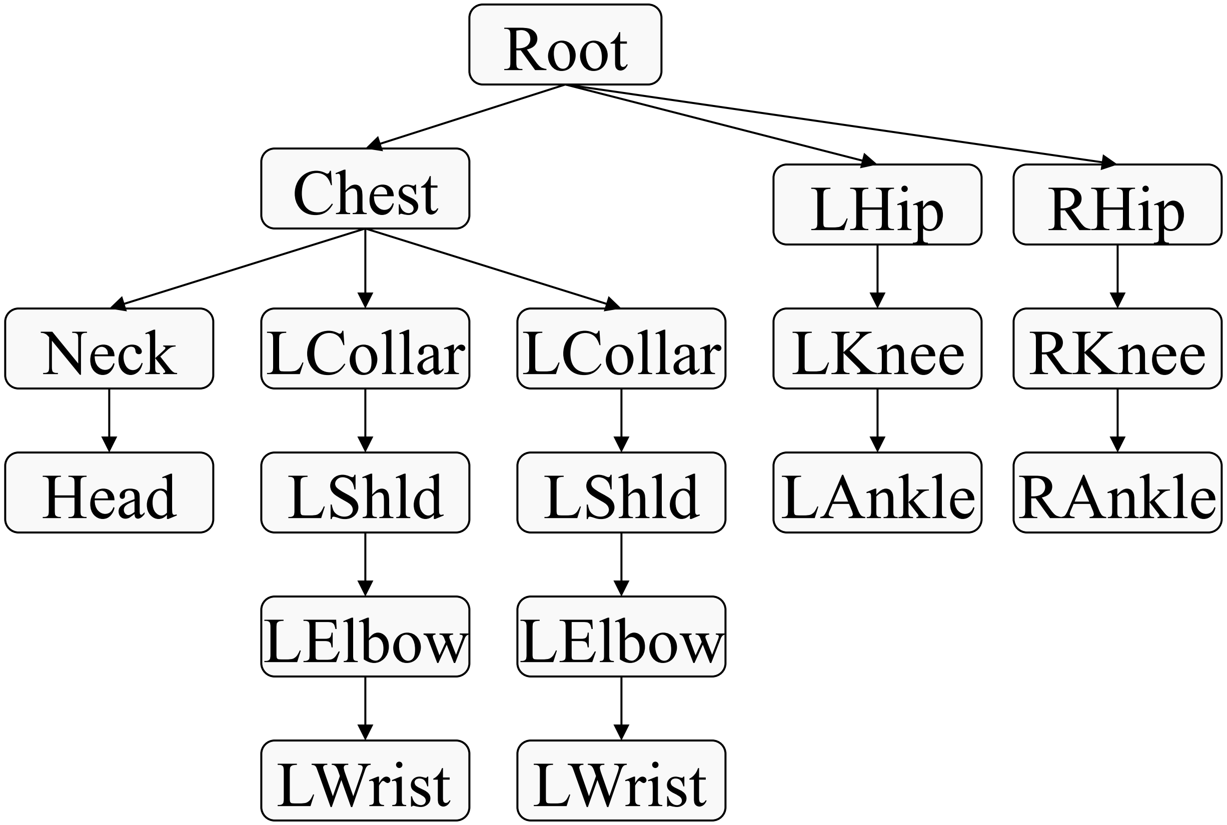
Scene Graph



Angel Figures 8.8 & 8.9

Articulated Figures

- Well-suited for humanoid characters



Root

Chest

LHip

RHip

Neck

LCollar

LCollar

LKnee

RKnee

Head

LShld

LShld

LAnkle

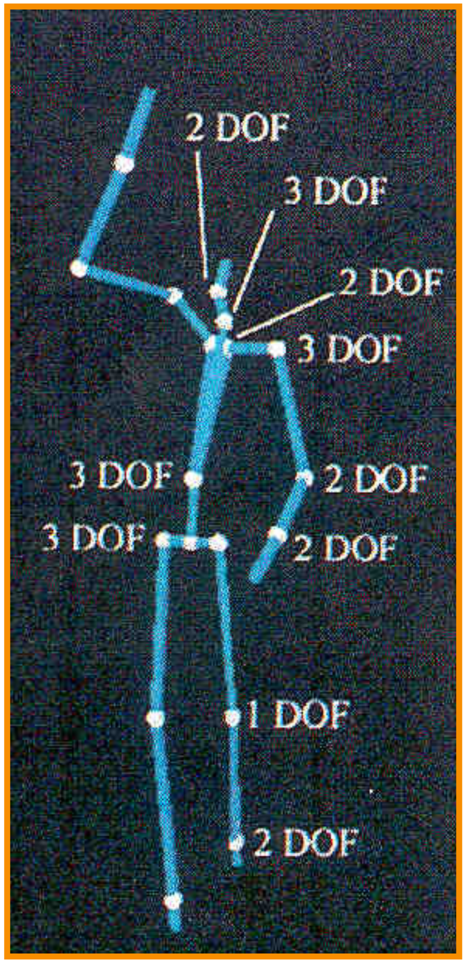
RAnkle

LElbow

LElbow

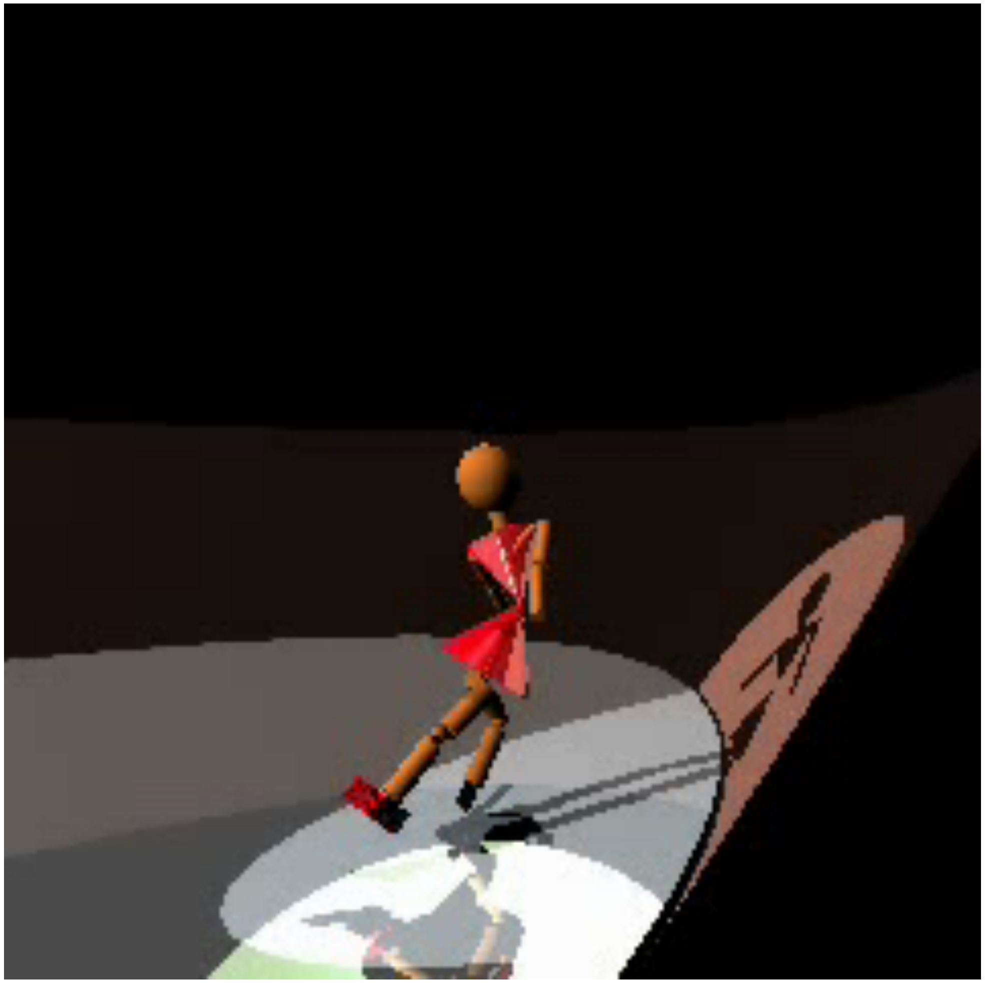
LWrist

LWrist



Rose et al. `96

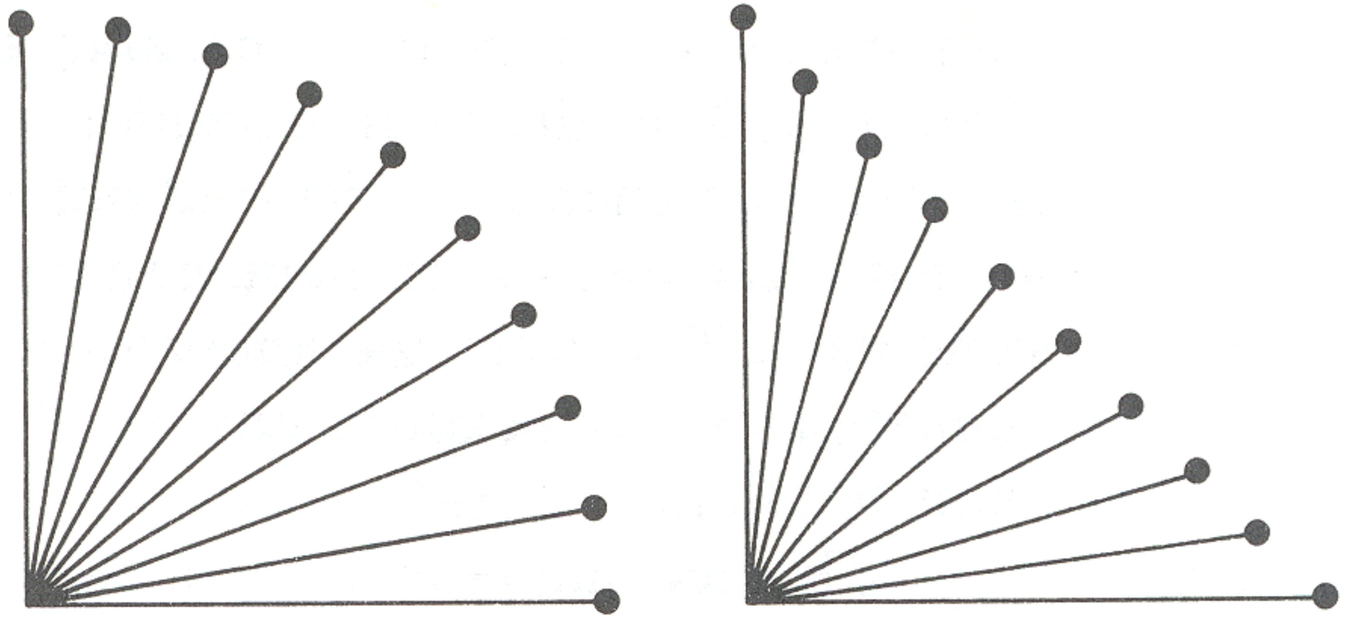
Example: Ice Skating



