Character Animation

COS 426

Syllabus

I. Image processing

II. Modeling

III. Rendering

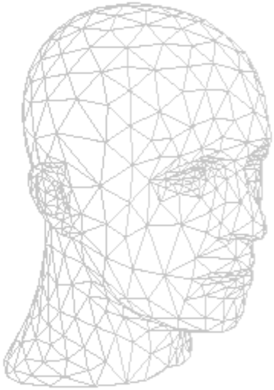
IV. Animation

Image Processing

(Rusty Coleman, CS426, Fall99)

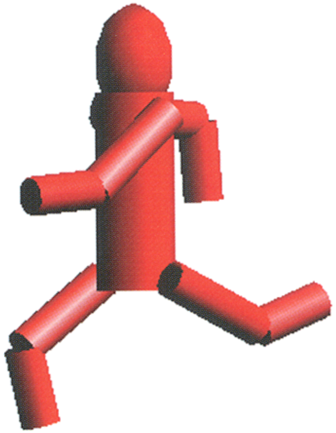
Rendering

(Michael Bostock, CS426, Fall99)



Modeling

(Dennis Zorin, CalTech)



Animation

(Angel, Plate 1)

Computer Animation

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

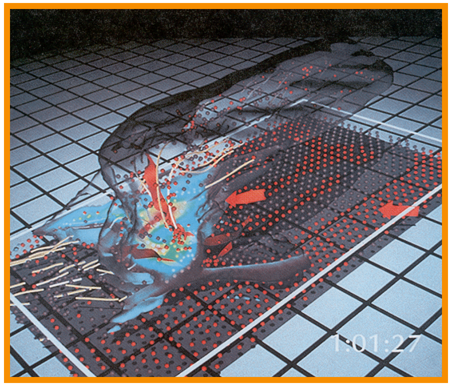
Pixar

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



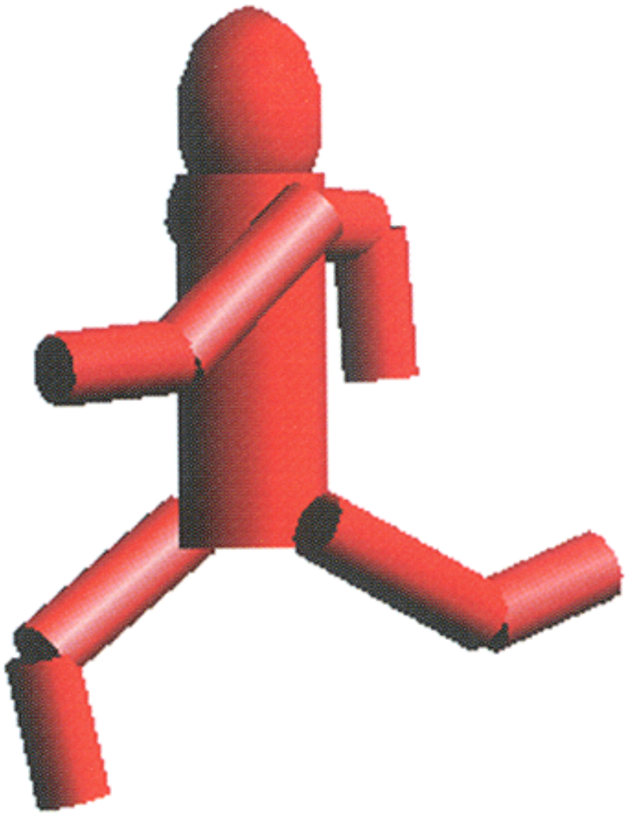
University of Illinois

Computer Animation

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

Character Animation Methods

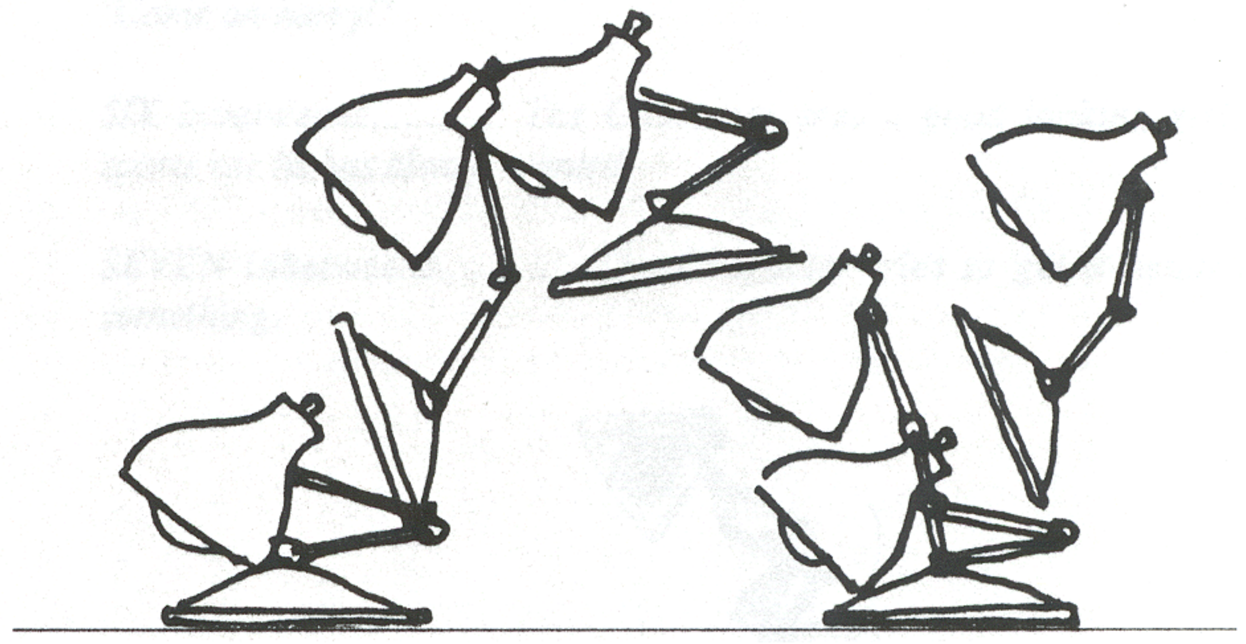
- Keyframing / Forward Kinematics
- Inverse Kinematics
- Dynamics
- Motion capture



Angel Plate 1

Keyframe Animation

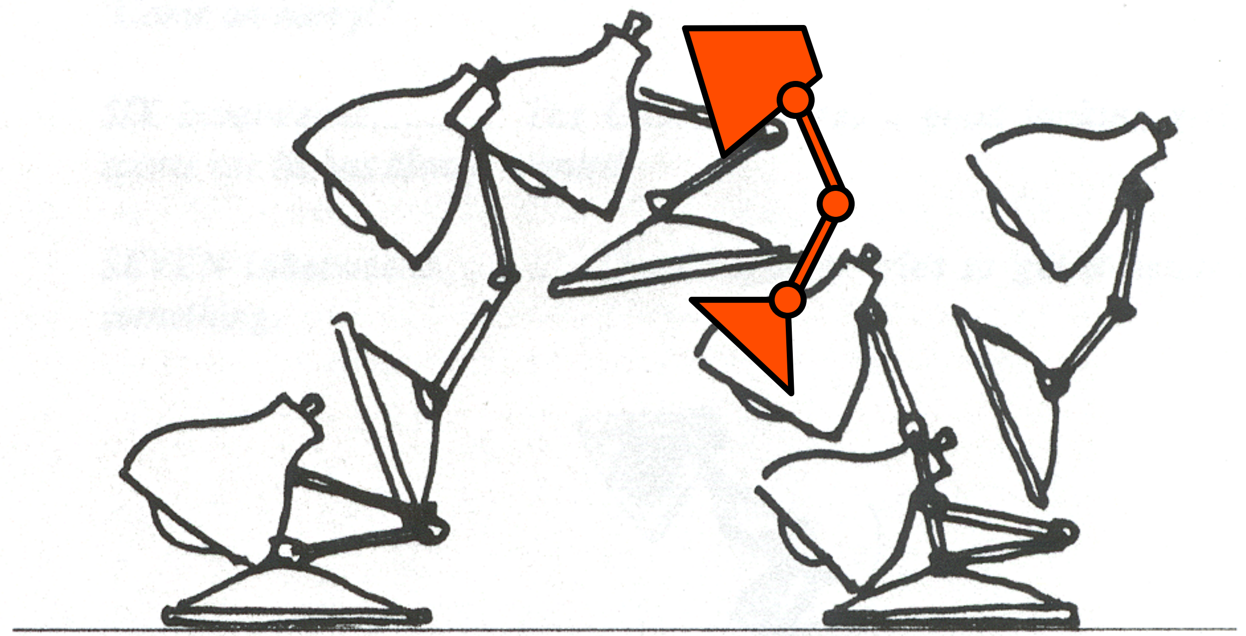
- Define character poses at specific time steps called "keyframes"



Lasseter `87

Keyframe Animation

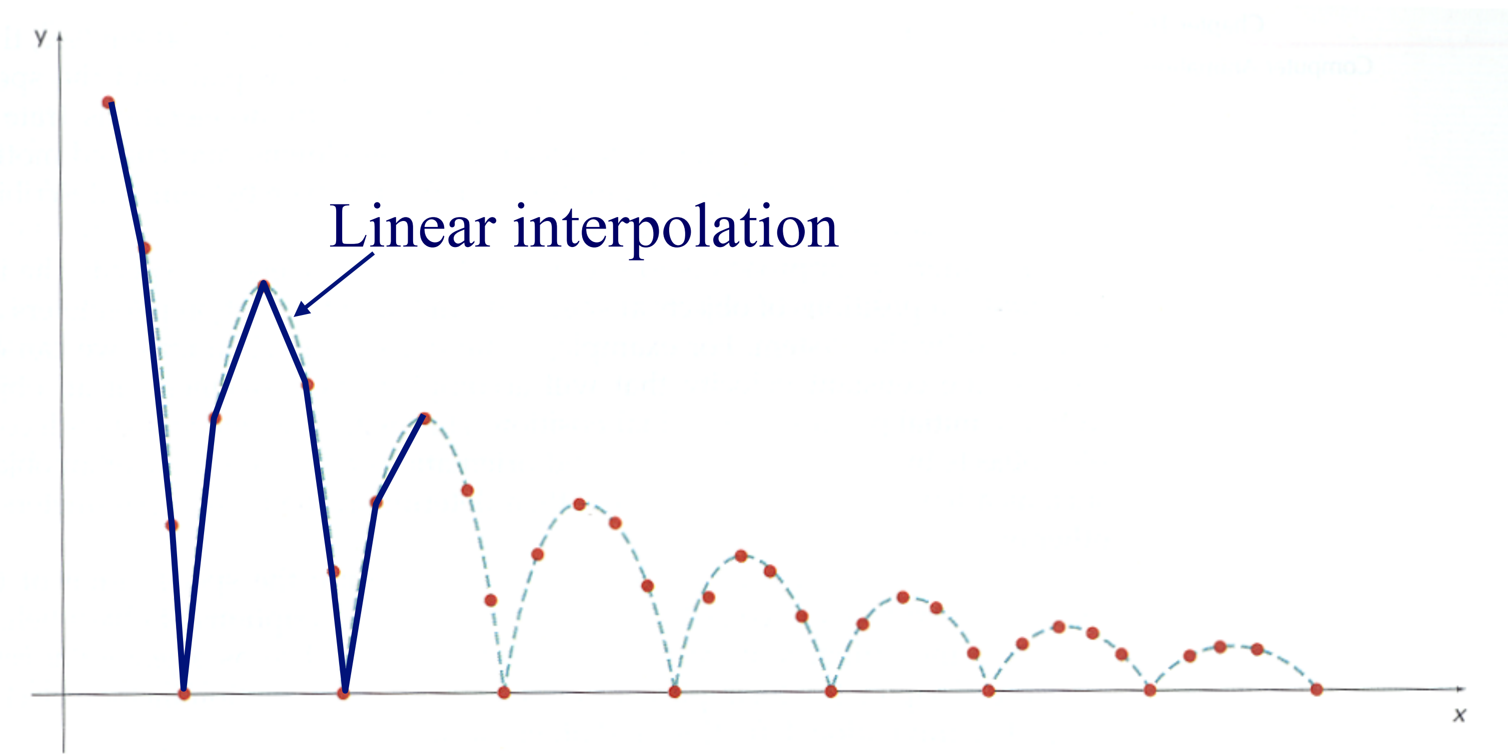
- Interpolate variables describing keyframes to determine poses for character in between



Lasseter `87

Keyframe Animation

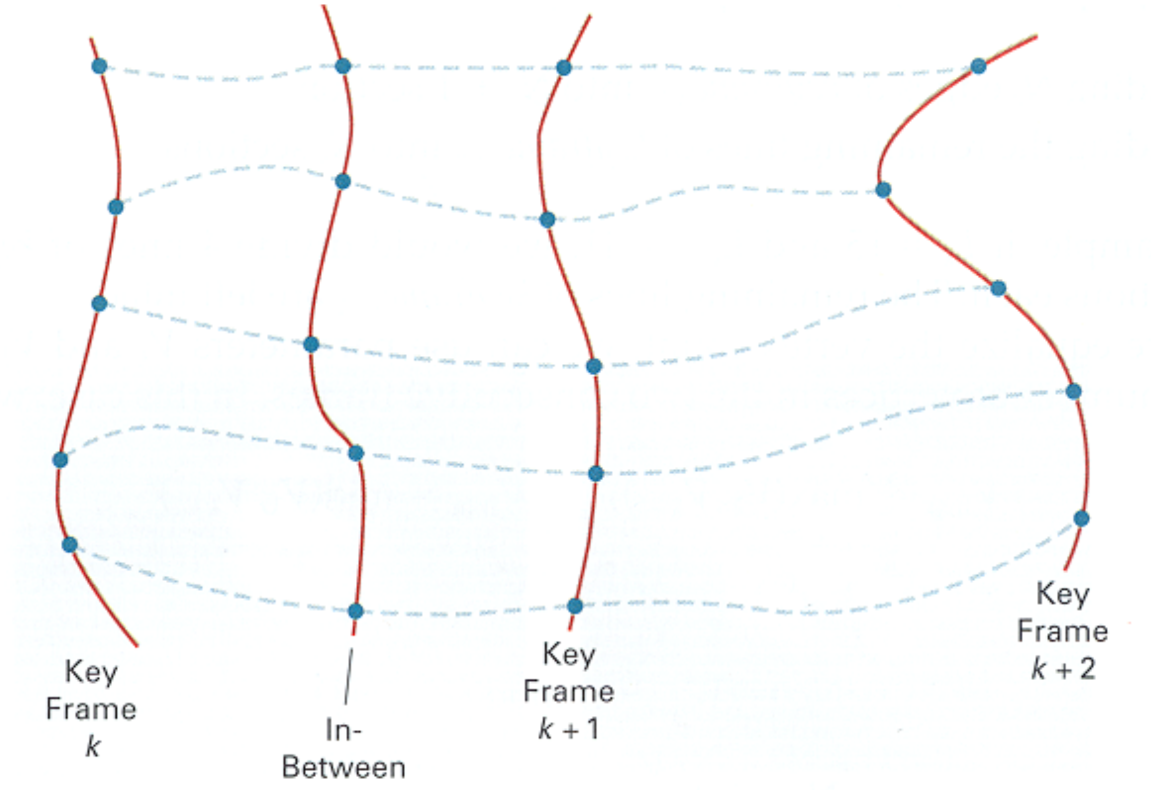
- Inbetweening:
  - Linear interpolation - usually not enough continuity