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

Articulated Figures

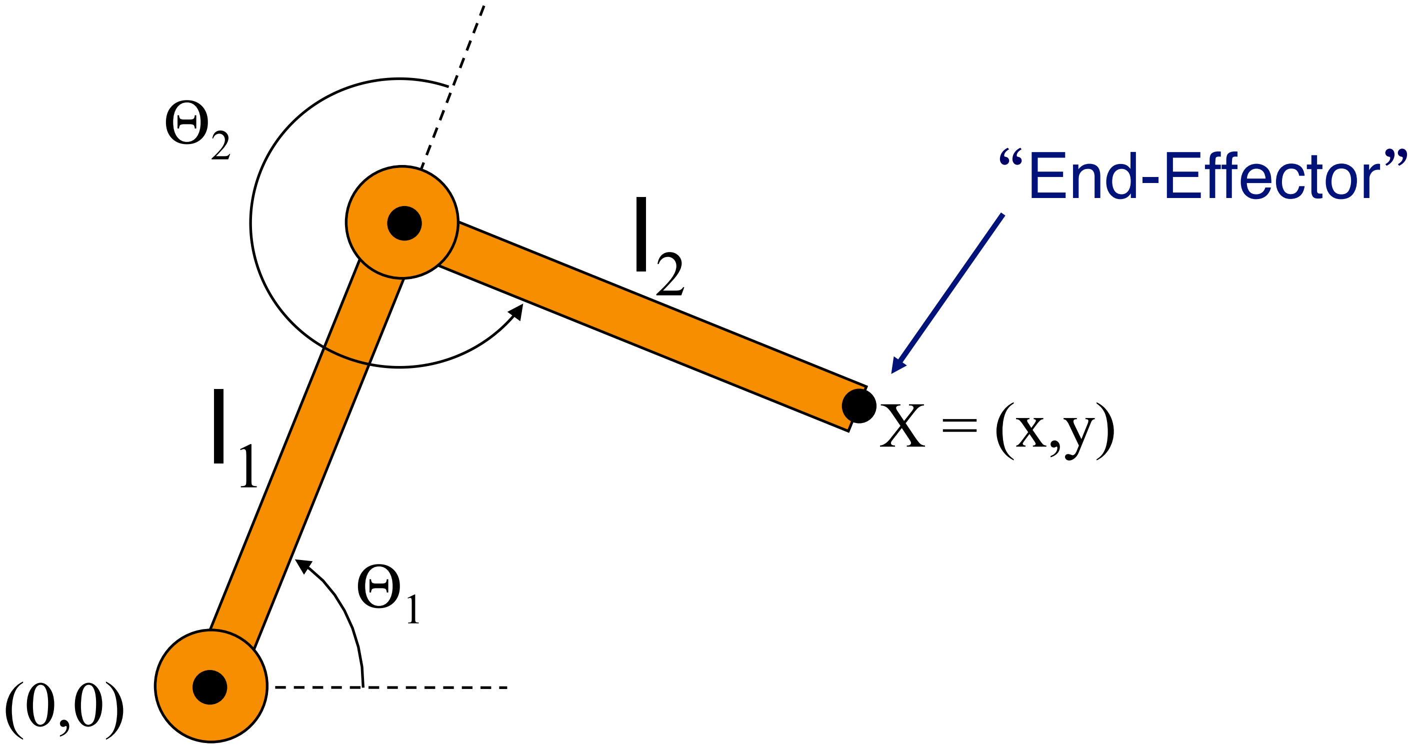
- Animation focuses on joint angles



Watt & Watt

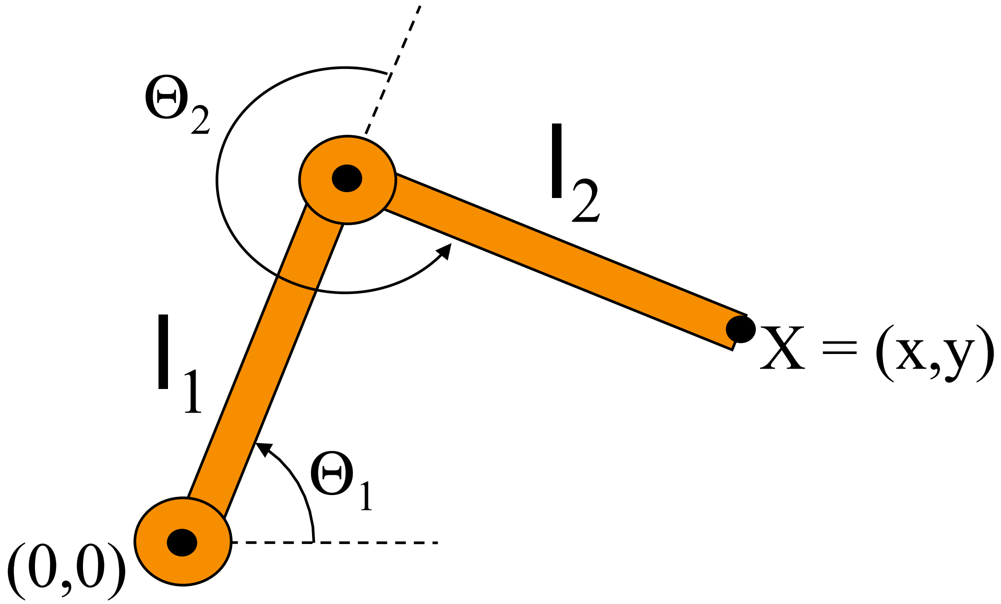
Forward Kinematics

- Describe motion of articulated character



Forward Kinematics

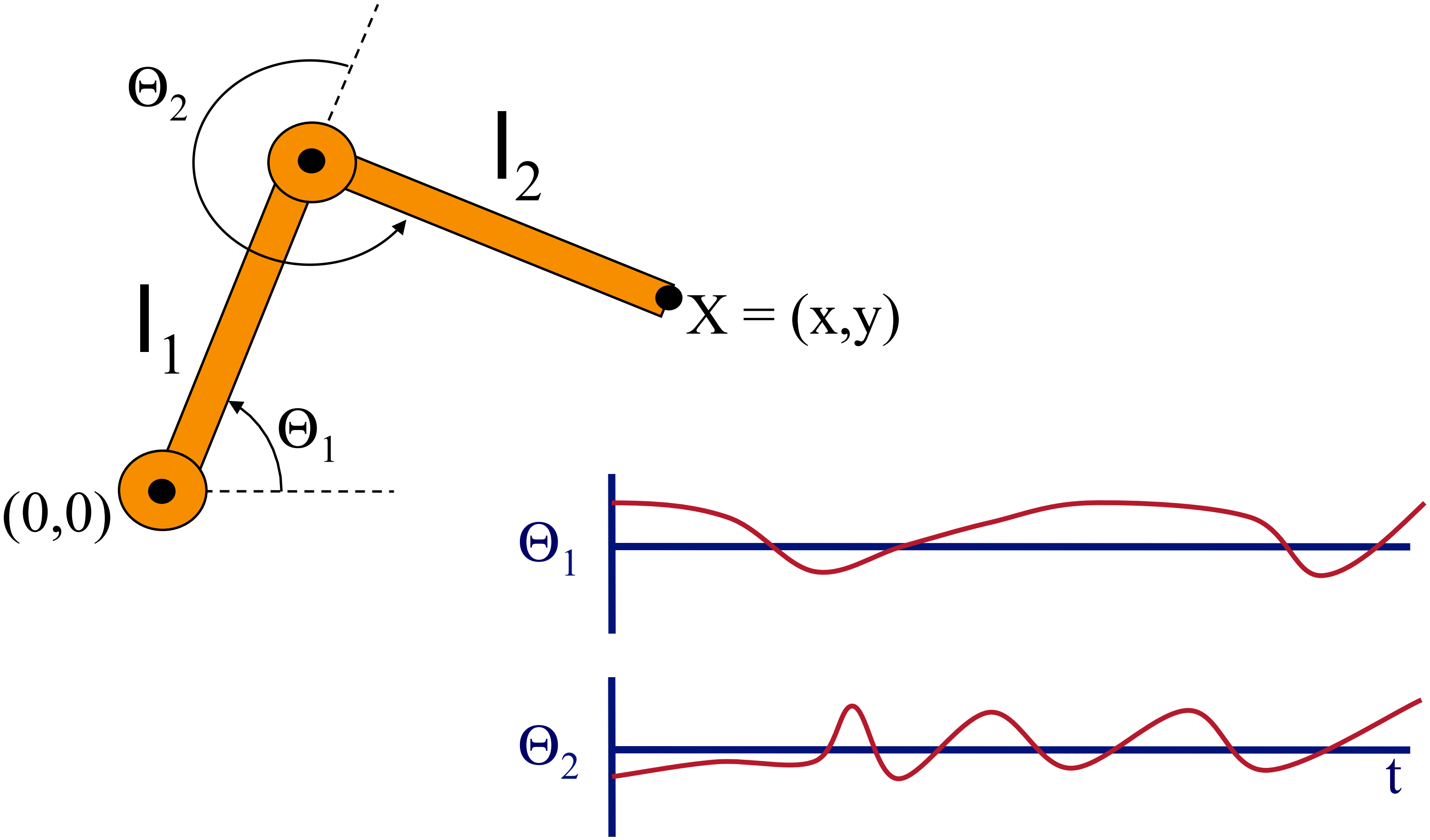
- Animator specifies joint angles: Θ_1 and Θ_2
- Computer finds positions of end-effector: X