H&B Figure 16.16

Keyframe Animation

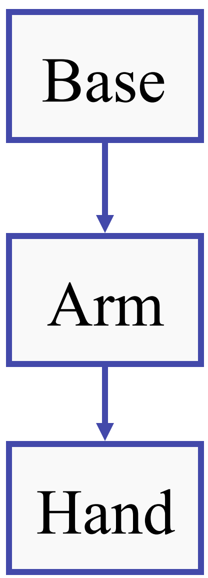
- Inbetweening:
  - Spline interpolation - maybe good enough



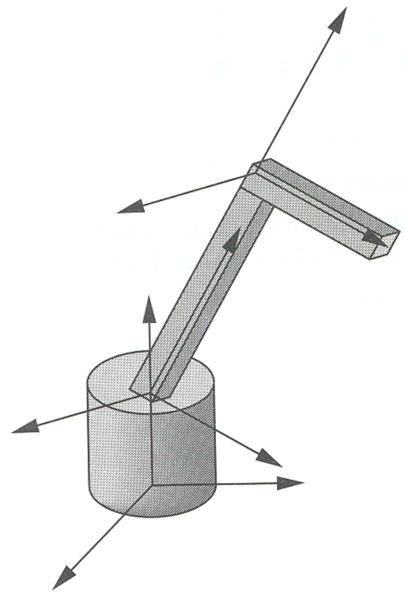
H&B Figure 16.11

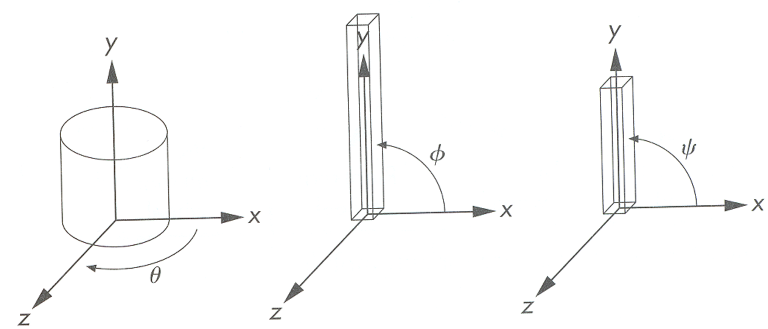
Articulated Figures

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



Scene Graph

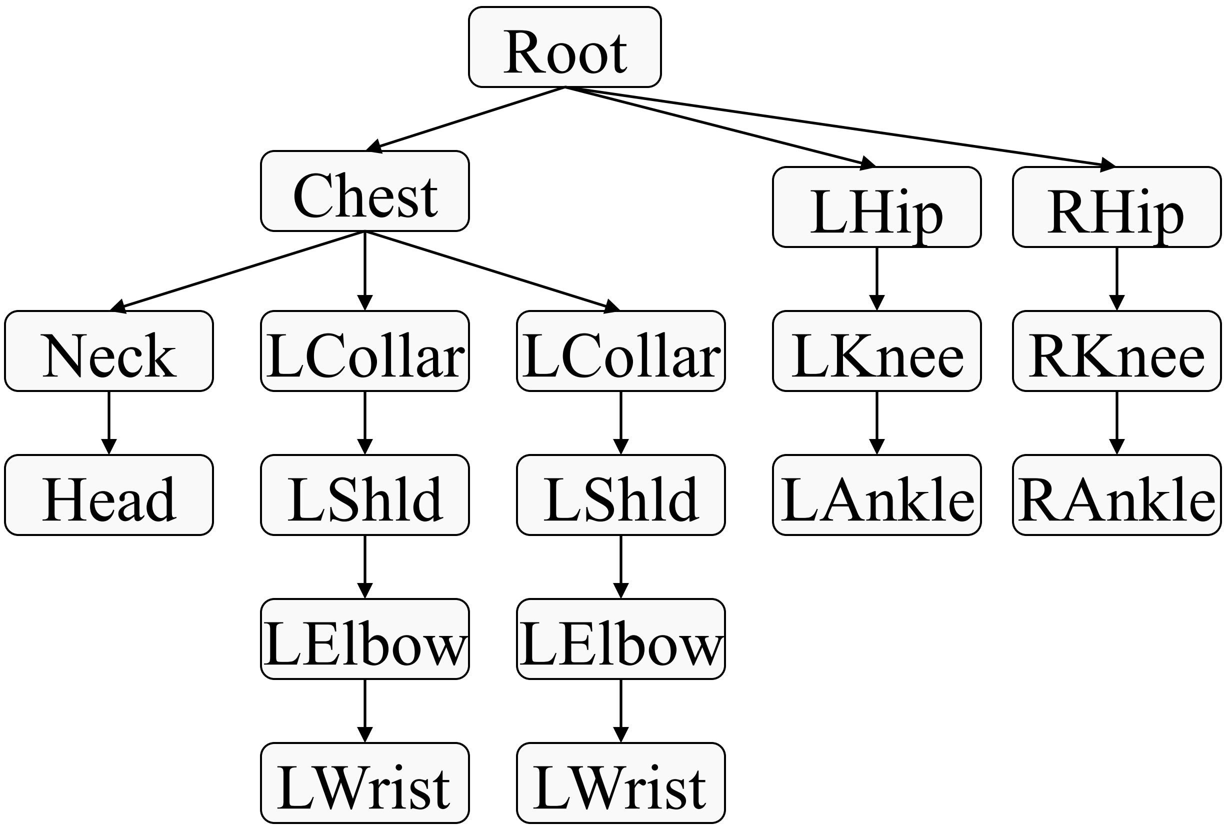


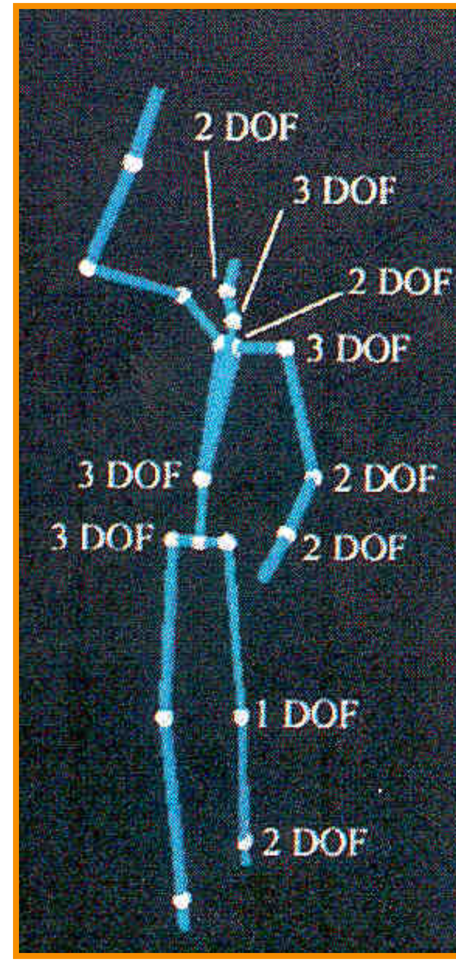


Angel Figures 8.8 & 8.9

Articulated Figures

- Well-suited for humanoid characters

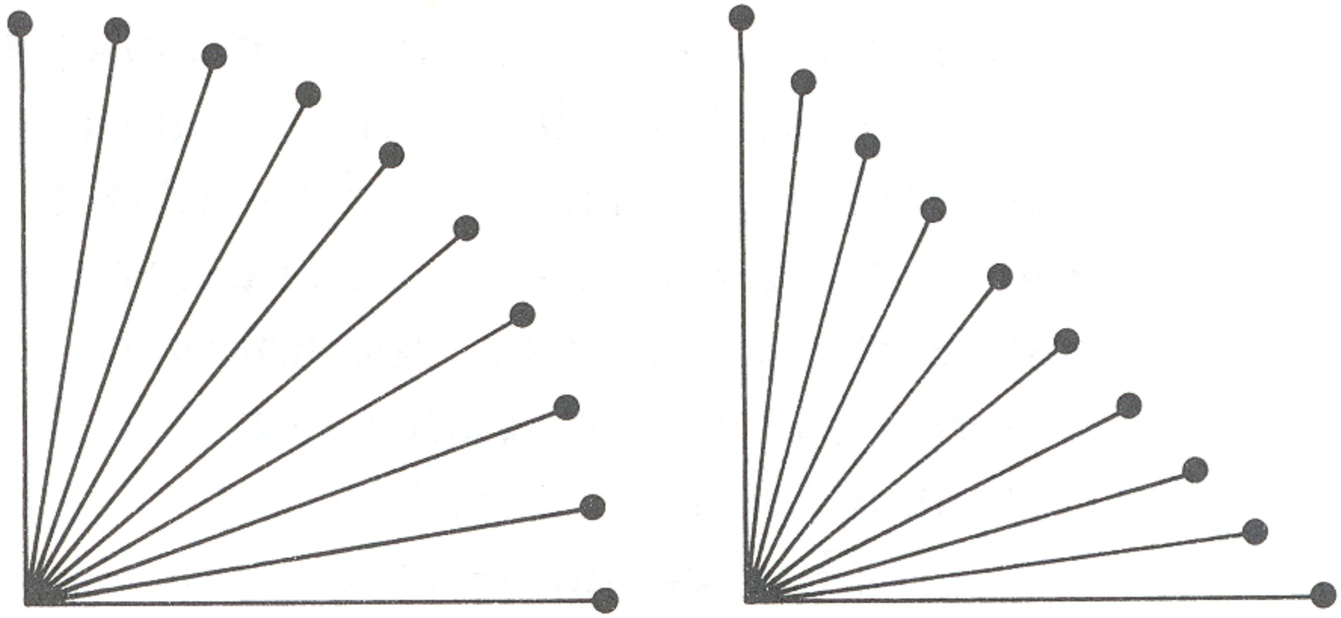




Rose et al. `96

Articulated Figures

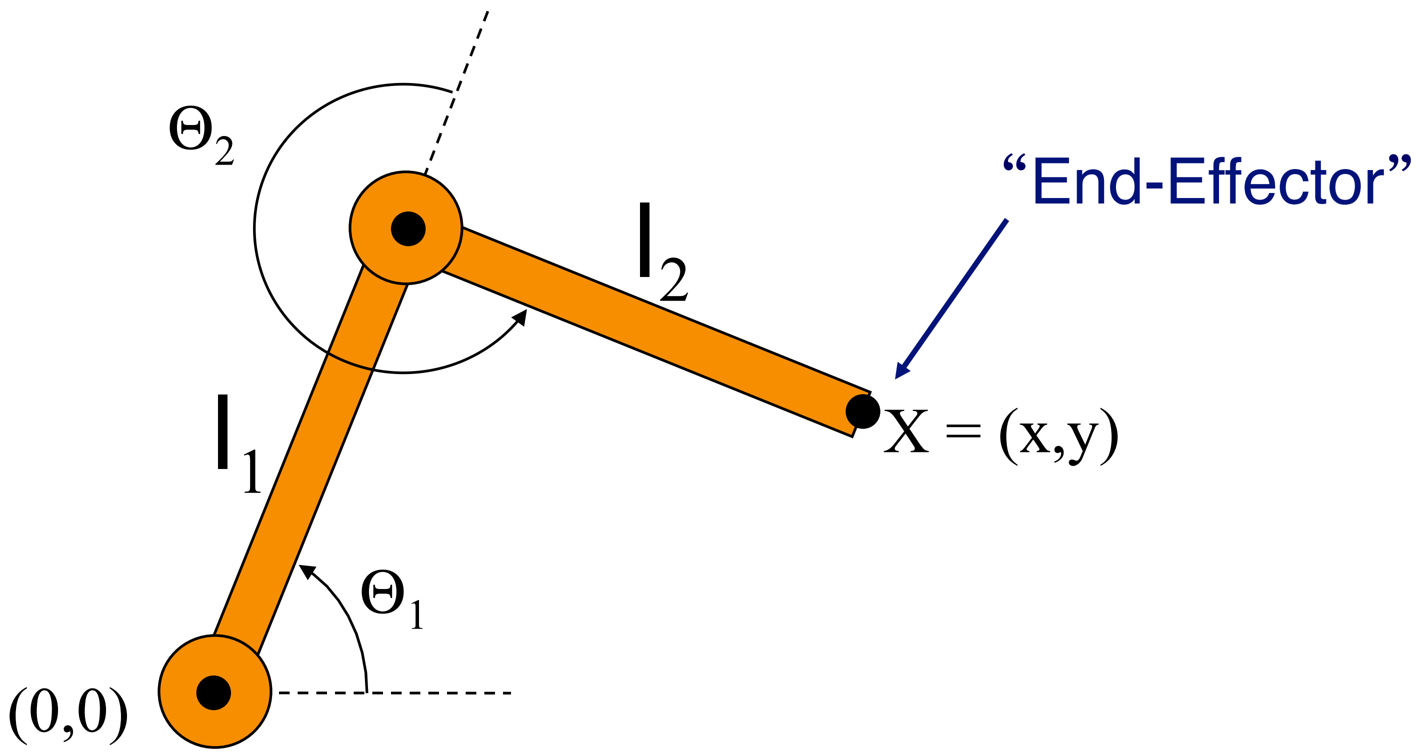
- Animation focuses on joint angles



Watt & Watt

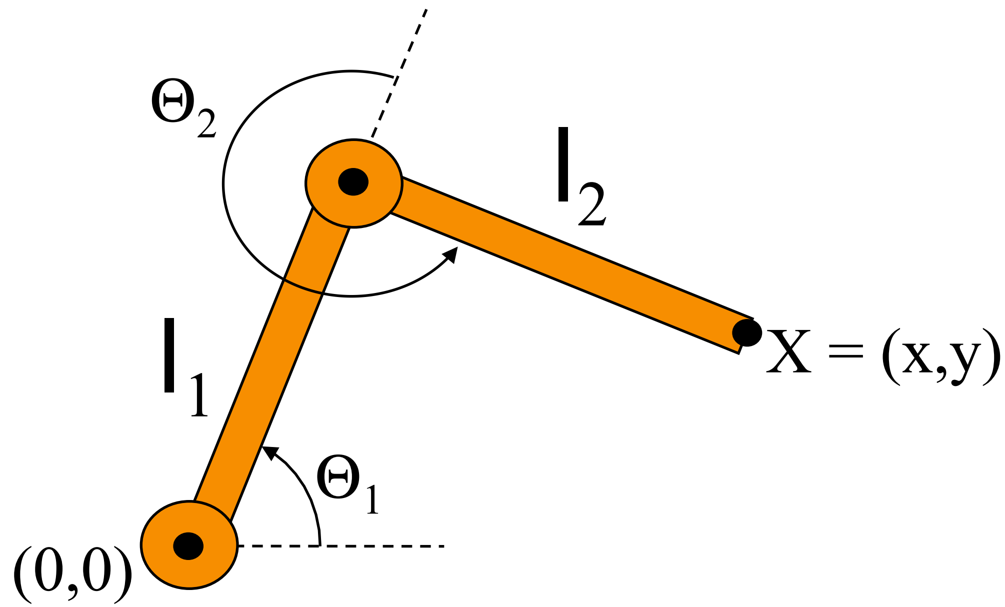
Forward Kinematics

- Describe motion of articulated character



Forward Kinematics

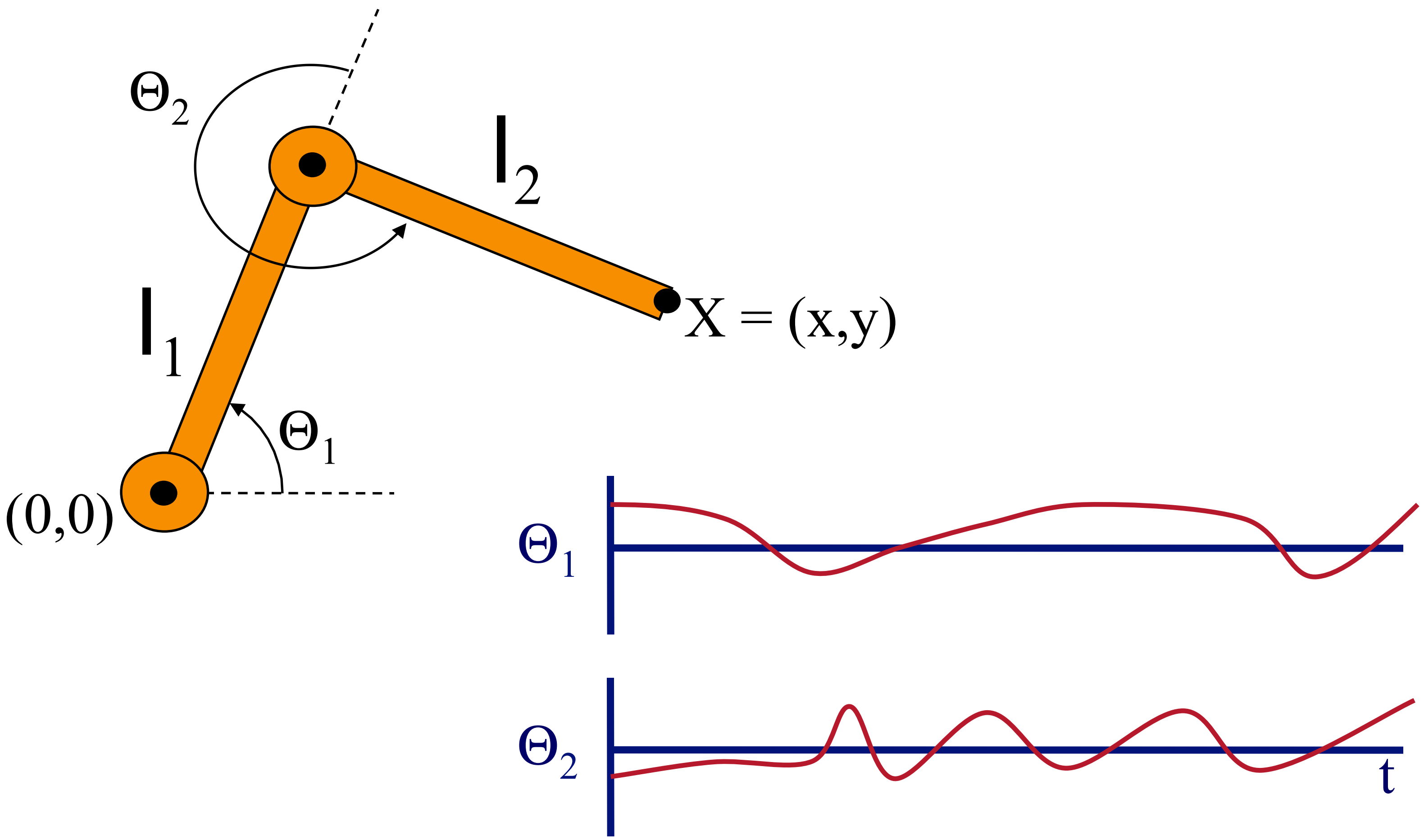
- Animator specifies joint angles: Θ_1 and Θ_2
- Computer finds positions of end-effector: X



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

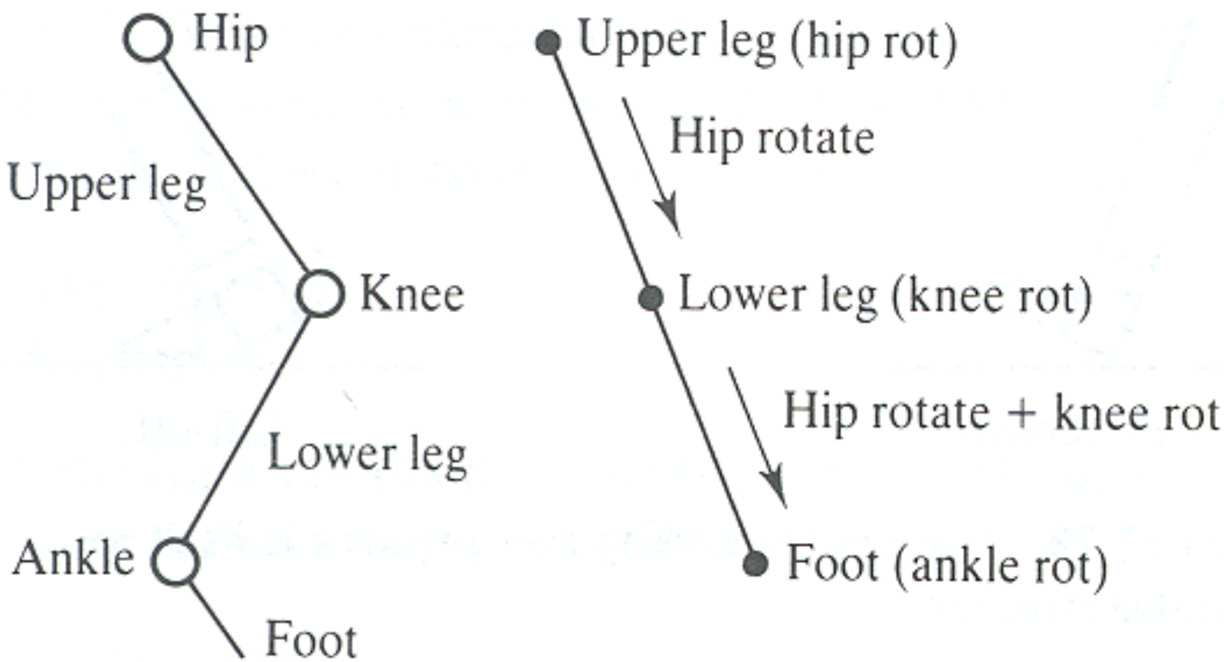
Forward Kinematics

- Joint motions specified e.g. by spline curves



Example: Walk Cycle

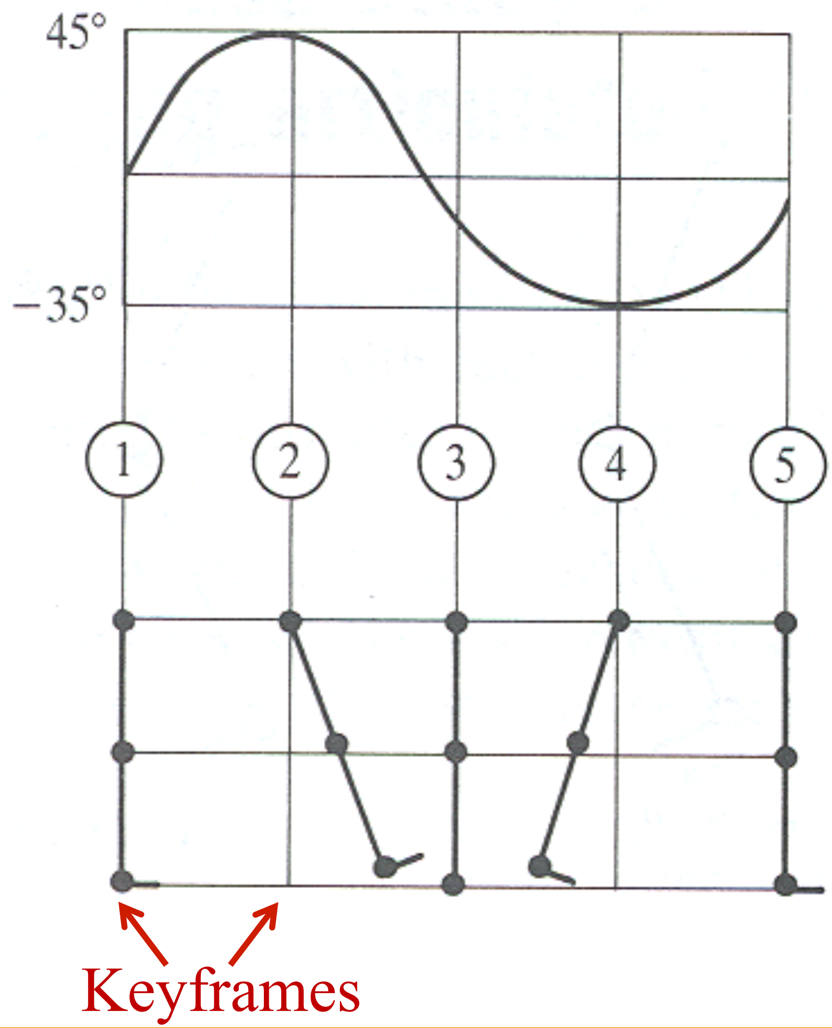
- Articulated figure:



Watt & Watt

Example: Walk Cycle

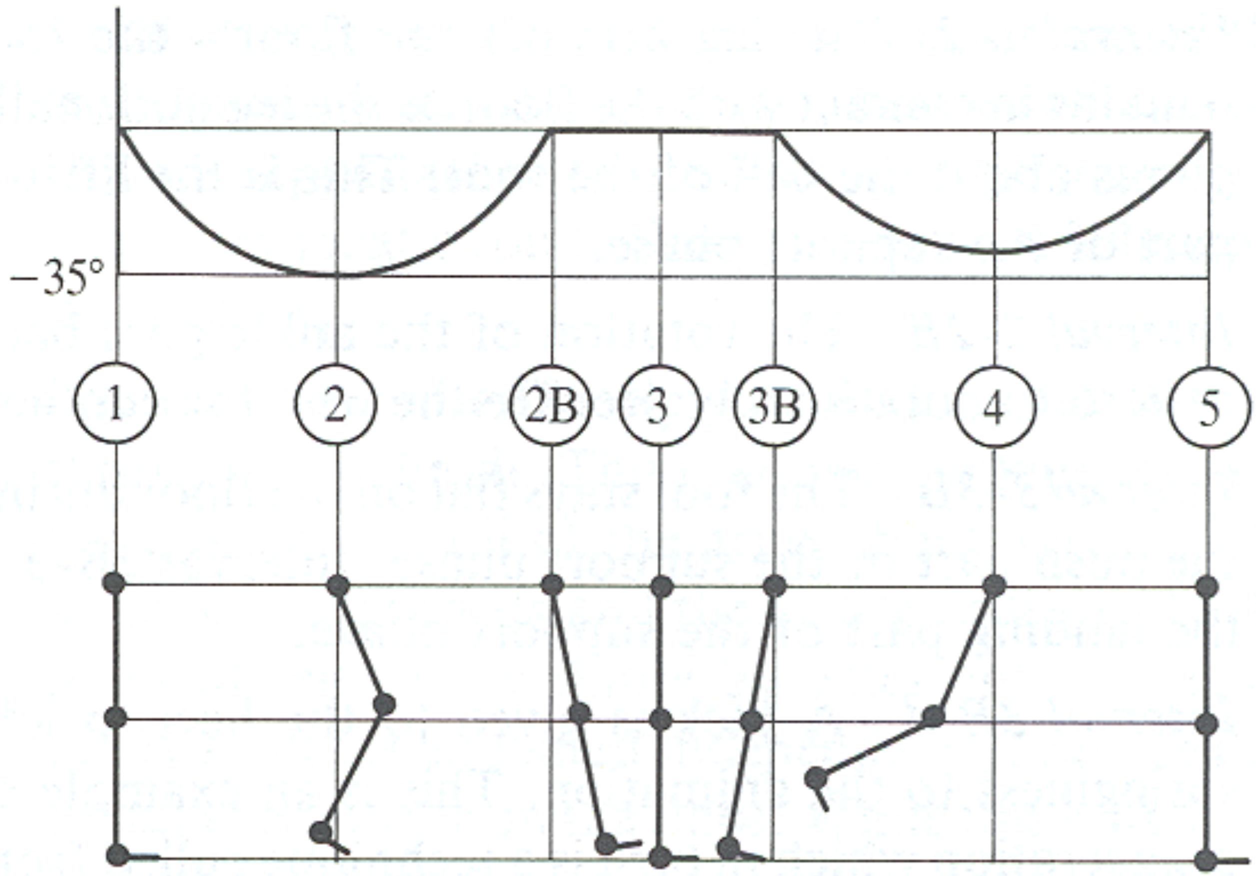
- Hip joint orientation:



Watt & Watt

Example: Walk Cycle

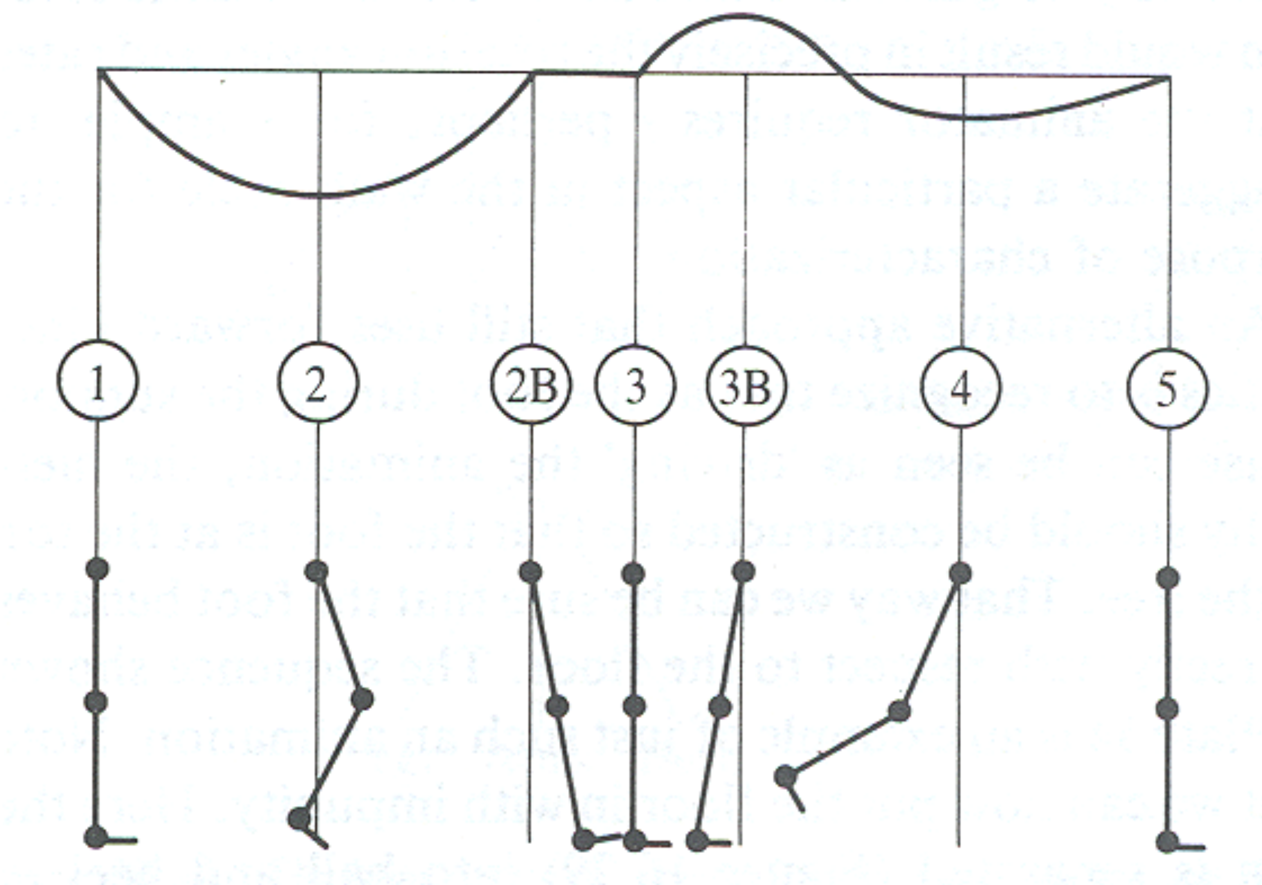
- Knee joint orientation:



Watt & Watt

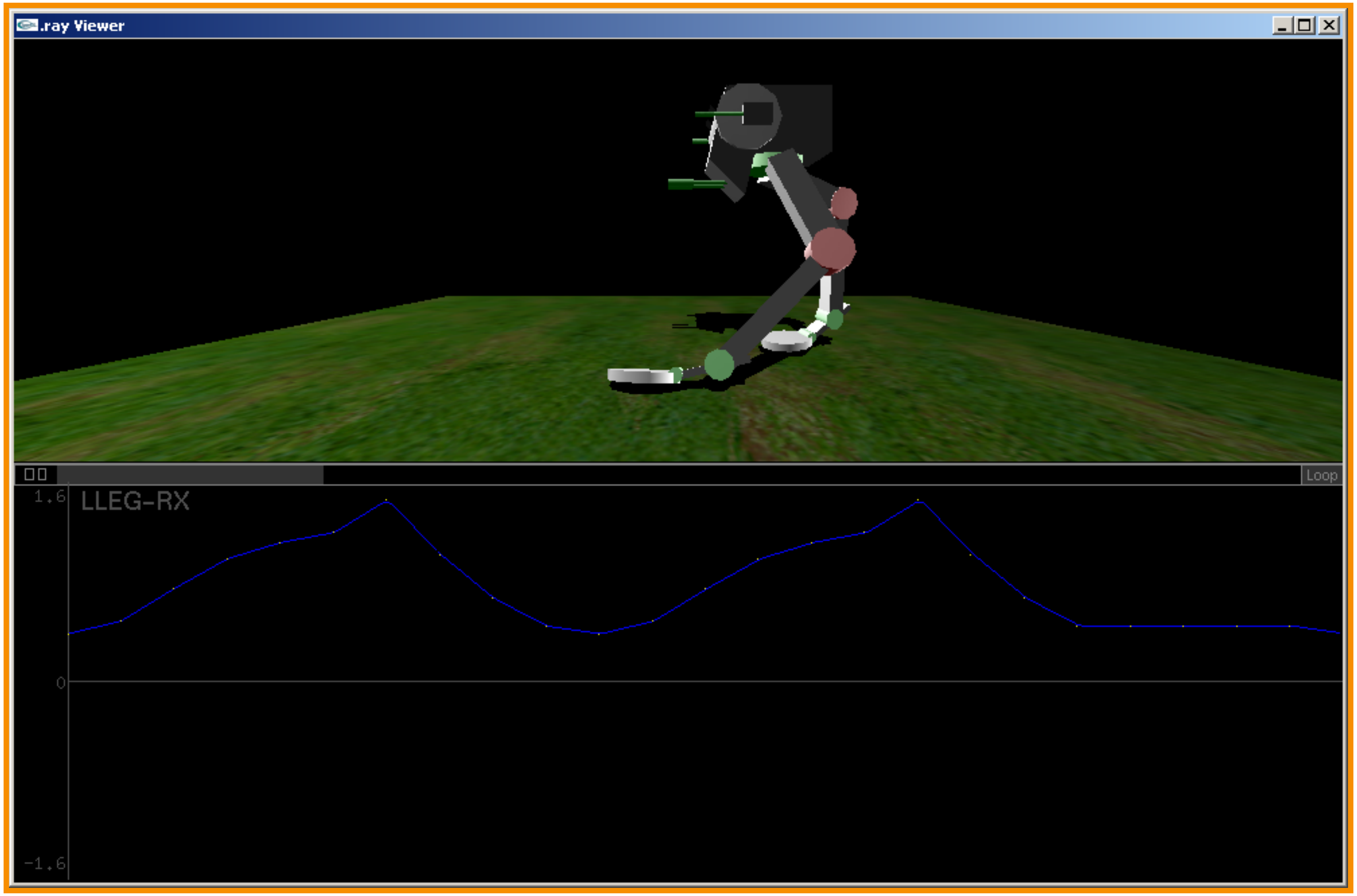
Example: Walk Cycle

- Ankle joint orientation:



Watt & Watt

Example: Robot



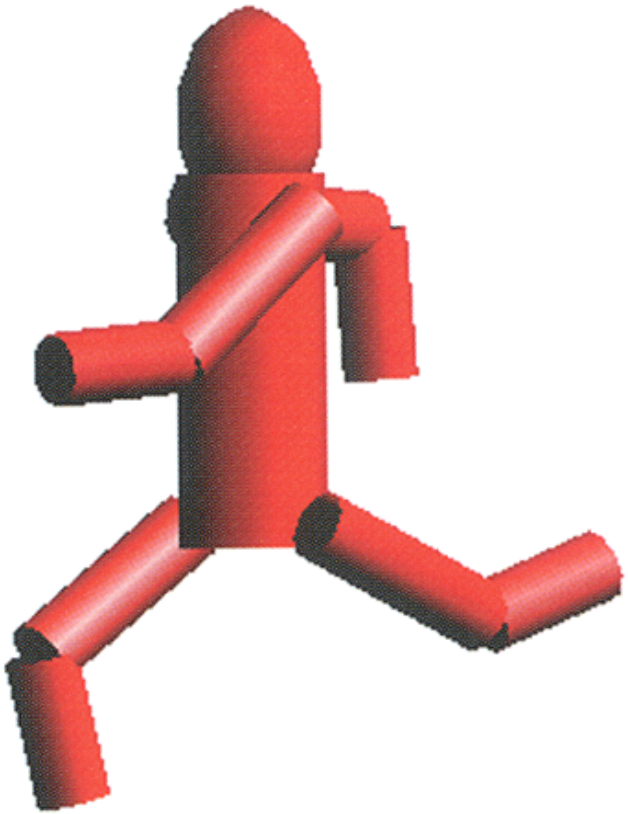
Mihai Parparita, COS 426, Princeton University, 2003

Example: Ice Skating

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

Character Animation Methods

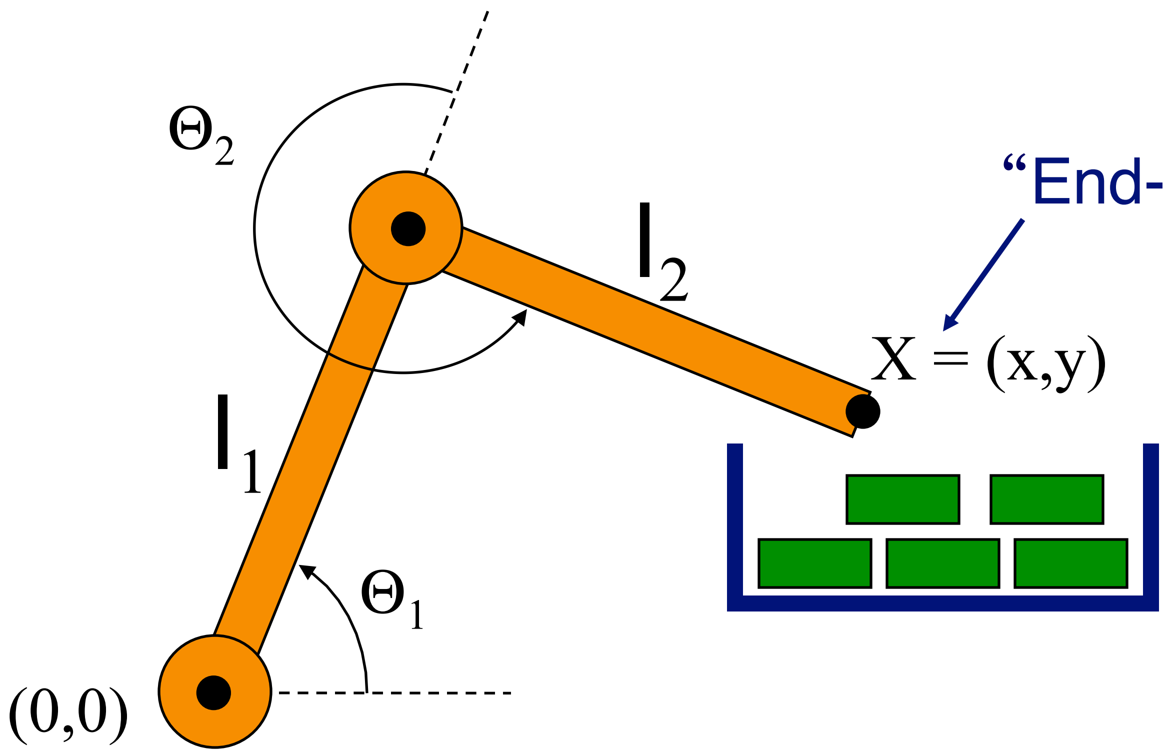
- Keyframing / Forward Kinematics
- Inverse Kinematics
- Dynamics
- Motion capture



Angel Plate 1

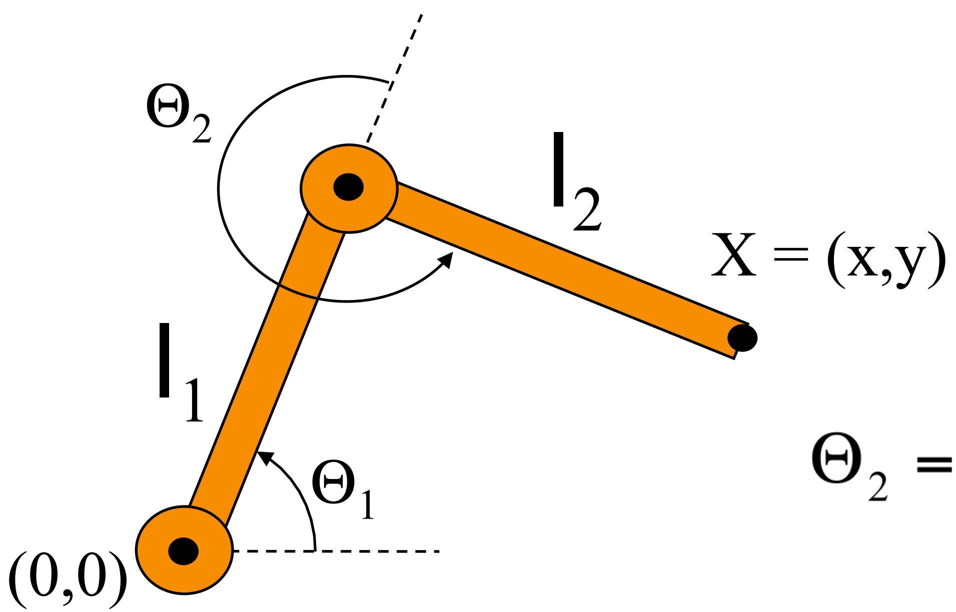
Inverse Kinematics

- 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:

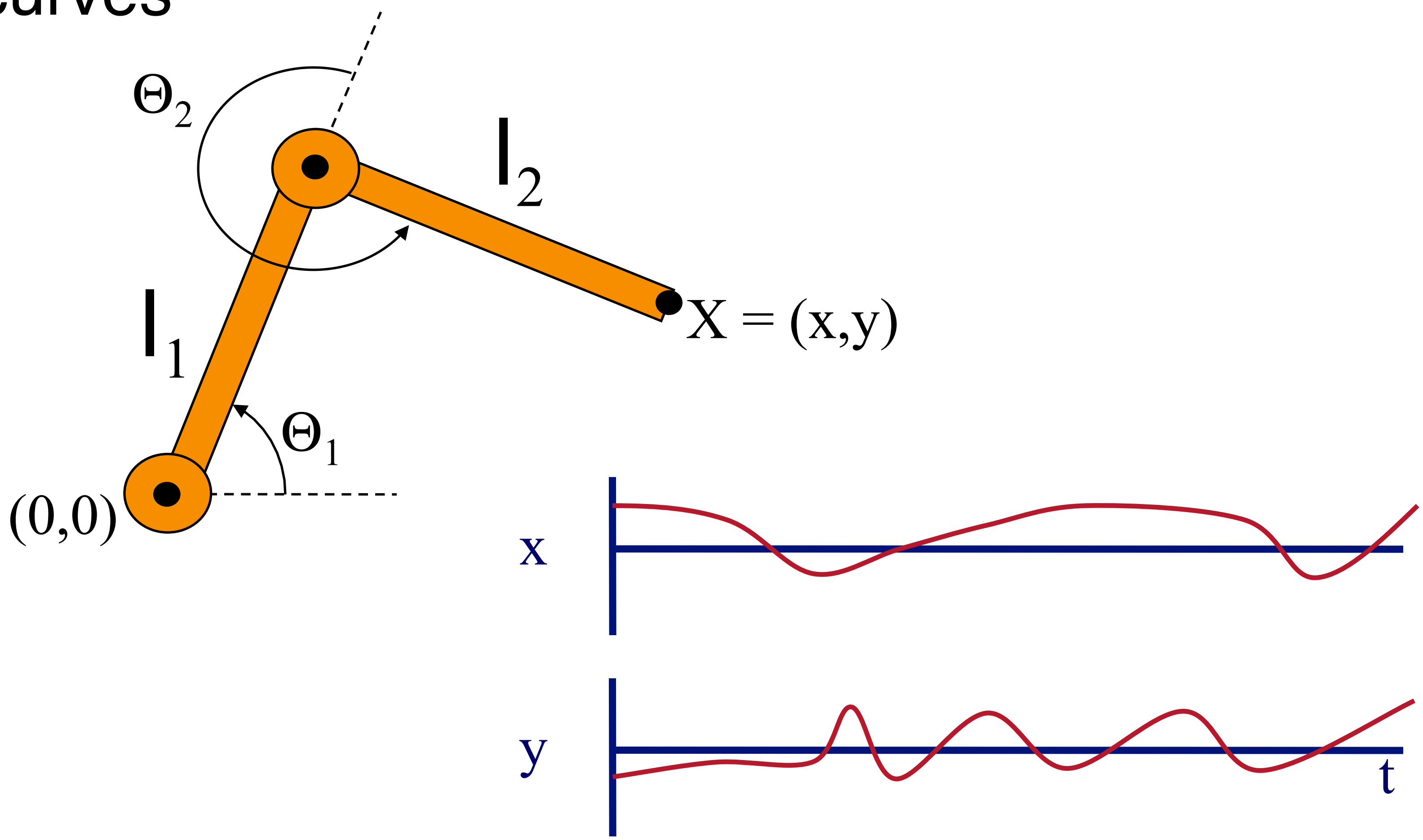


$$\Theta_2 = \cos^{-1}\left(\frac{x^2 + x^2 - l_1^{\,2} - l_2^{\,2}}{2 l_1 l_2}\right)$$