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

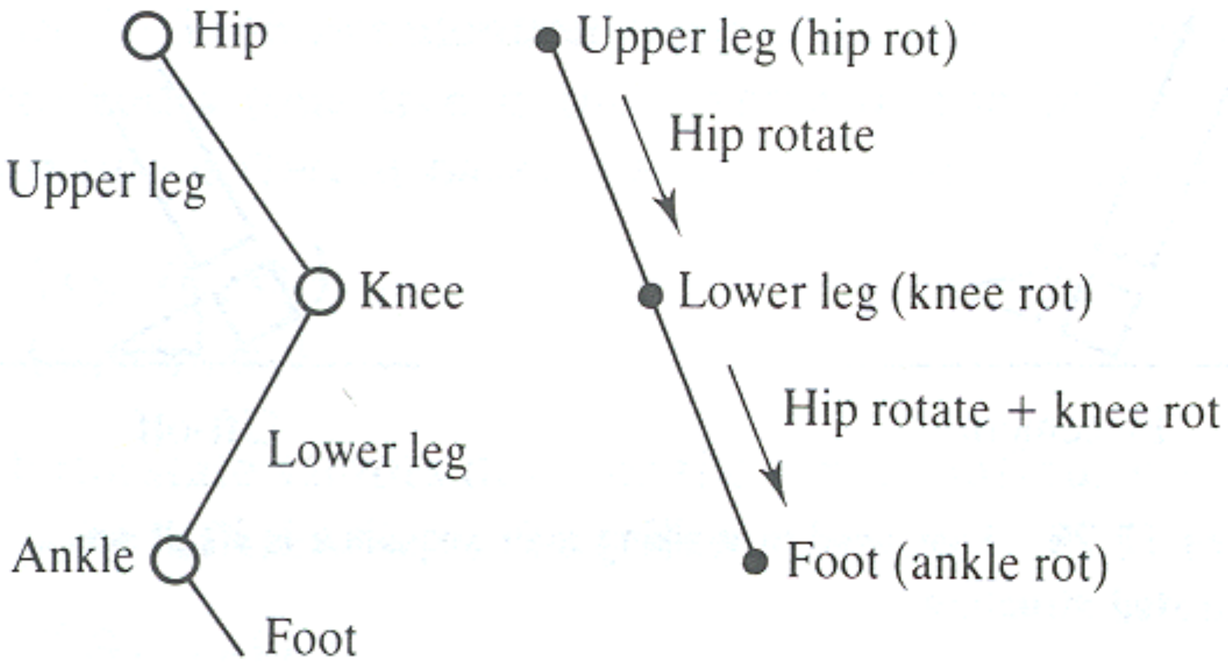
Forward Kinematics

- Joint motions specified e.g. by spline curves



Example: Walk Cycle

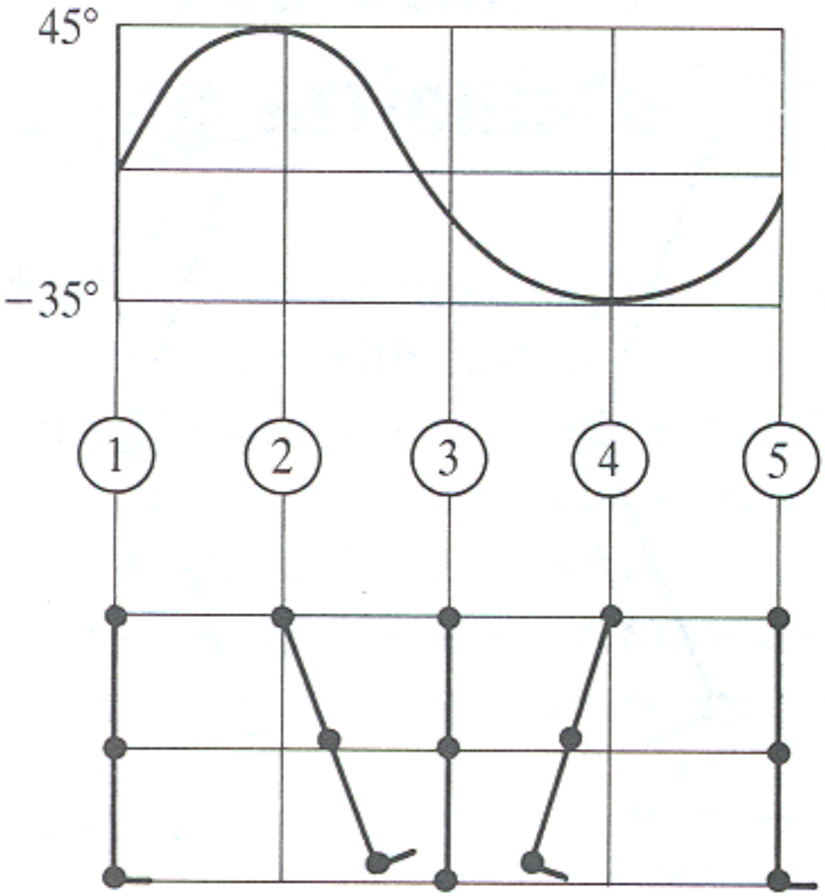
- Articulated figure:



Watt & Watt

Example: Walk Cycle

- Hip joint orientation:

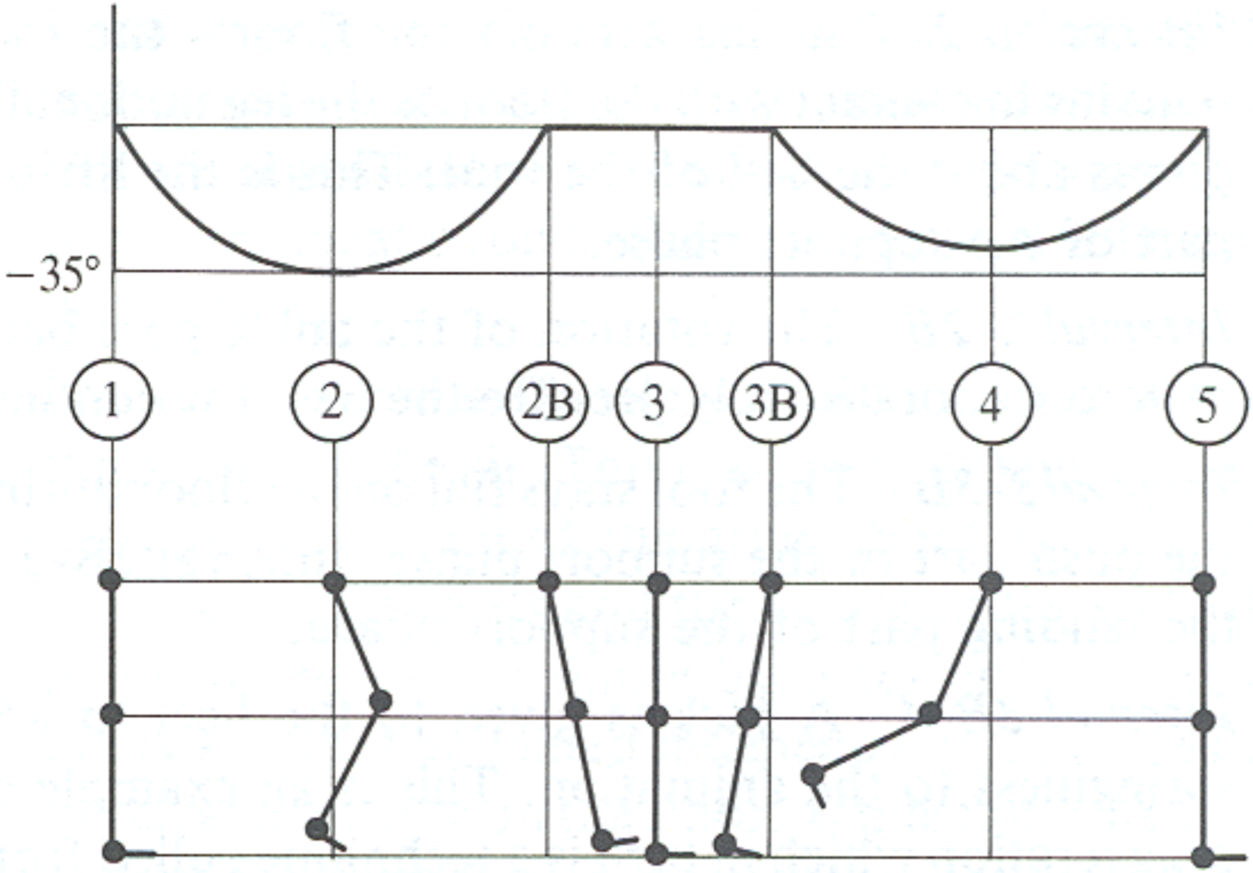


Keyframes

Watt & Watt

Example: Walk Cycle

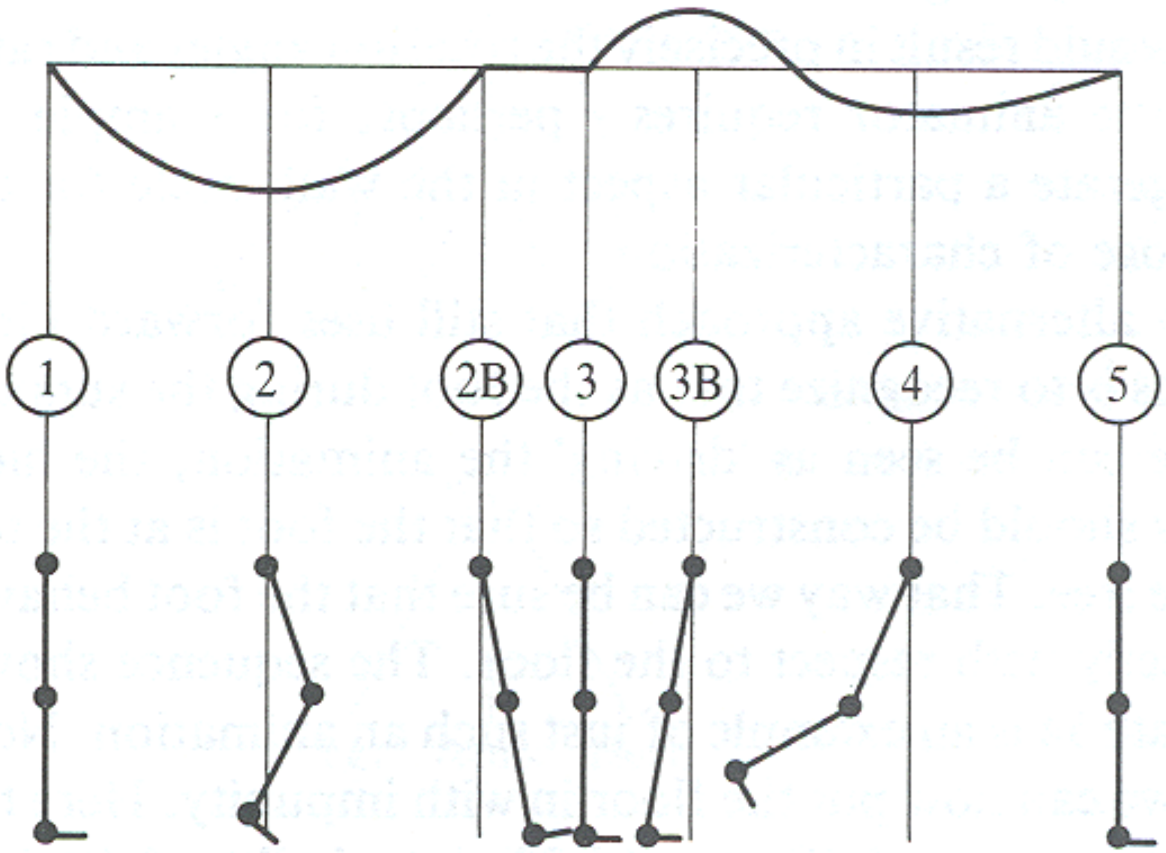
- Knee joint orientation:



Watt & Watt

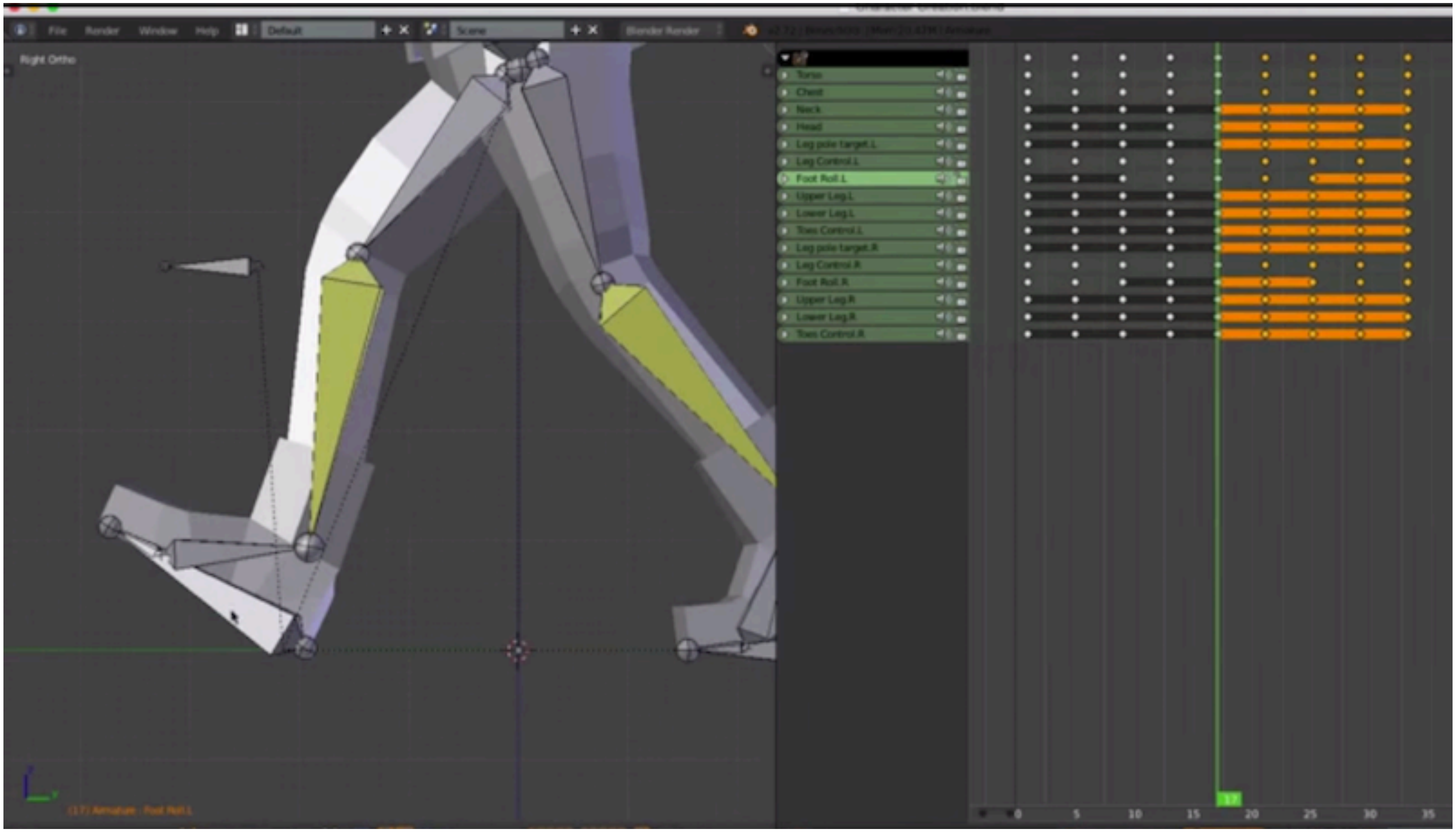
Example: Walk Cycle

- Ankle joint orientation:



Watt & Watt

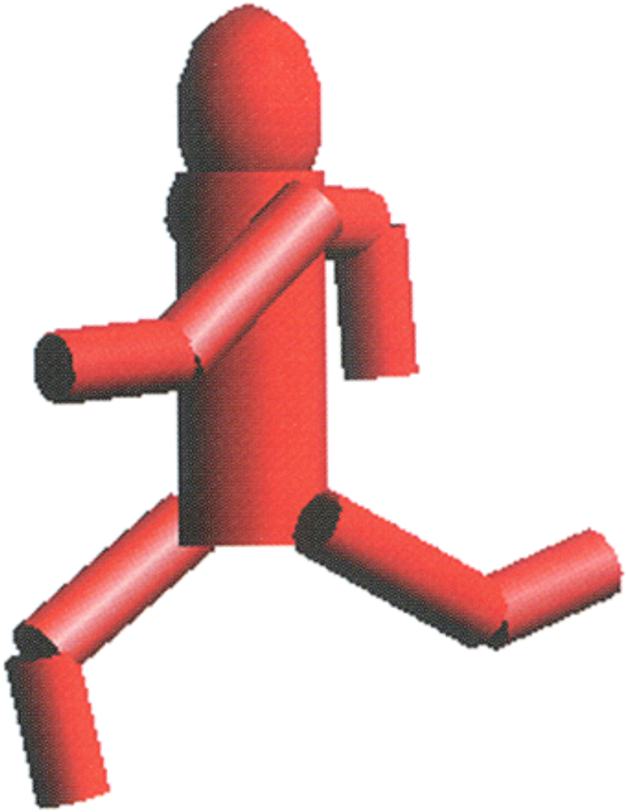
Example: walk cycle



Lague: www.youtube.com/watch?v=DuUWxUitJos

Character Animation Methods

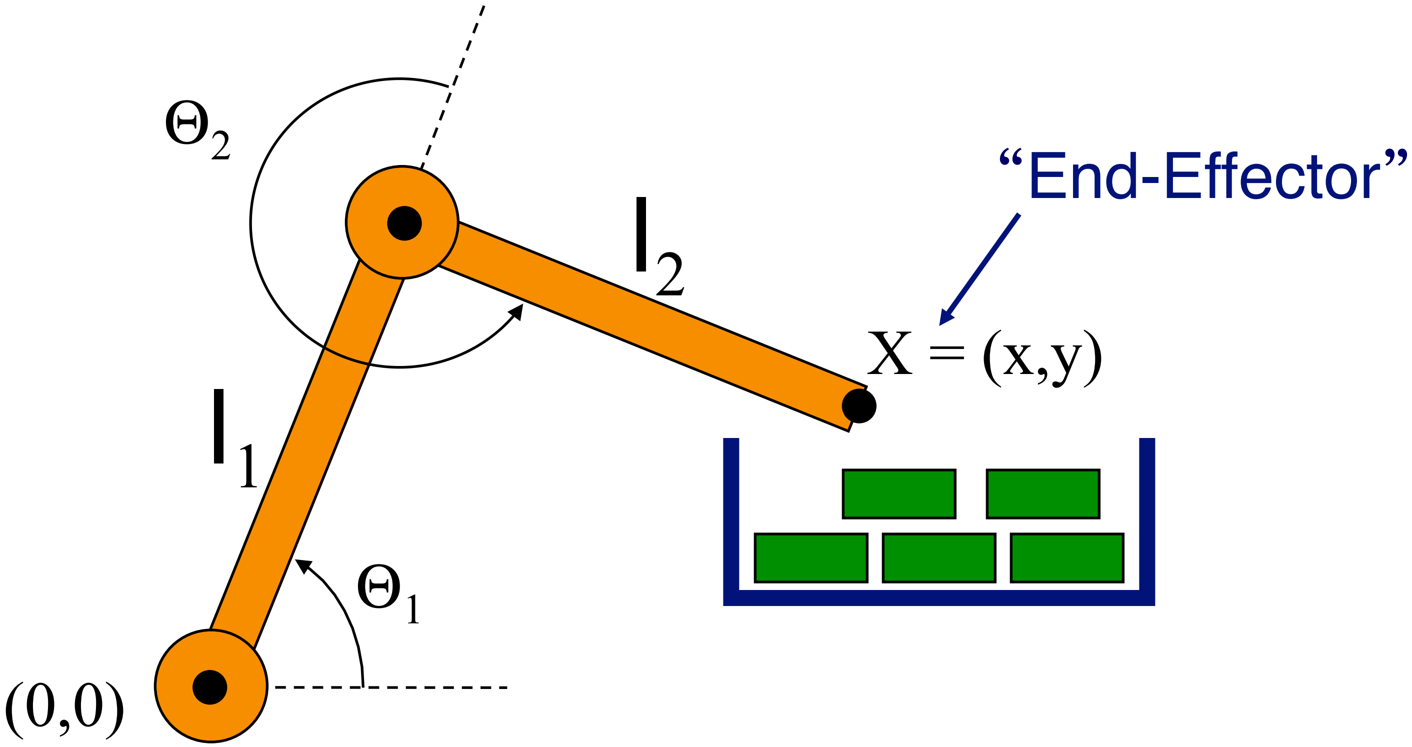
- Keyframing / Forward Kinematics
- Inverse Kinematics
- Dynamics
- Motion capture



Angel Plate 1

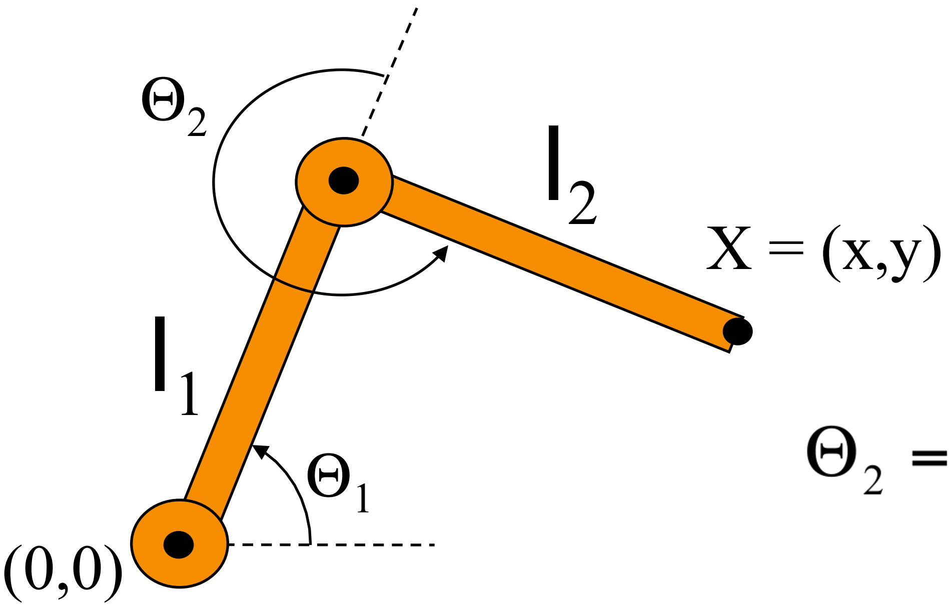
Inverse Kinematics

- 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:

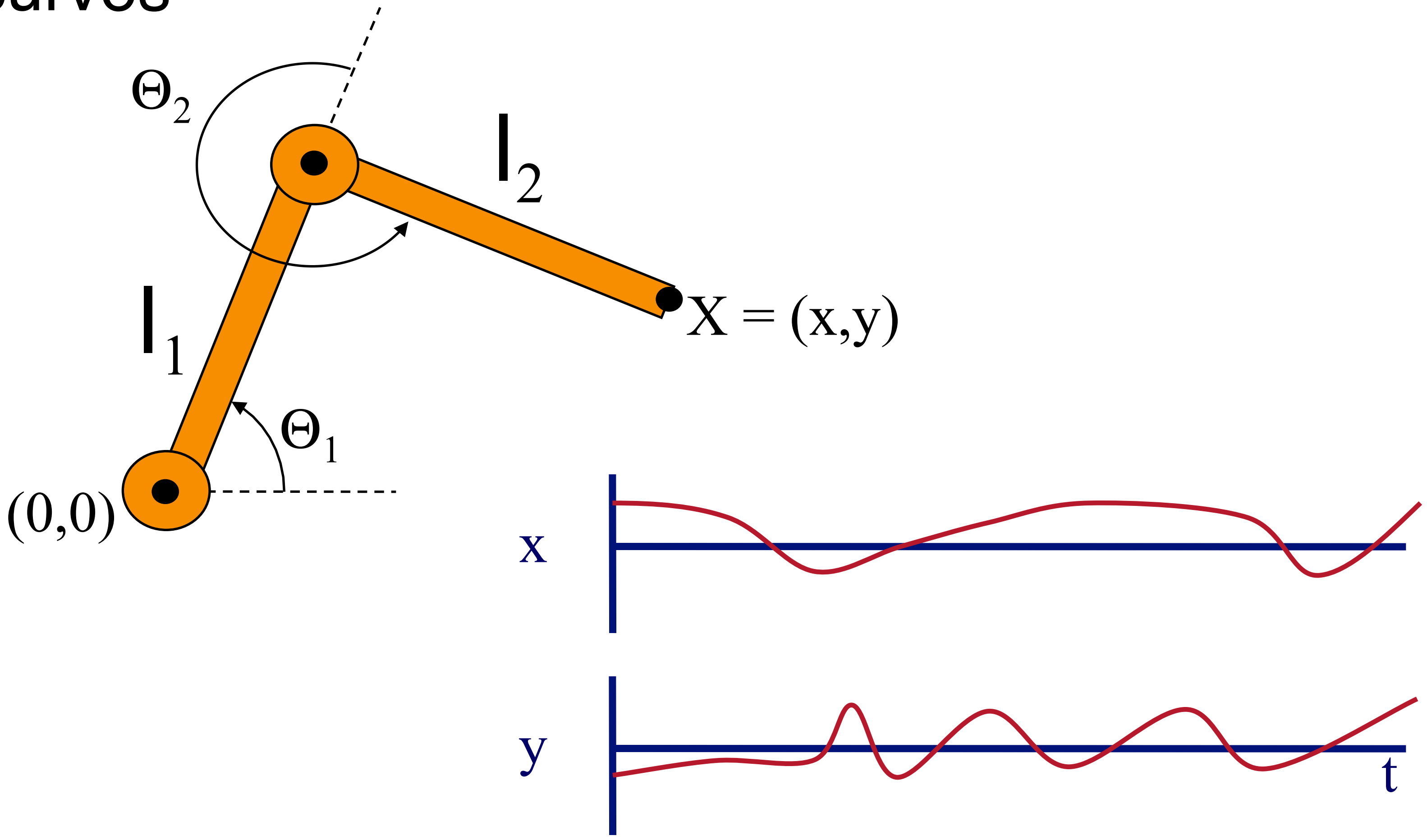


$$\Theta_2 = \cos^{-1}\left(\frac{x^2 + x^2 - l_1{}^2 - l_2{}^2}{2l_1l_2}\right)$$

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

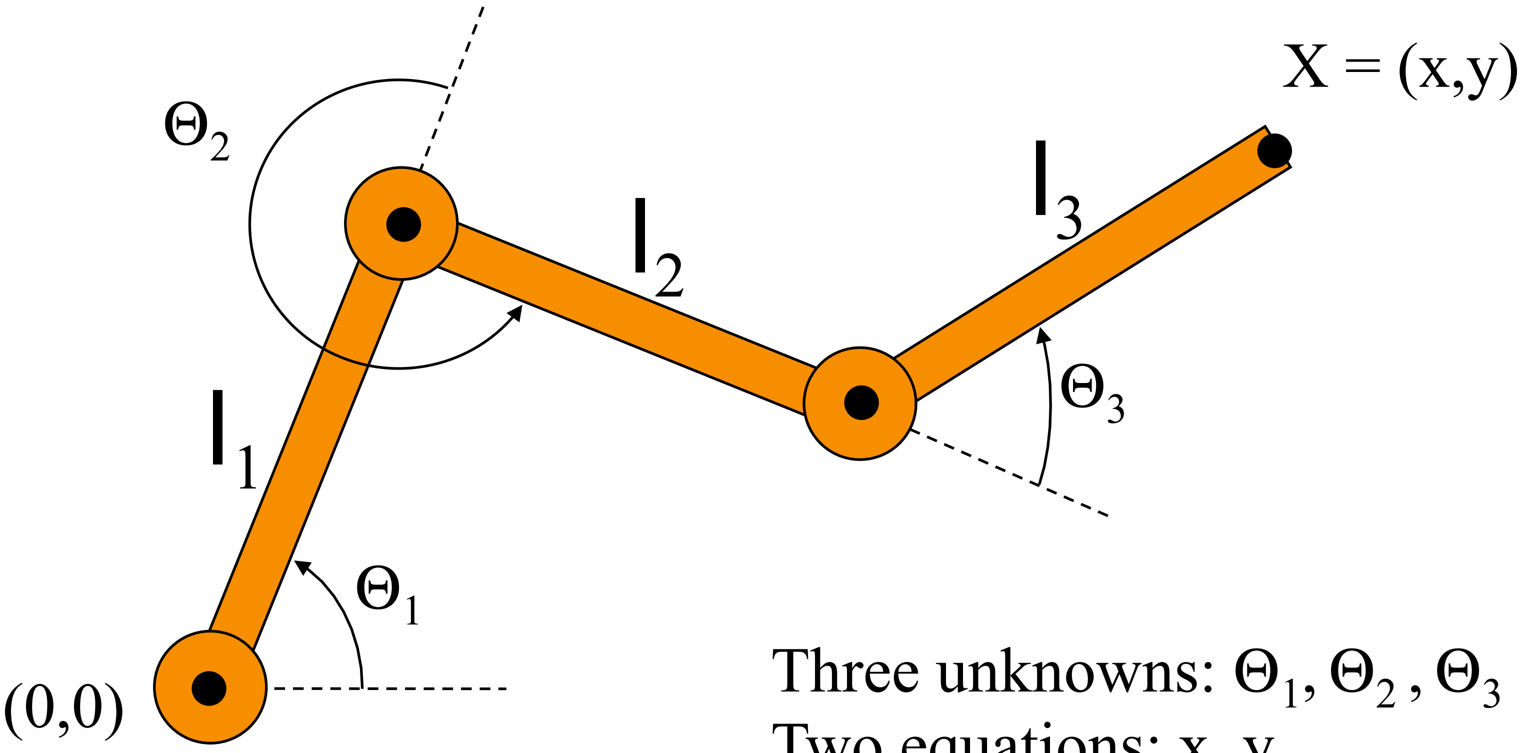
Inverse Kinematics

- End-effector postions can be specified by spline curves



Inverse Kinematics

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

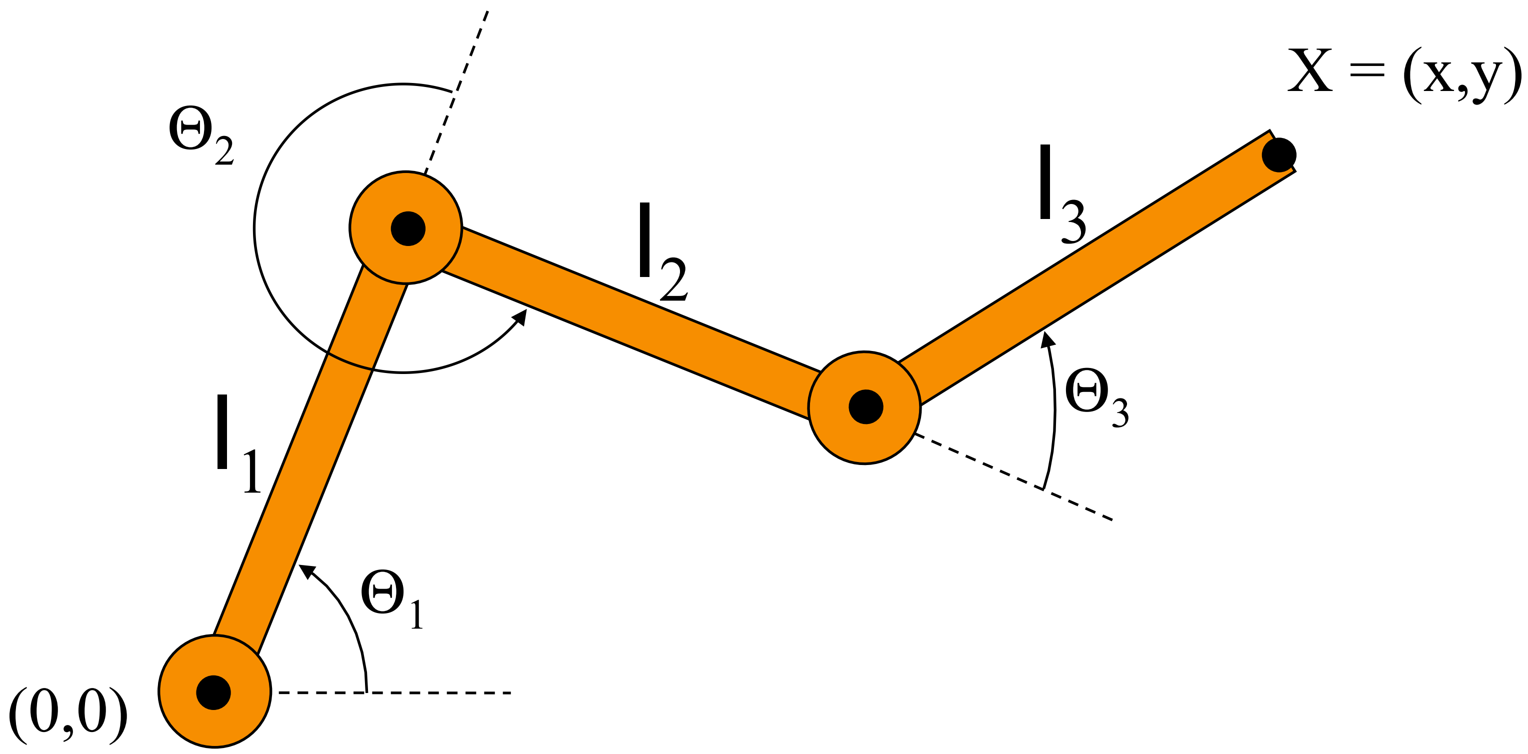


Three unknowns: $\Theta_1, \Theta_2, \Theta_3$

Two equations: x, y

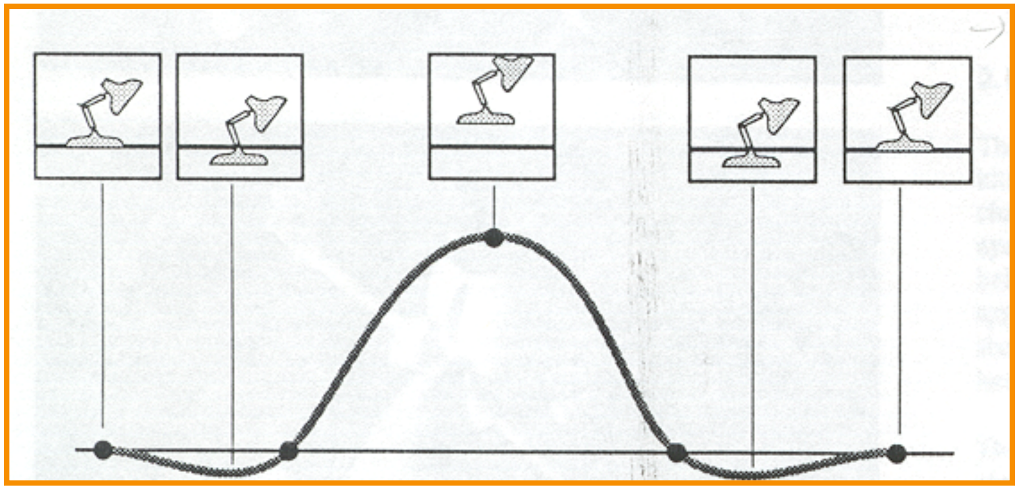
Inverse Kinematics

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



Kinematics

- Advantages
  - Simple to implement
  - Complete animator control
- Disadvantages
  - Motions may not follow physical laws
  - Tedious for animator