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

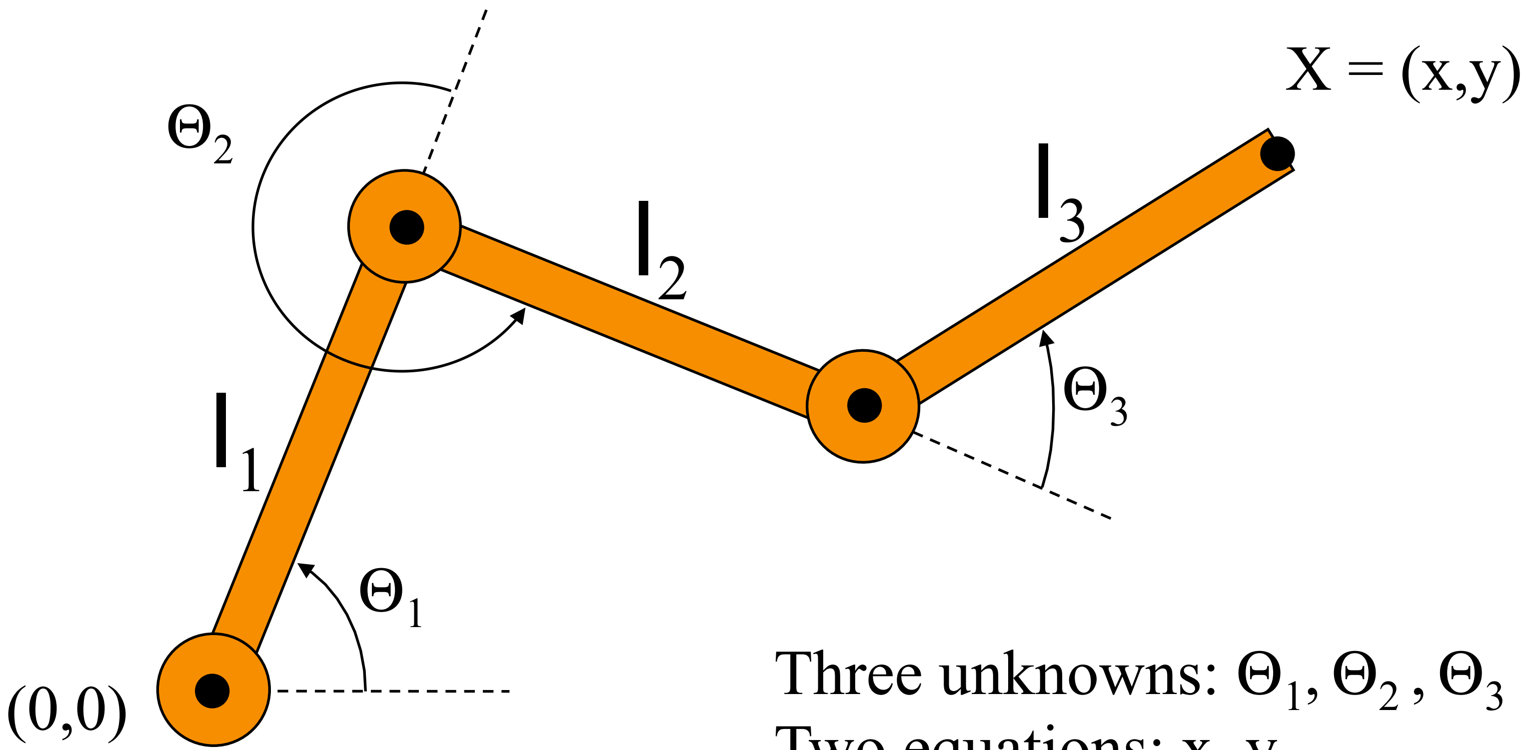
Inverse Kinematics

- End-effector postions can be specified by spline curves



Inverse Kinematics

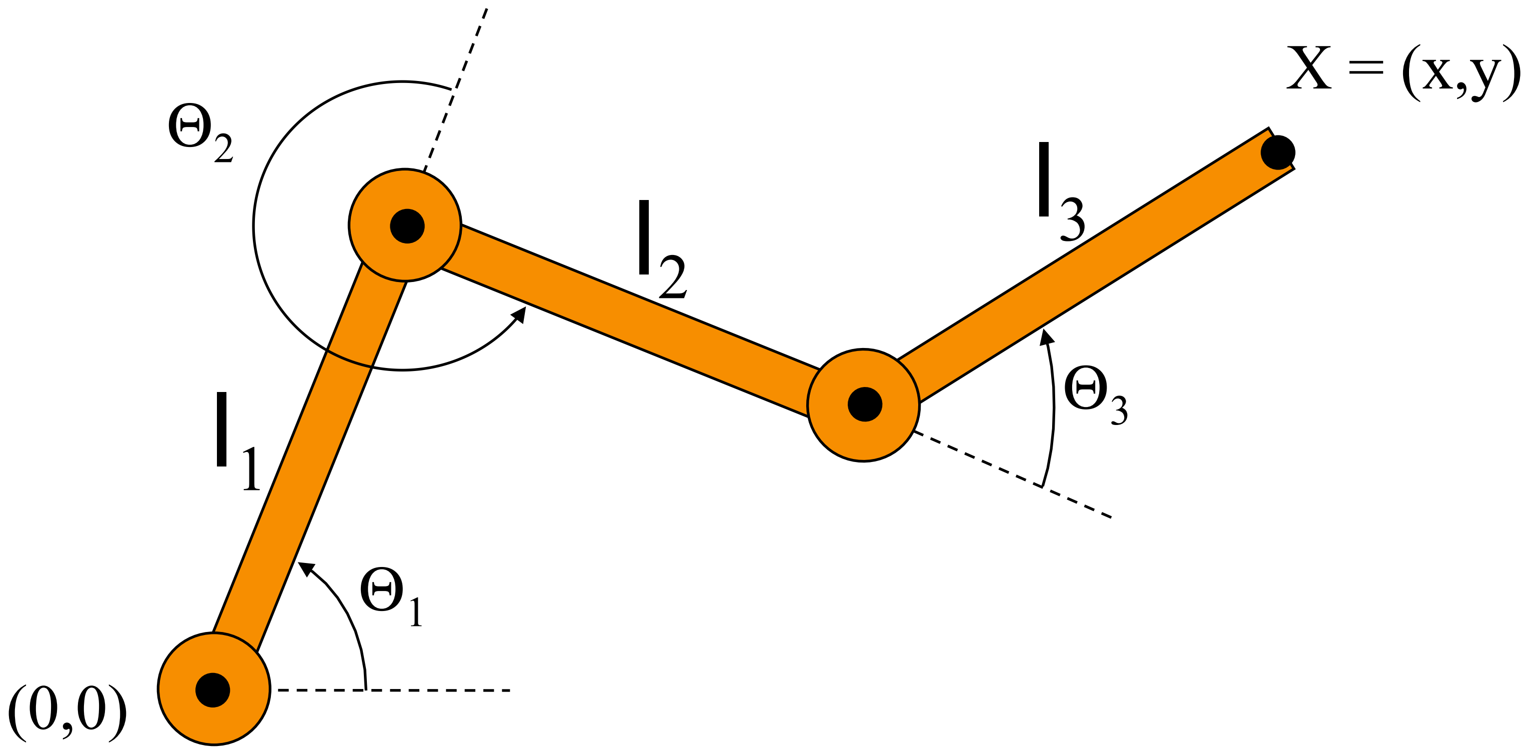
- Problem for more complex structures
  - System of equations is usually under-constrained
  - Multiple solutions



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



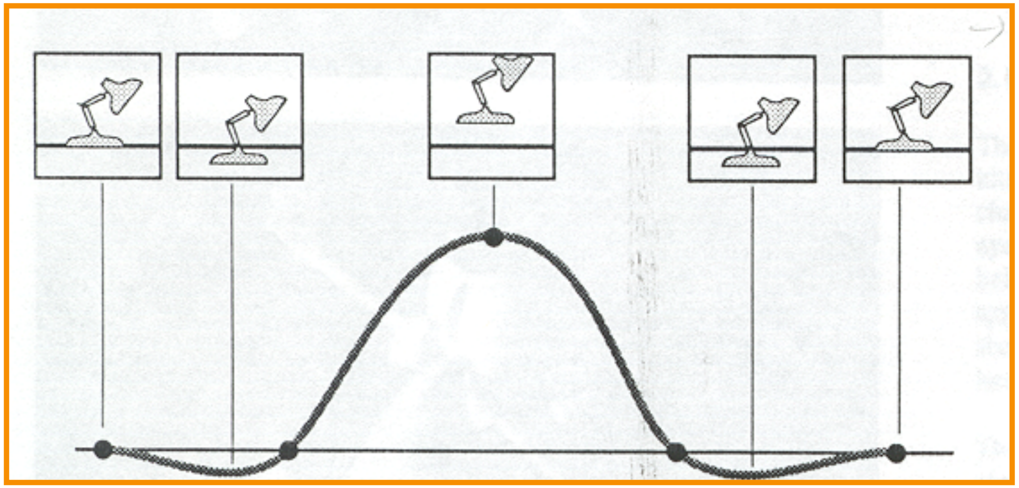
Example: Ball Boy

"Ballboy"

Fujito, Milliron, Ngan, & Sanocki
Princeton University

Kinematics

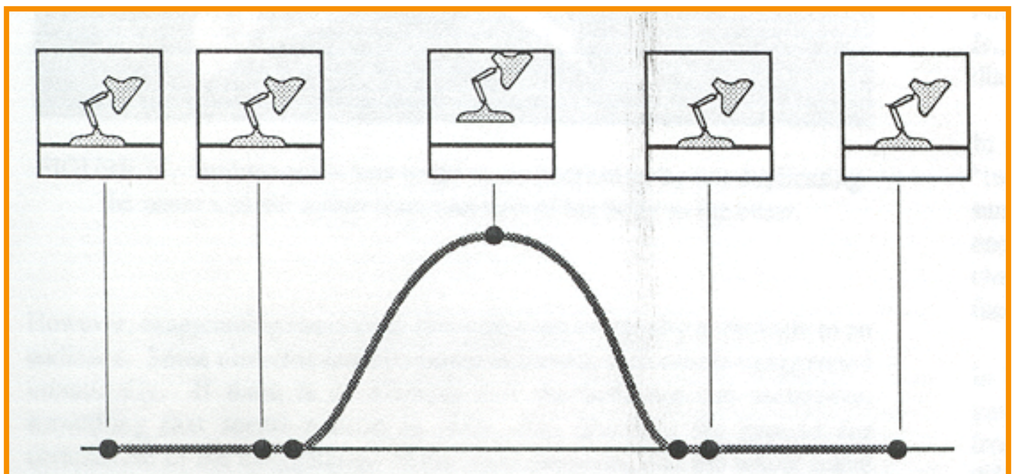
- Advantages
  - Simple to implement
  - Complete animator control
- Disadvantages
  - Motions may not follow physical laws
  - Tedious for animator



Lasseter `87

Kinematics

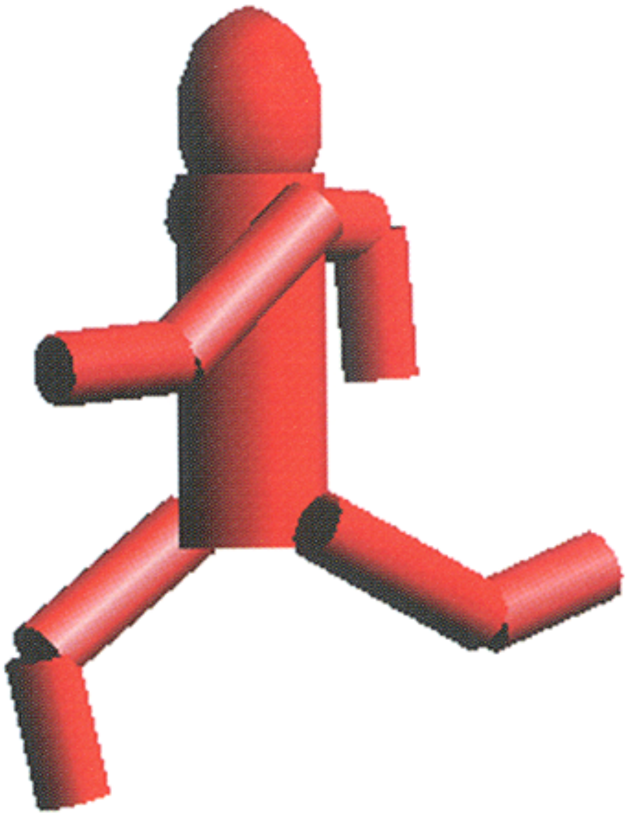
- Advantages
  - Simple to implement
  - Complete animator control
- Disadvantages
  - Motions may not follow physical laws
  - Tedious for animator



Lasseter `87

Character Animation Methods

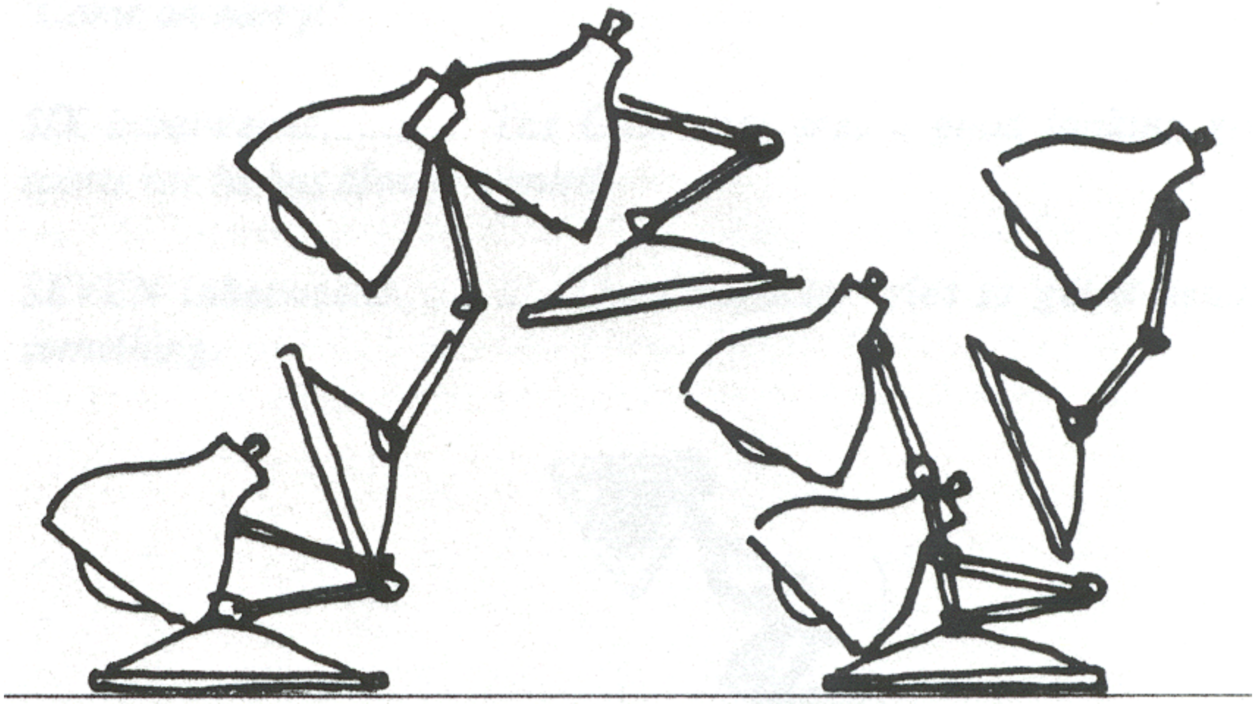
- Keyframing / Forward Kinematics
- Inverse Kinematics
- Dynamics
- Motion capture