Lasseter `87

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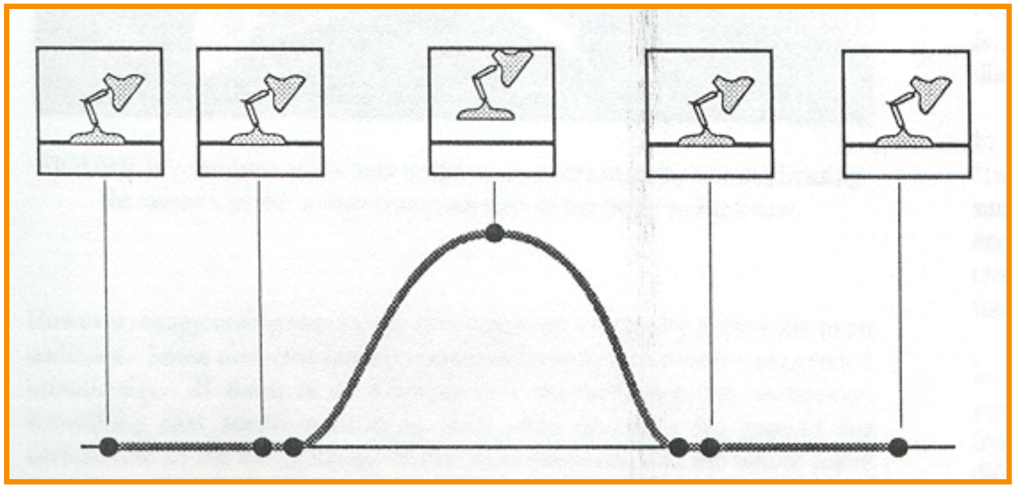

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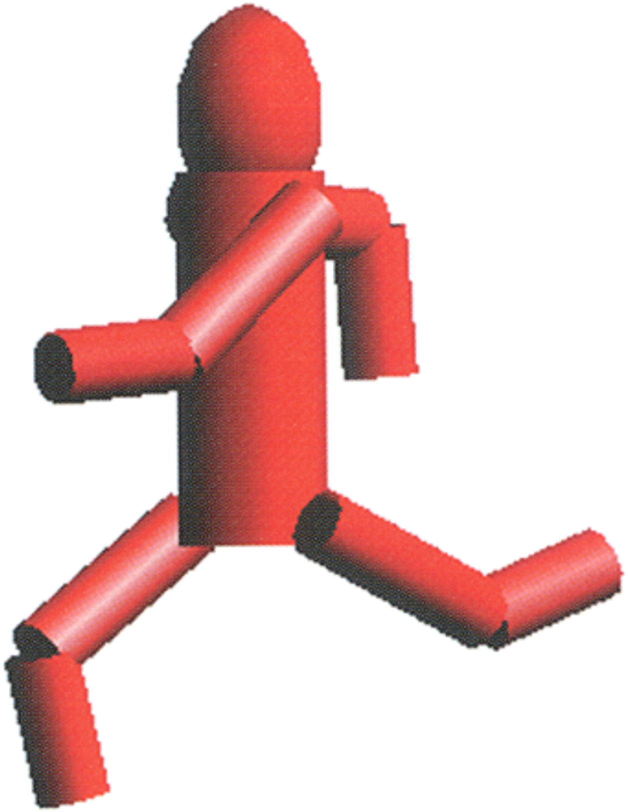
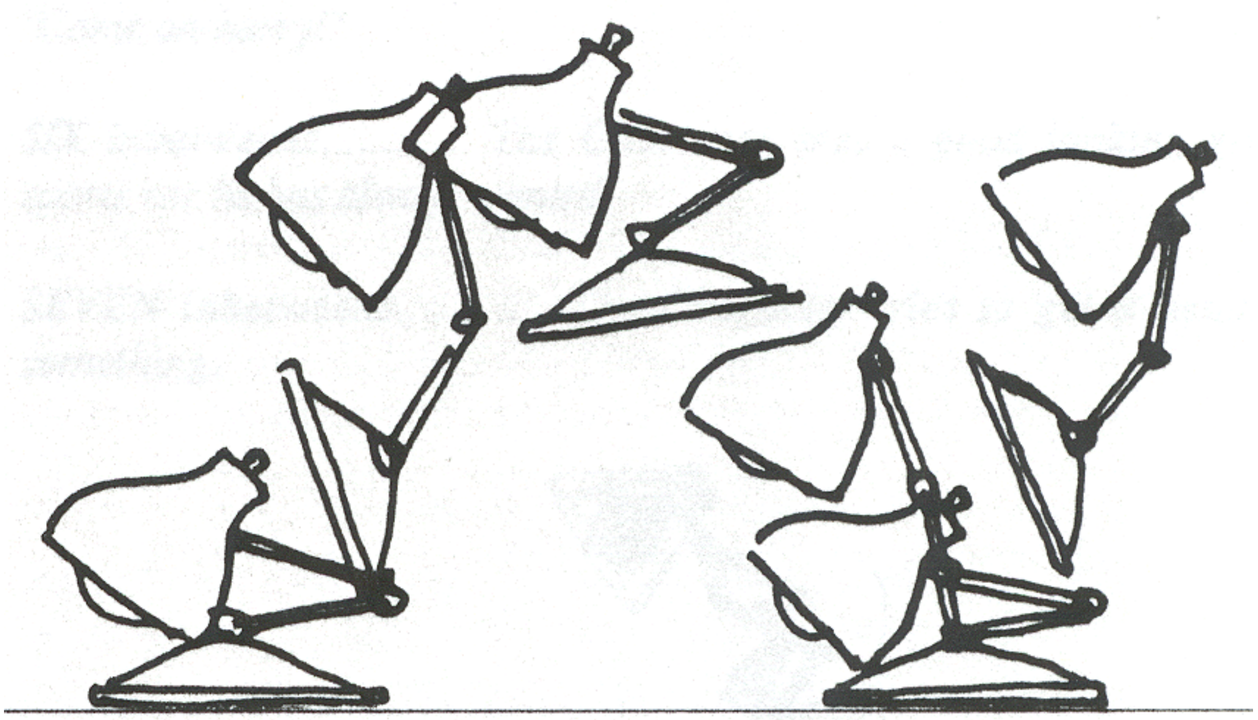


Angel Plate 1

Dynamics

- Simulation of physics ensures realism of motion



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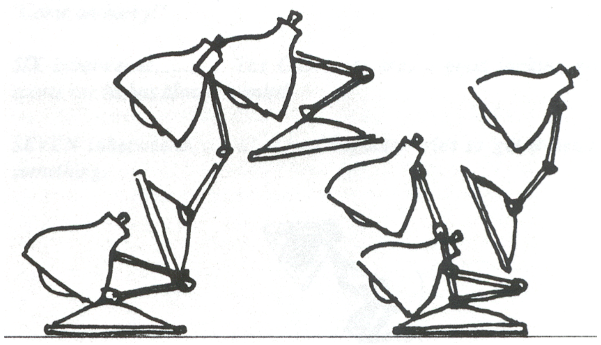
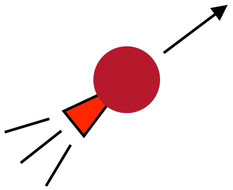
Spacetime Constraints

- 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:



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

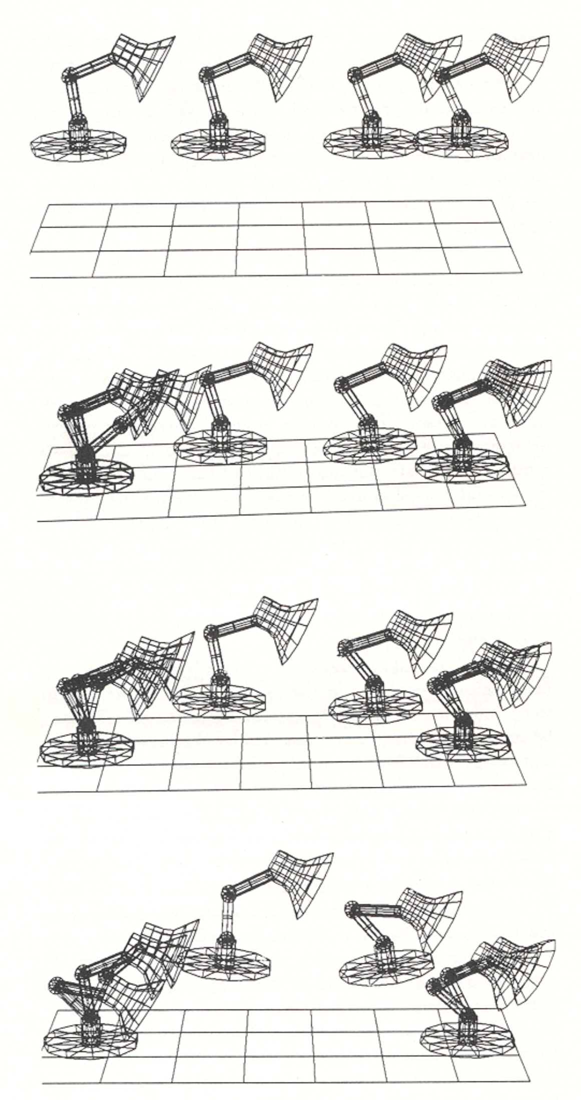
  - Suppose we want to move from a to b within t_0 to t_1 with minimum jet fuel:

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

Witkin & Kass `88

Spacetime Constraints

- Solve with iterative optimization methods



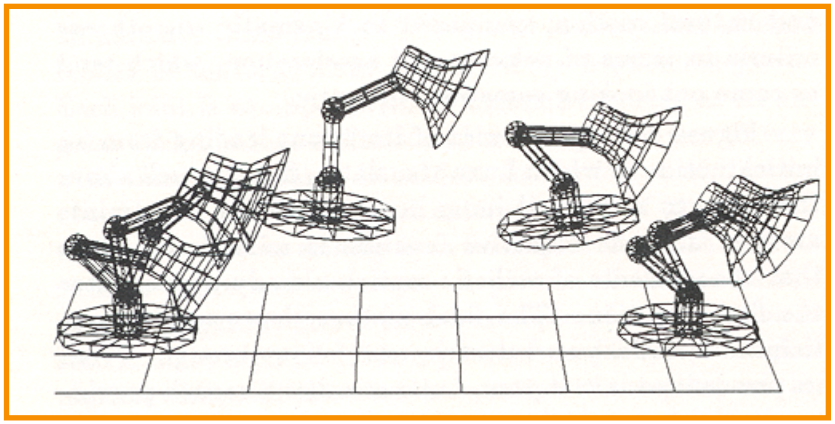
Witkin & Kass `88

Spacetime Constraints

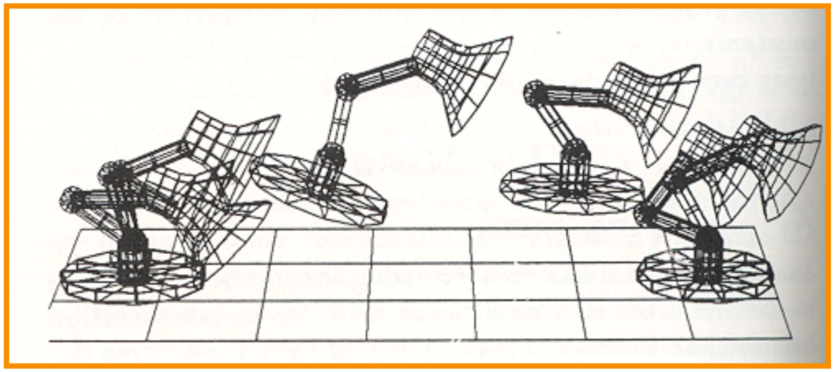
- Advantages:
  - Free animator from having to specify details of physically realistic motion with spline curves
  - Easy to vary motions due to new parameters and/or new constraints
- Challenges:
  - Specifying constraints and objective functions
  - Avoiding local minima during optimization

Spacetime Constraints

- Adapting motion:



Original Jump

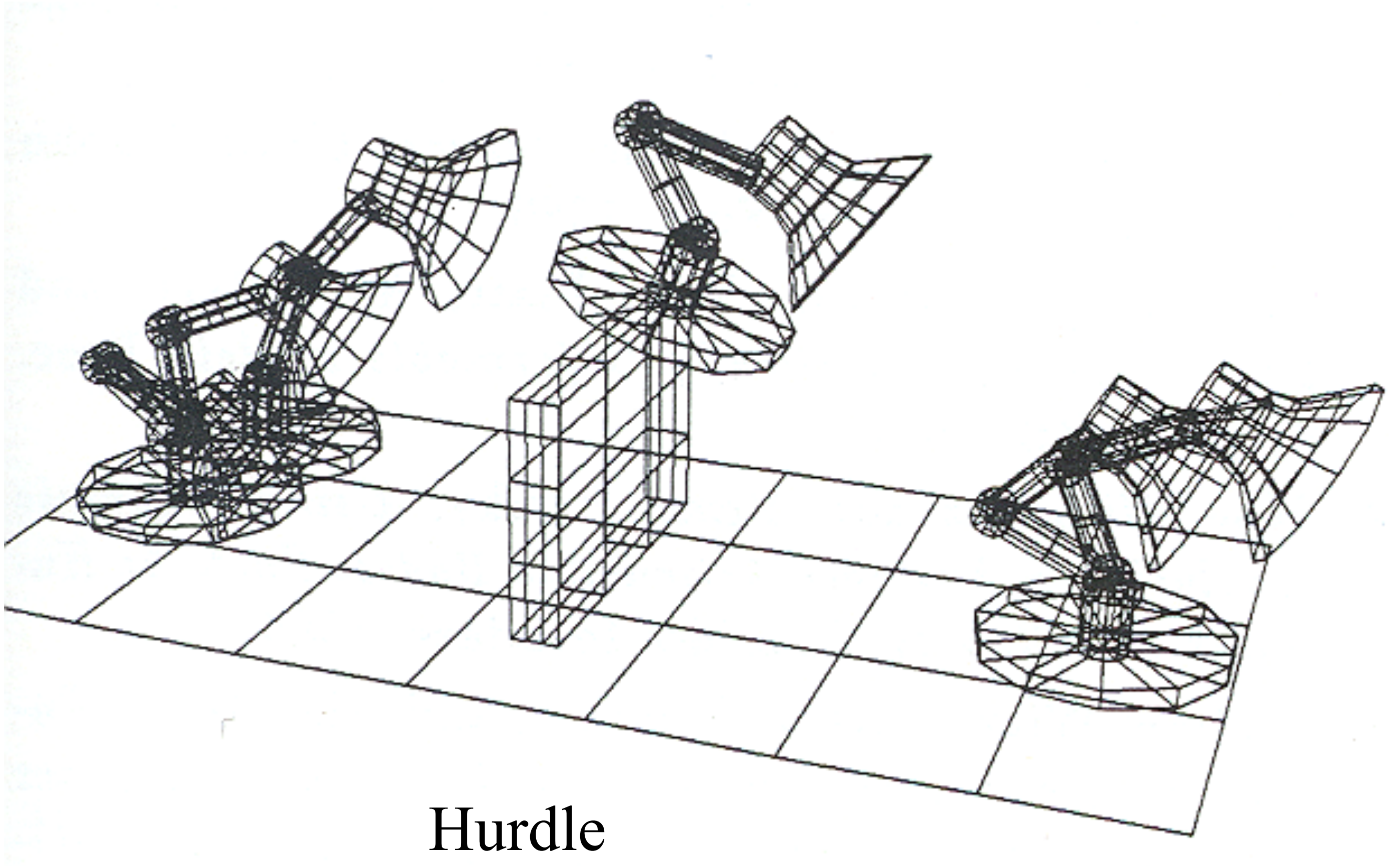


Heavier Base

Witkin & Kass `88

Spacetime Constraints

- Adapting motion:

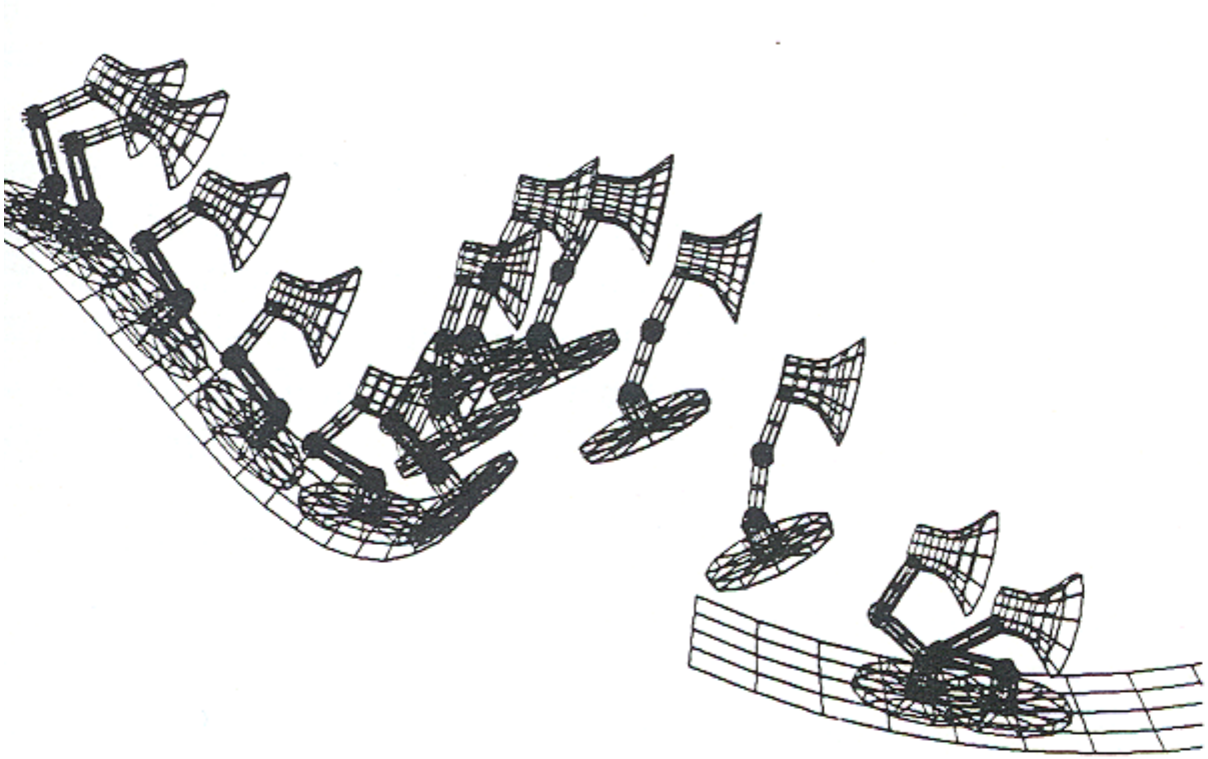


Hurdle

Witkin & Kass `88

Spacetime Constraints

- Adapting motion:



Ski Jump

Witkin & Kass `88

Spacetime Constraints

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- Challenges:
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Character Animation Methods

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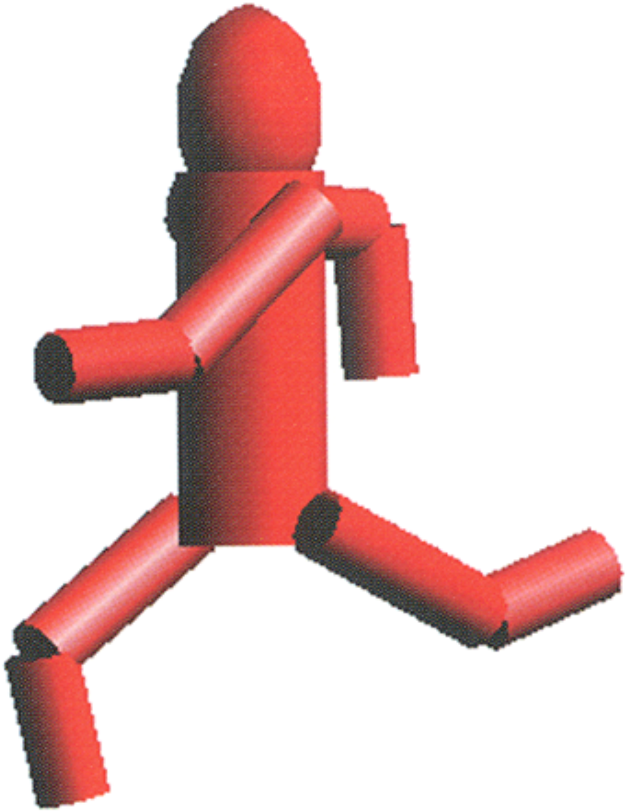
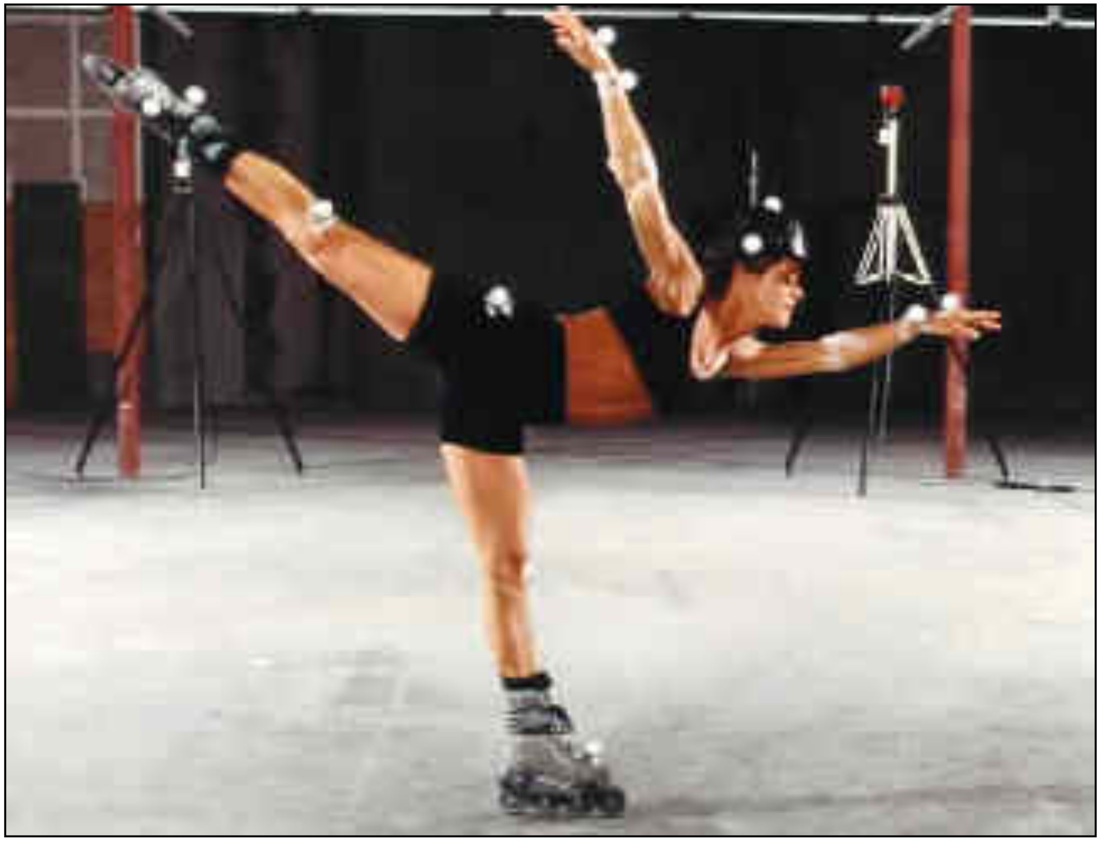


Angel Plate 1

Motion Capture

- Measure motion of real characters and then simply “play it back” with kinematics



Gleicher

Motion Capture

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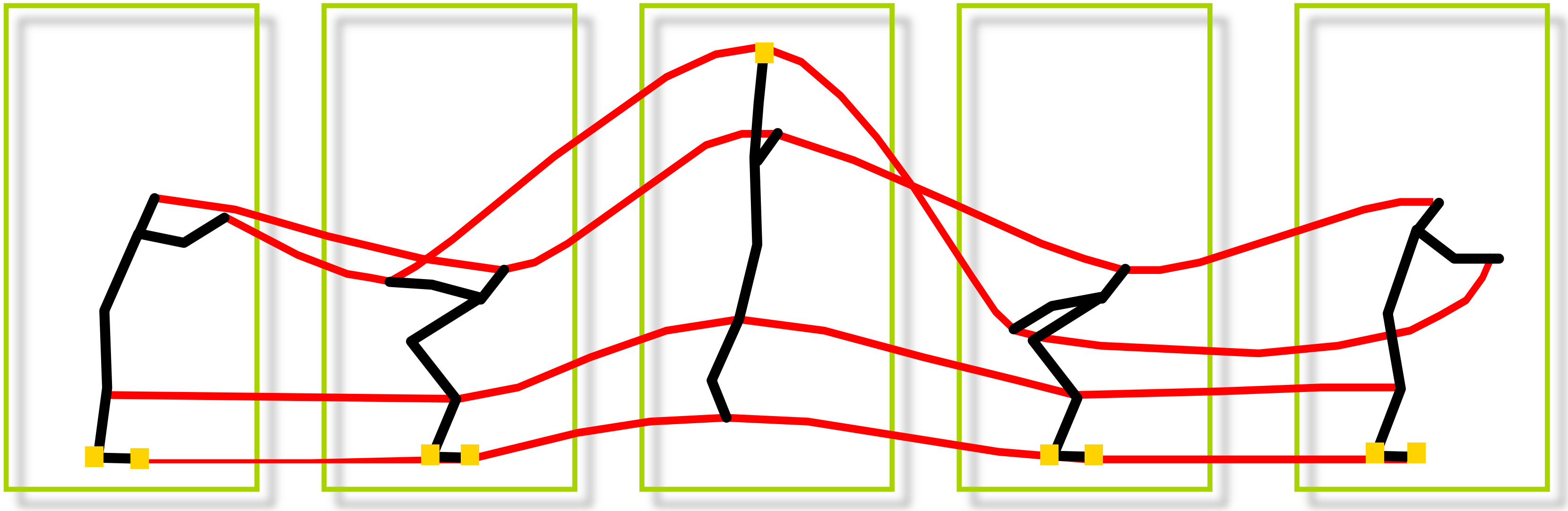


Captured Motion

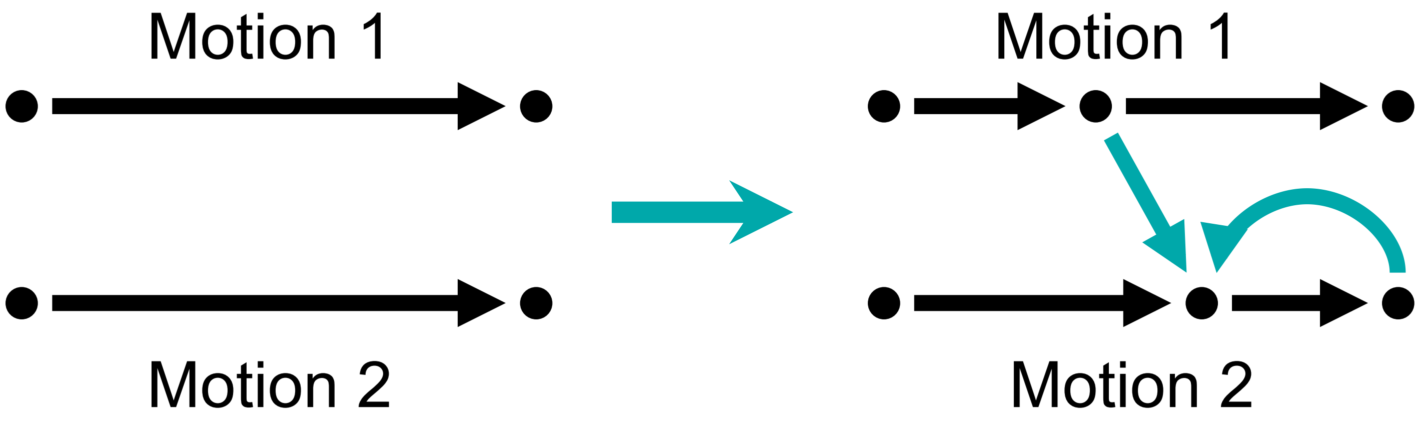
Motion Capture

- Advantage:
  - Physical realism
- Challenge:
  - Animator control

Gleicher

Motion Capture

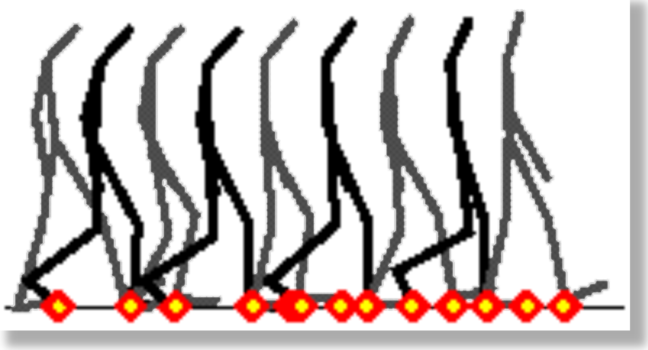
- Motion graphs:



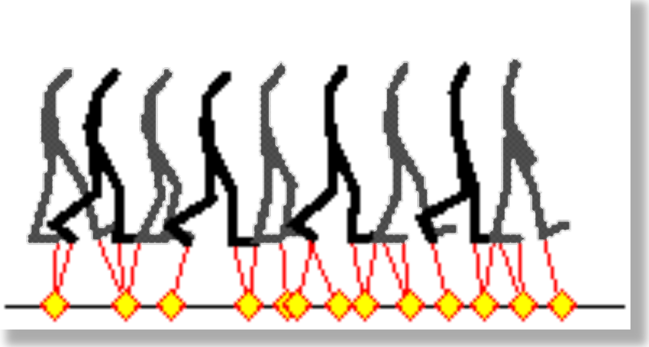
Motion Capture

- Retargeting motion:

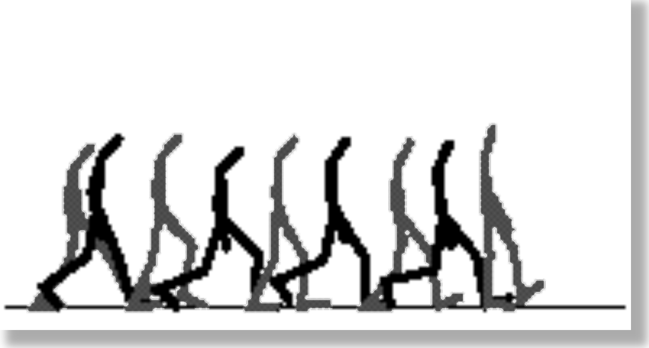
Original motion data + constraints:



New character:



New motion data:



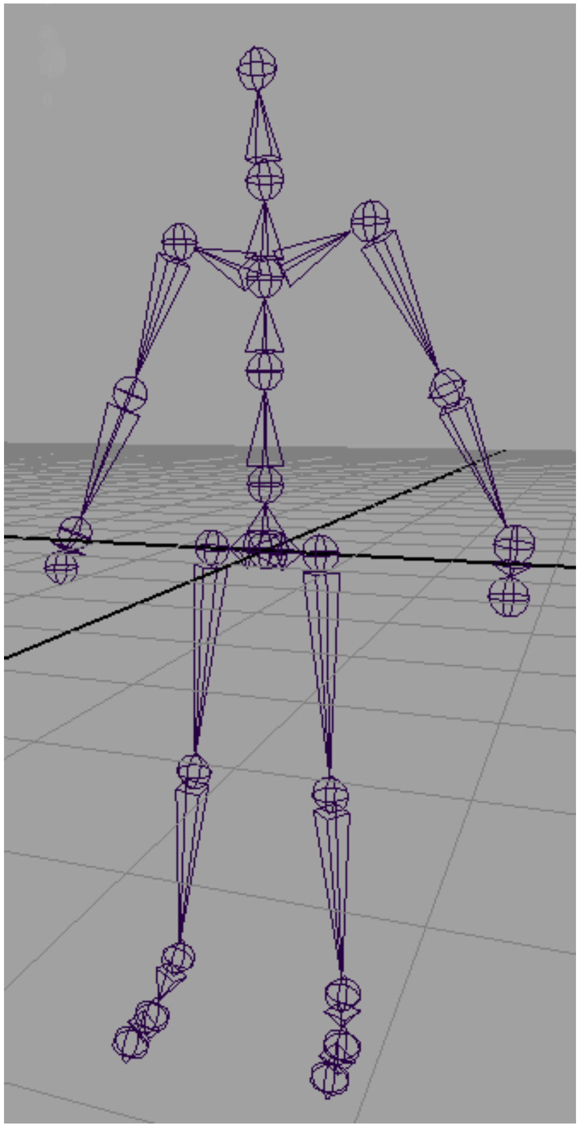
Gleicher

Beyond Skeletons…

- Skinning
- Motion blur

Kinematic Skeletons

- Hierarchy of transformations ("bones")
  - Changes to parent affect all descendent bones
- So far: bones affect objects in scene or parts of a mesh
  - Equivalently, each point on a mesh acted upon by one bone
  - Leads to discontinuities when parts of mesh animated
- Extension: each point on a mesh acted upon by more than one bone



Linear Blend Skinning

- Each vertex of skin potentially influenced by all bones
  - Normalized weight vector $w^{(v)}$ gives influence of each bone transform
  - When bones move, influenced vertices also move

- Computing a transformation T_v for a skinned vertex
  - For each bone
    - Compute global bone transformation T_b from transformation hierarchy
  - For each vertex
    - Take a linear combination of bone transforms
    - Apply transformation to vertex in original pose

$$T_v = \sum_{b \in B} w_b^{(v)} T_b$$

- Equivalently, transformed vertex position is weighted combination of positions transformed by bones

$$v_{transformed} = \sum_{b \in B} w_b^{(v)} \left(T_b v \right)$$

Assigning Weights: “Rigging”

- Painted by hand
- Automatic: function of relative distances to nearest bones
  - Smoothness of skinned surface depends on smoothness of weights!

Beyond Skeletons…

- Skinning
- Motion blur

Summary

- Kinematics
  - Animator specifies poses (joint angles or positions) at keyframes and computer determines motion by kinematics and interpolation
- Dynamics
  - Animator specifies physical attributes, constraints, and starting conditions and computer determines motion by physical simulation
- Motion capture
  - Compute captures motion of real character and provides tools for animator to edit it