Angel Plate 1

Dynamics

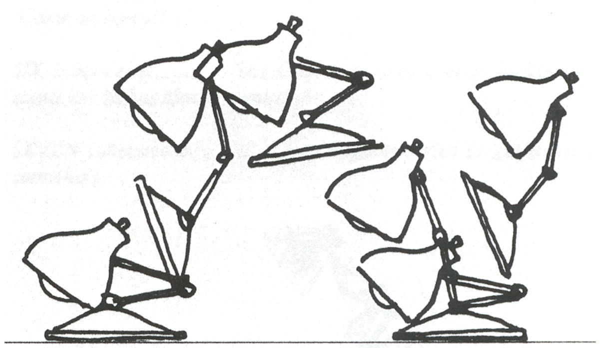
- Simulation of physics ensures realism of motion



Lasseter `87

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

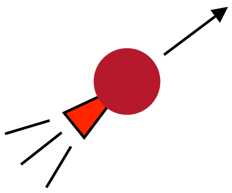


Computer Animation

Pixar

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:



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

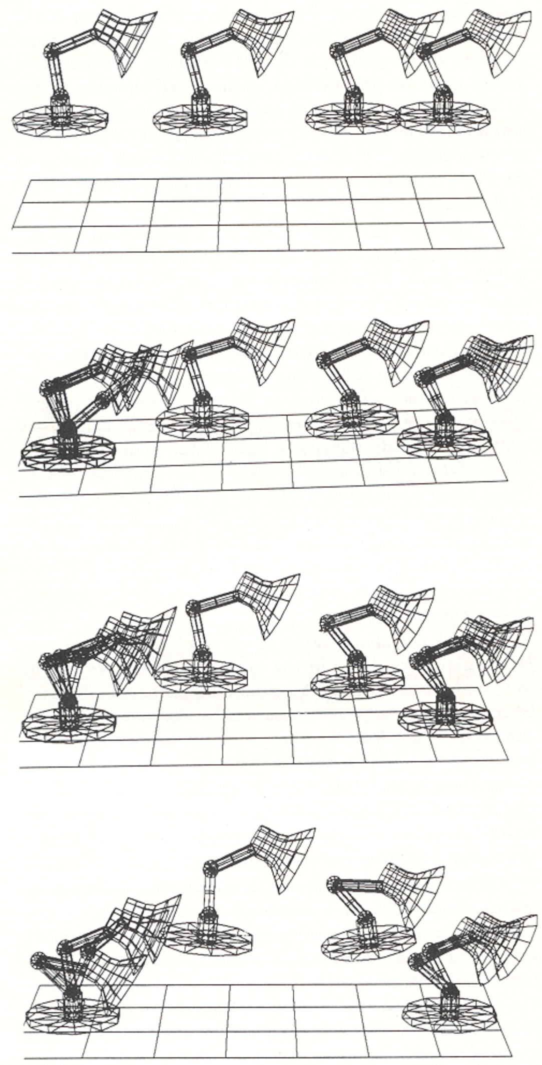
  - Suppose we want to move from a to b within t_0 to t_1 with minimum jet fuel:

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

Witkin & Kass `88

Spacetime Constraints

- Solve with iterative optimization methods



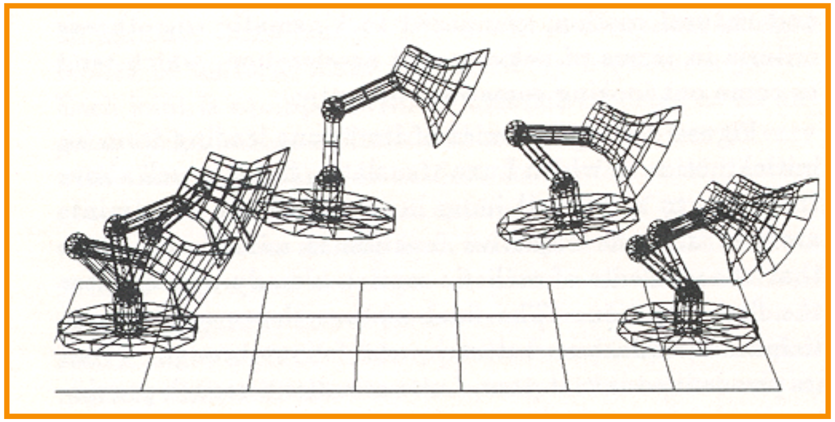
Witkin & Kass `88

Spacetime Constraints

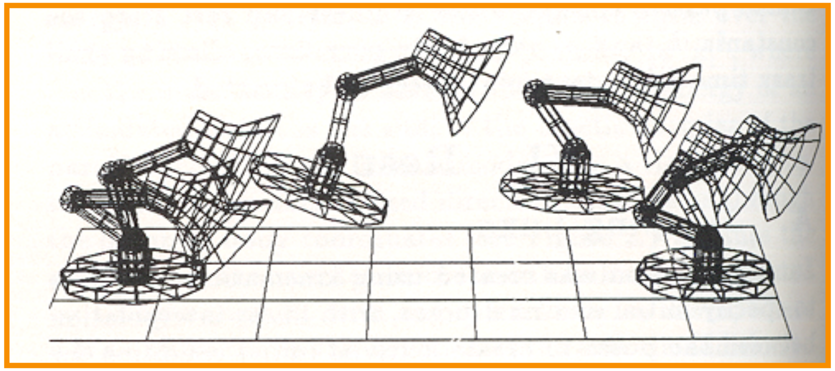
- Advantages:
  - Free animator from having to specify details of physically realistic motion with spline curves
  - Easy to vary motions due to new parameters and/or new constraints
- Challenges:
  - Specifying constraints and objective functions
  - Avoiding local minima during optimization

Spacetime Constraints

- Adapting motion:



Original Jump

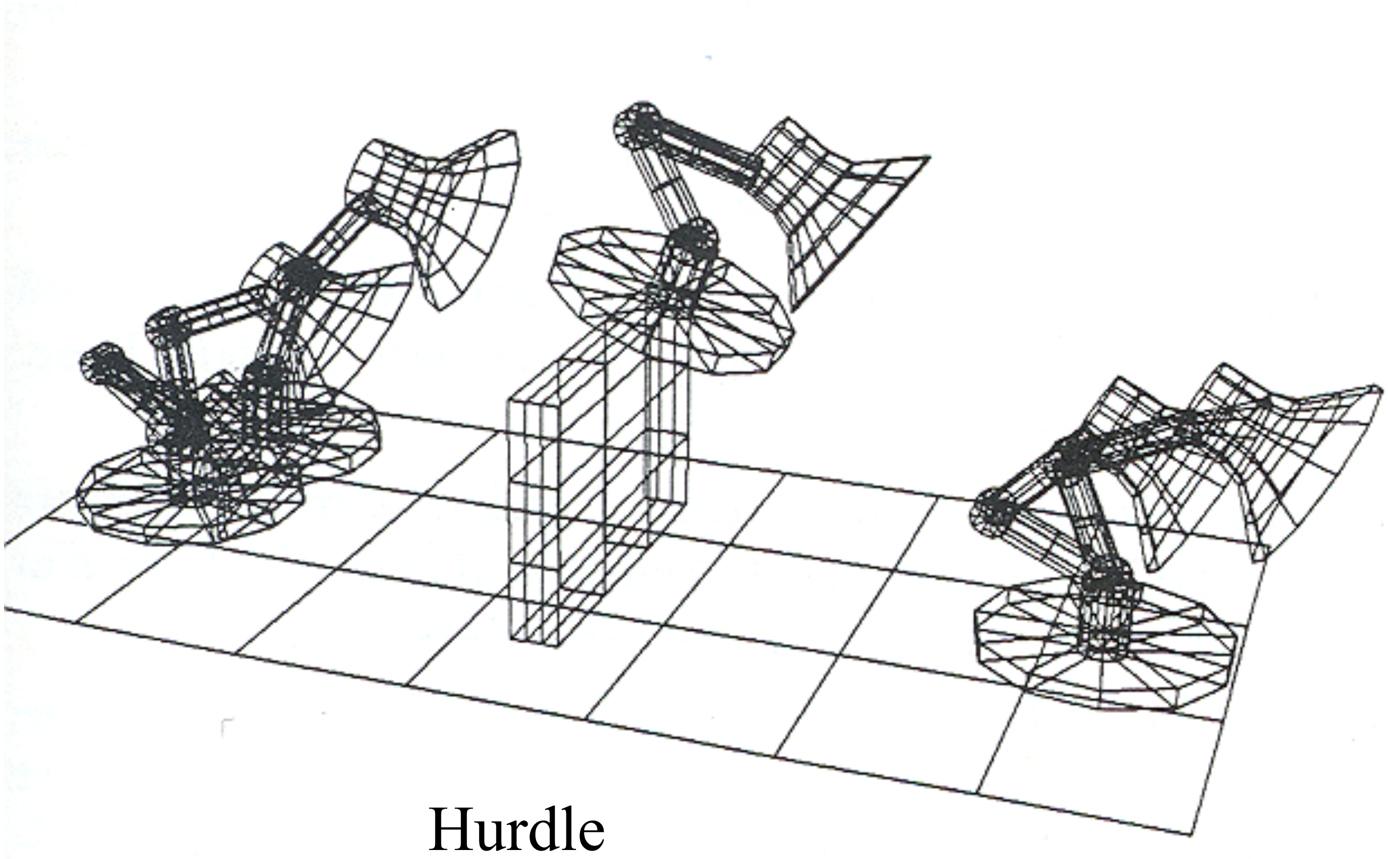


Heavier Base

Witkin & Kass `88

Spacetime Constraints

- Adapting motion:

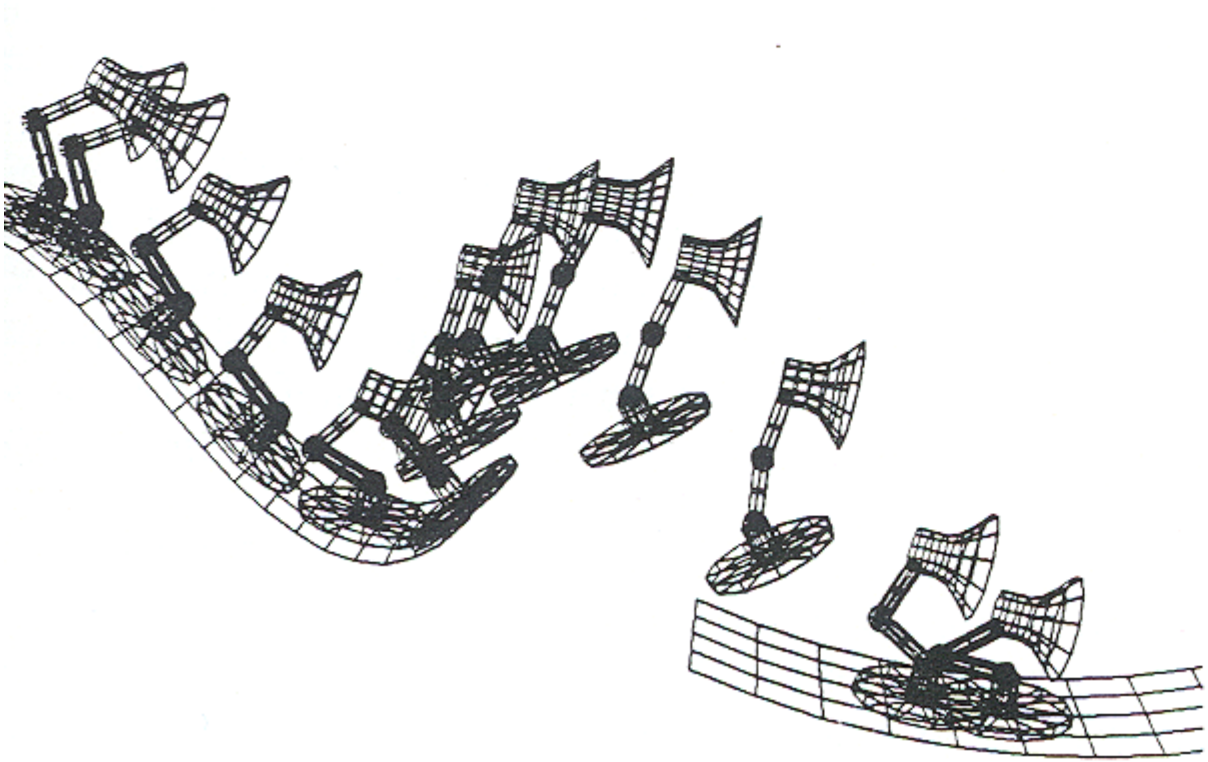


Hurdle

Witkin & Kass `88

Spacetime Constraints

- Adapting motion:



Ski Jump

Witkin & Kass `88

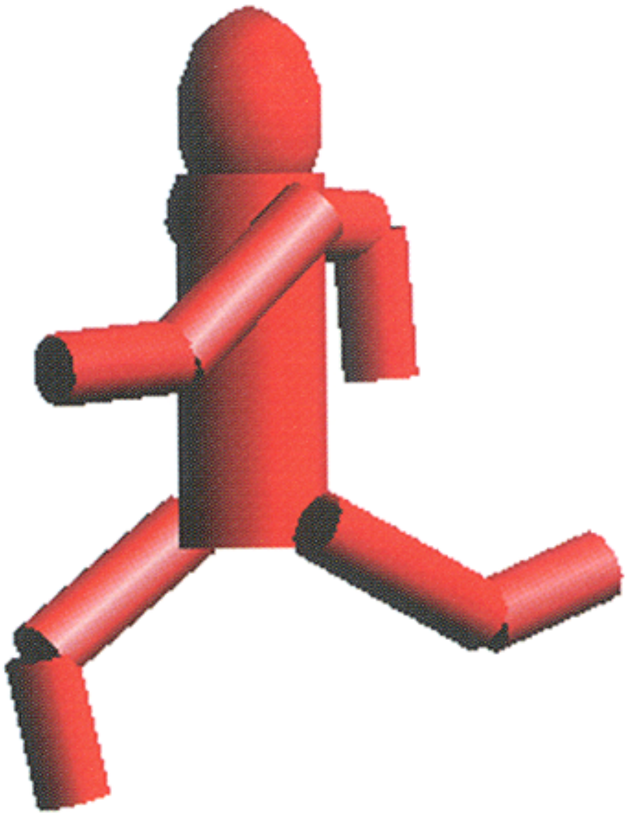
Spacetime Constraints

- 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

Character Animation Methods

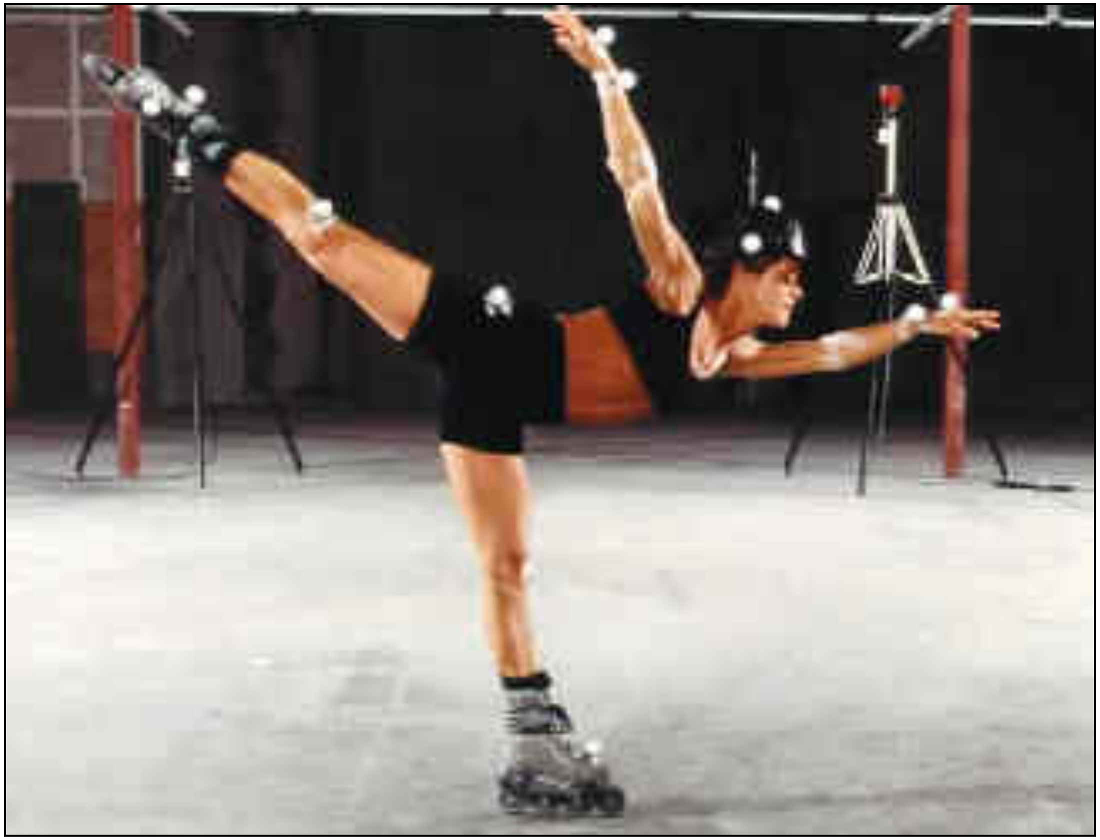
- Keyframing / Forward Kinematics
- Inverse Kinematics
- Dynamics
- Motion capture



Angel Plate 1

Motion Capture

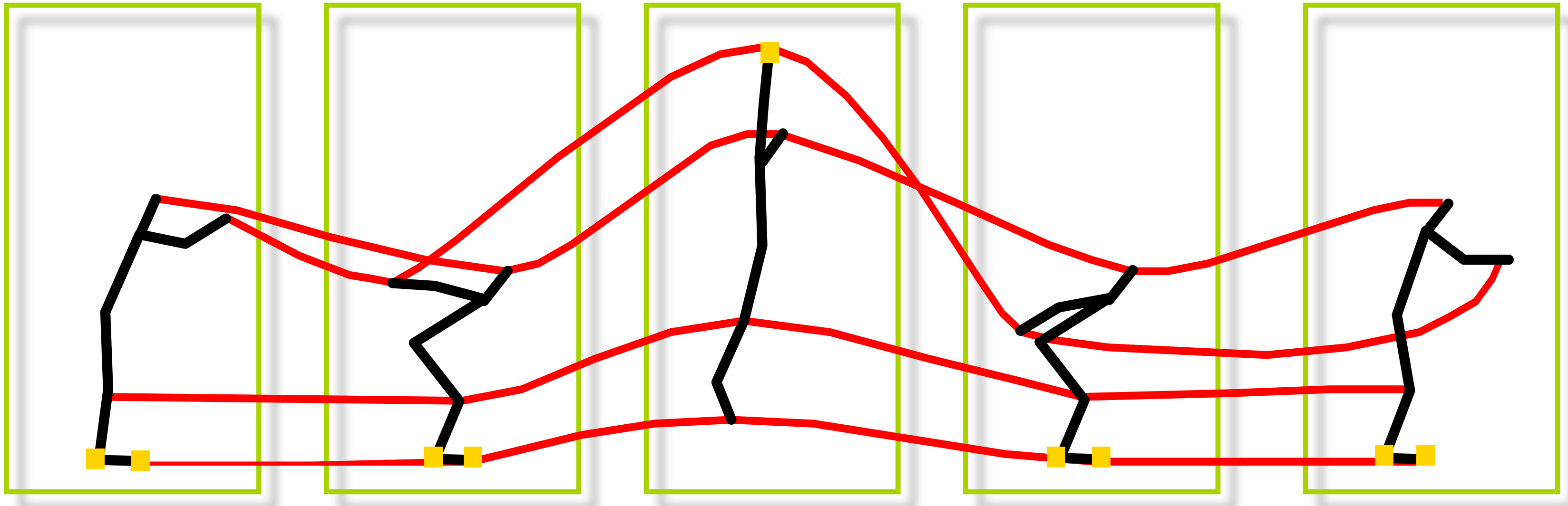
- Measure motion of real characters and then simply “play it back” with kinematics



Gleicher

Motion Capture

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



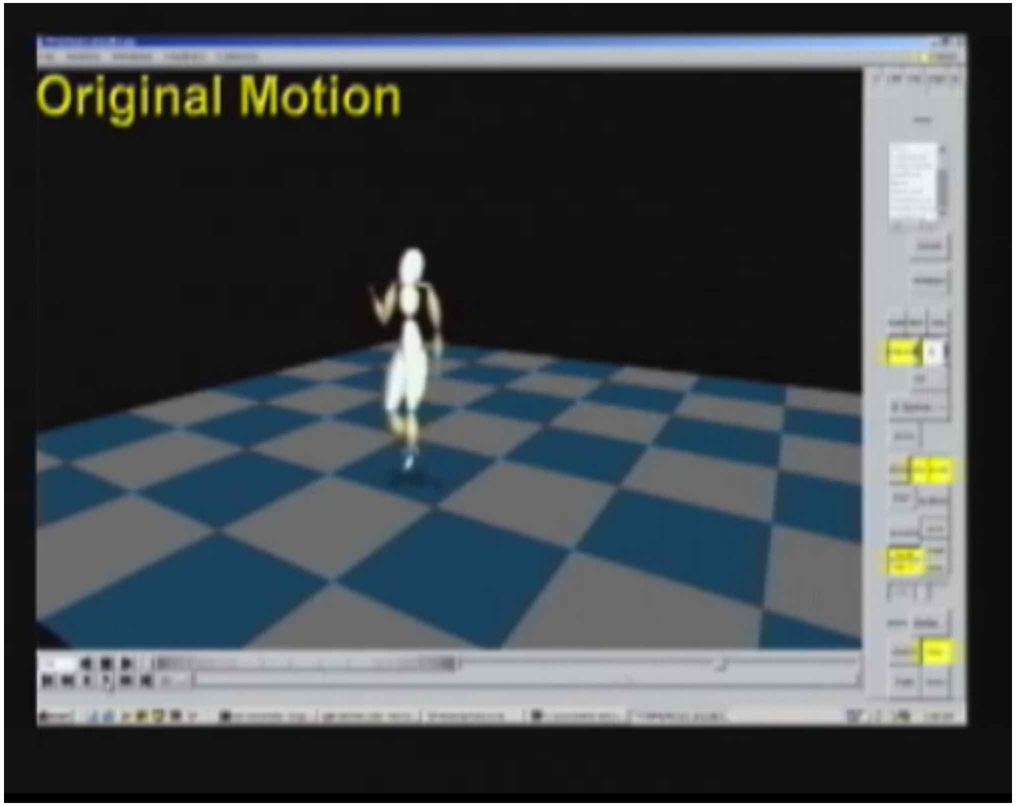
Captured Motion

Motion Capture

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

Motion Capture

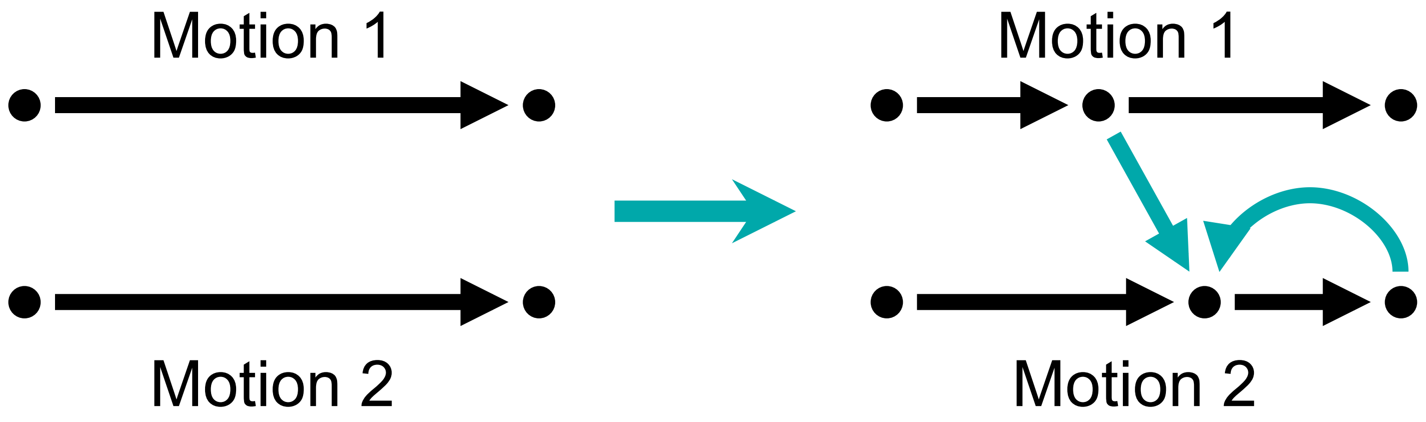
- Editing motion:



Gleicher

Motion Capture

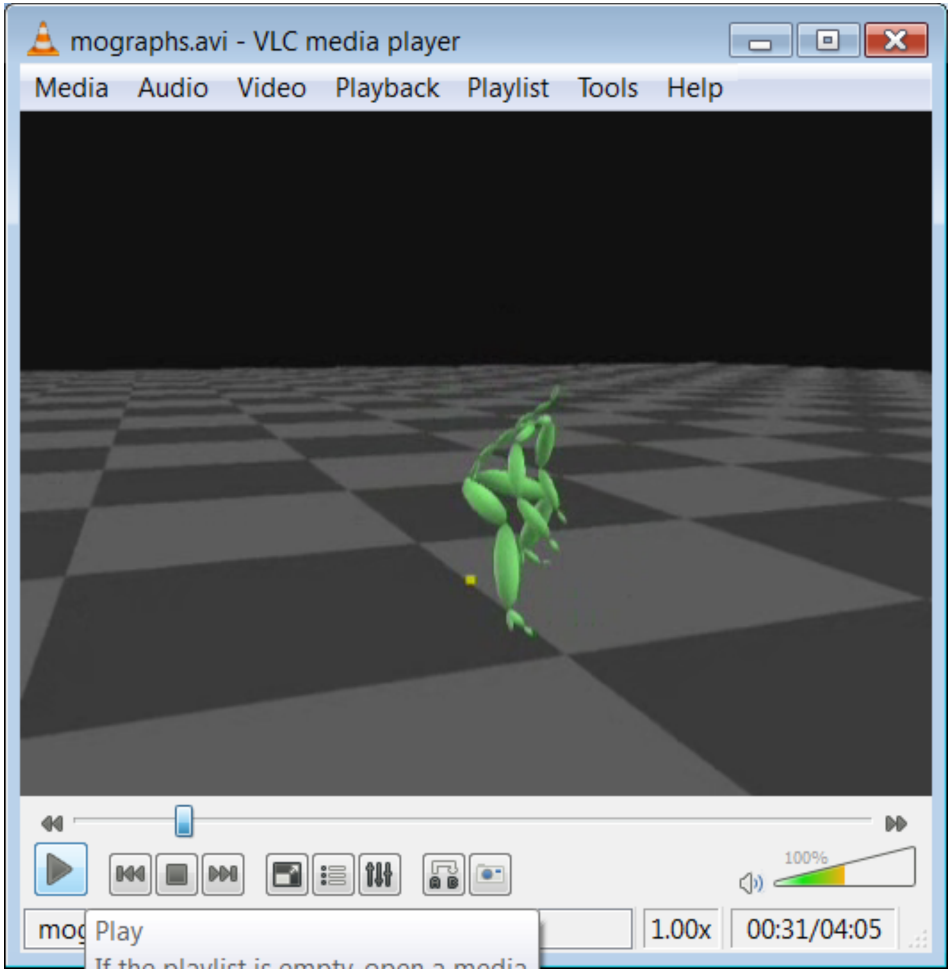
- Motion graphs:



Kovacs & Gleicher

Motion Capture

- Motion graphs:

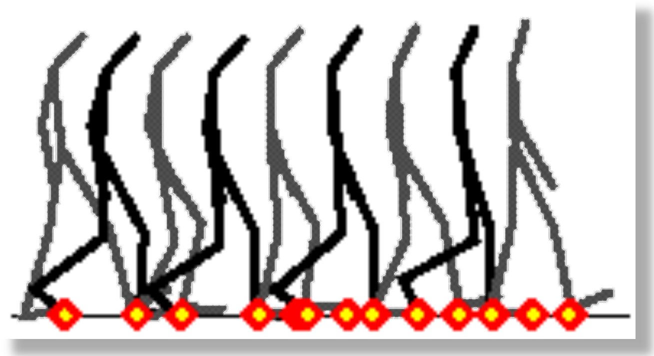


Kovacs & Gleicher

Motion Capture

- Retargeting motion:

Original motion data + constraints:



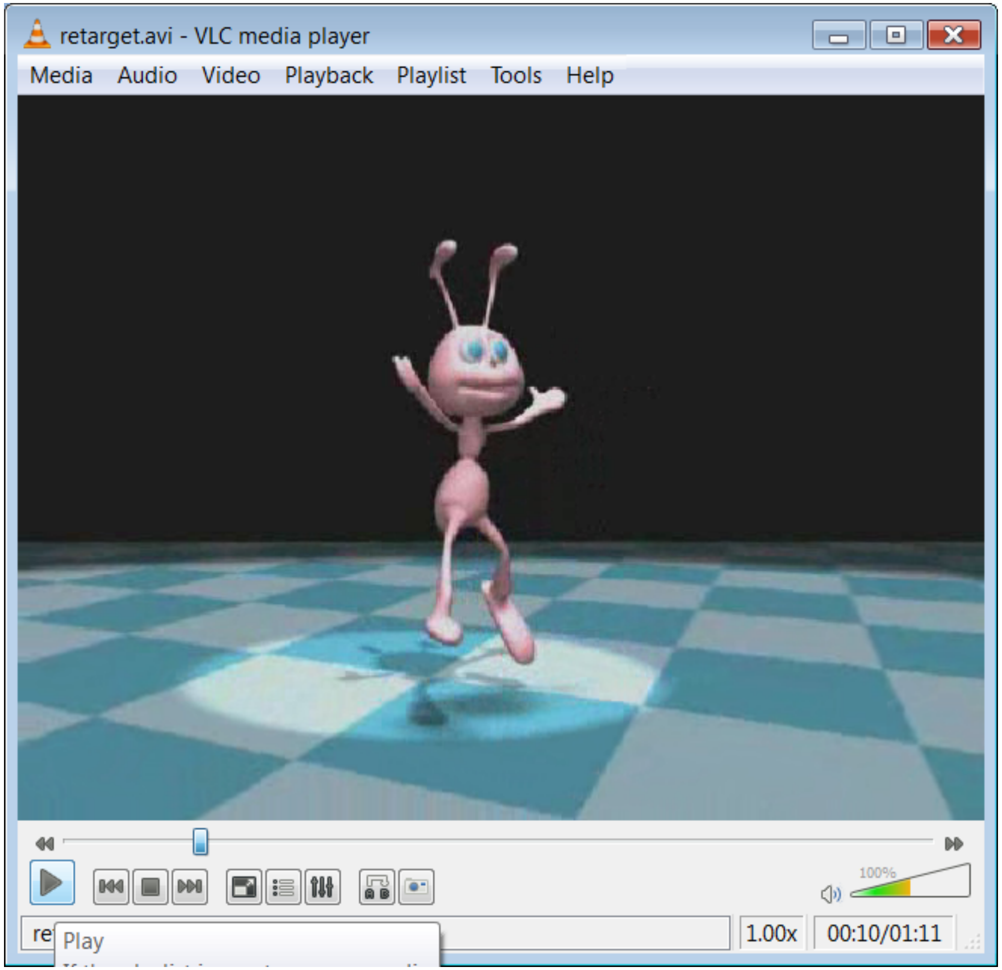
New character:

New motion data:

Gleicher

Motion Capture

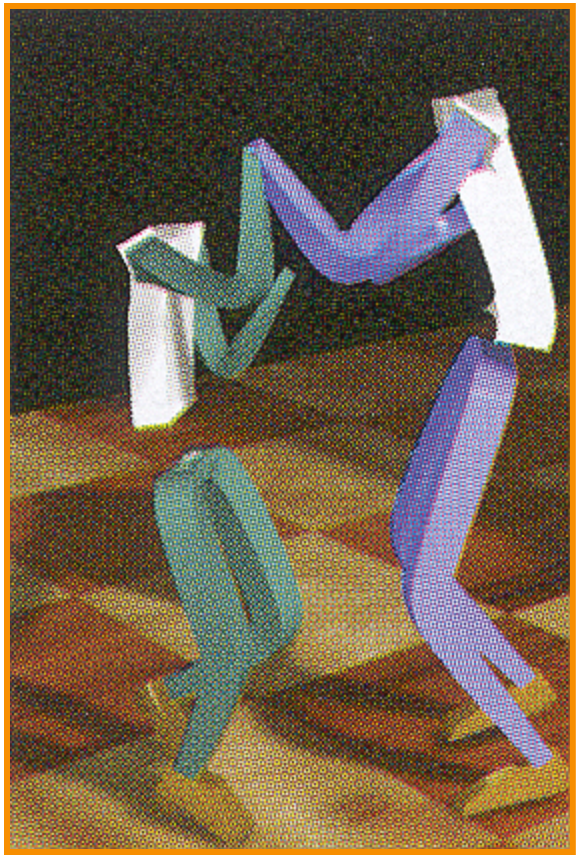
- Retargeting motion:



Gleicher

Motion Capture

- Morphing motion:

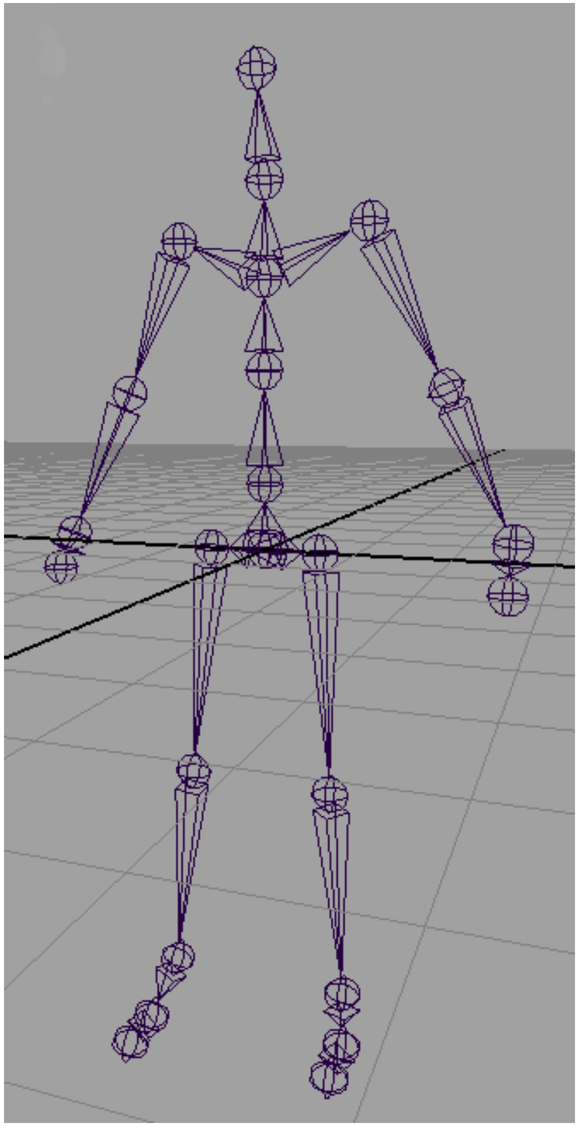


Beyond Skeletons…

- 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"

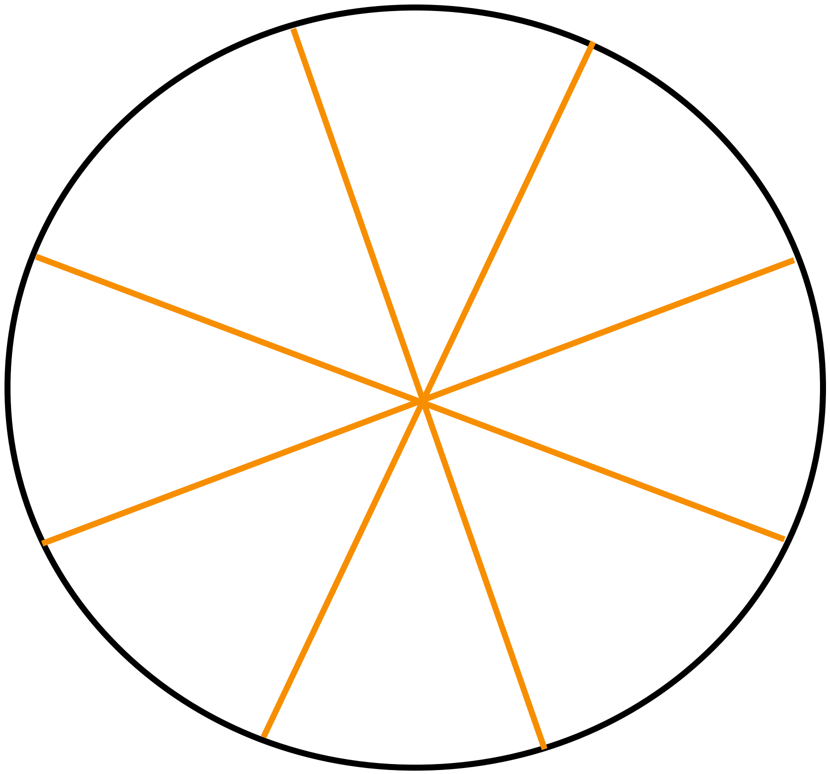
- Painted by hand
- Automatic: function of relative distances to nearest bones
    - Smoothness of skinned surface depends on smoothness of weights!

Beyond Skeletons…

- Skinning
- Motion blur

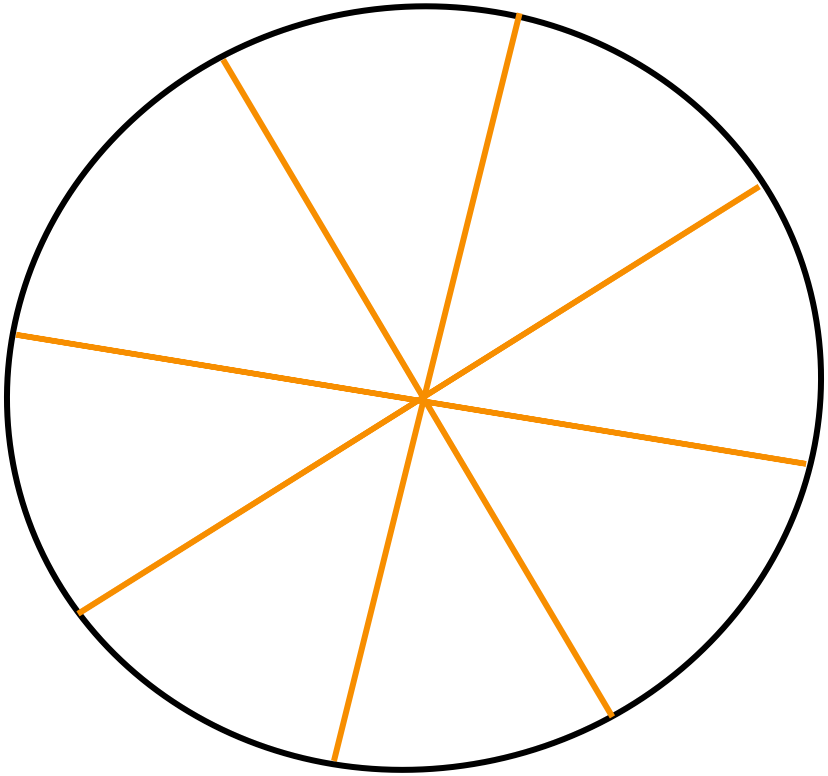
Temporal Aliasing

- Artifacts due to limited temporal resolution
  - Strobing
  - Flickering



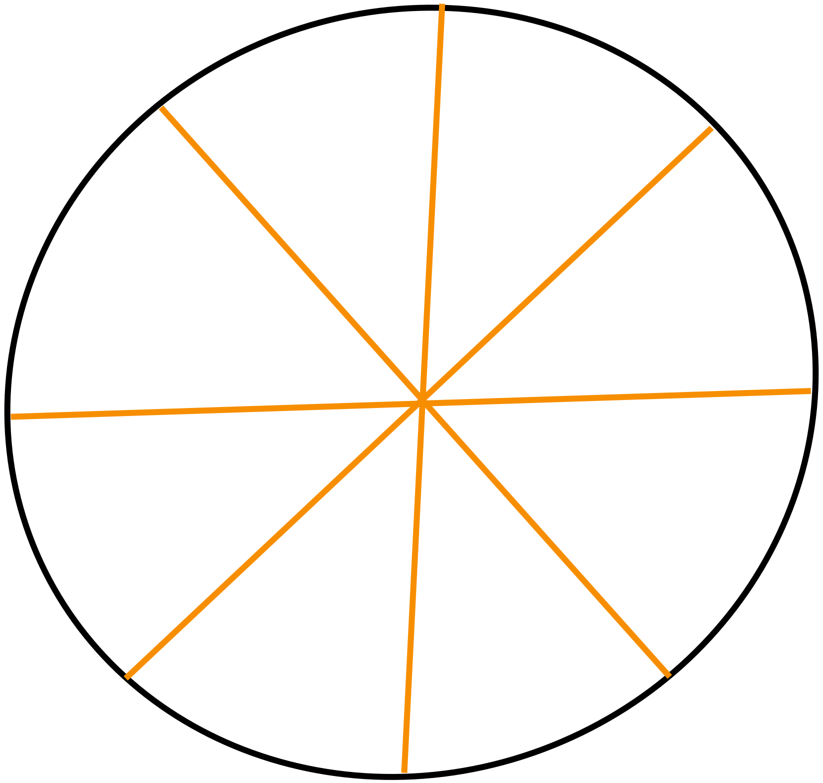
Temporal Aliasing

- Artifacts due to limited temporal resolution
  - Strobing
  - Flickering



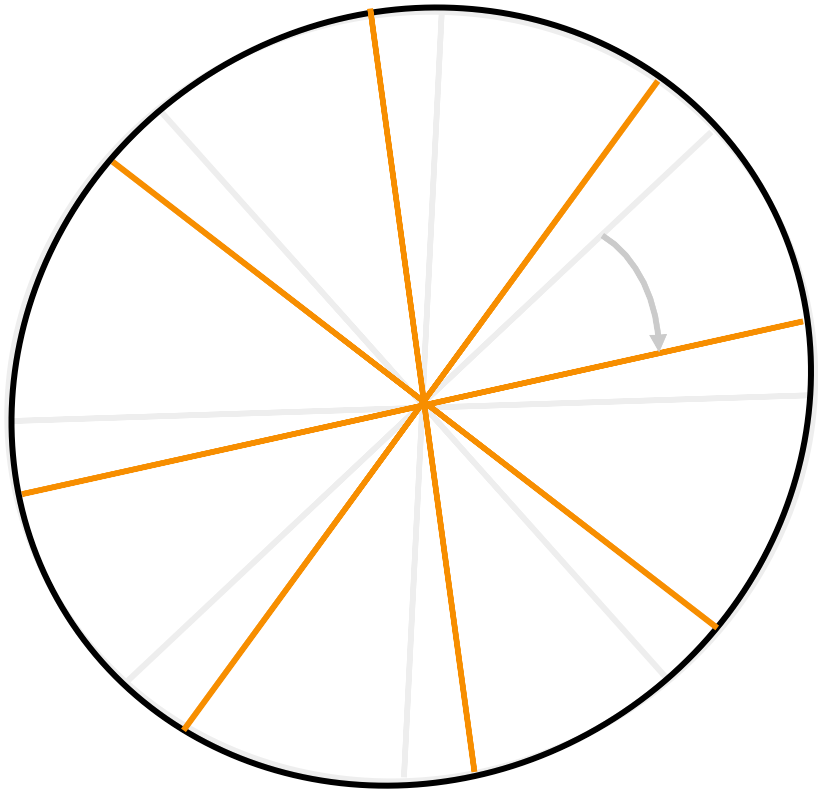
Temporal Aliasing

- Artifacts due to limited temporal resolution
  - Strobing
  - Flickering



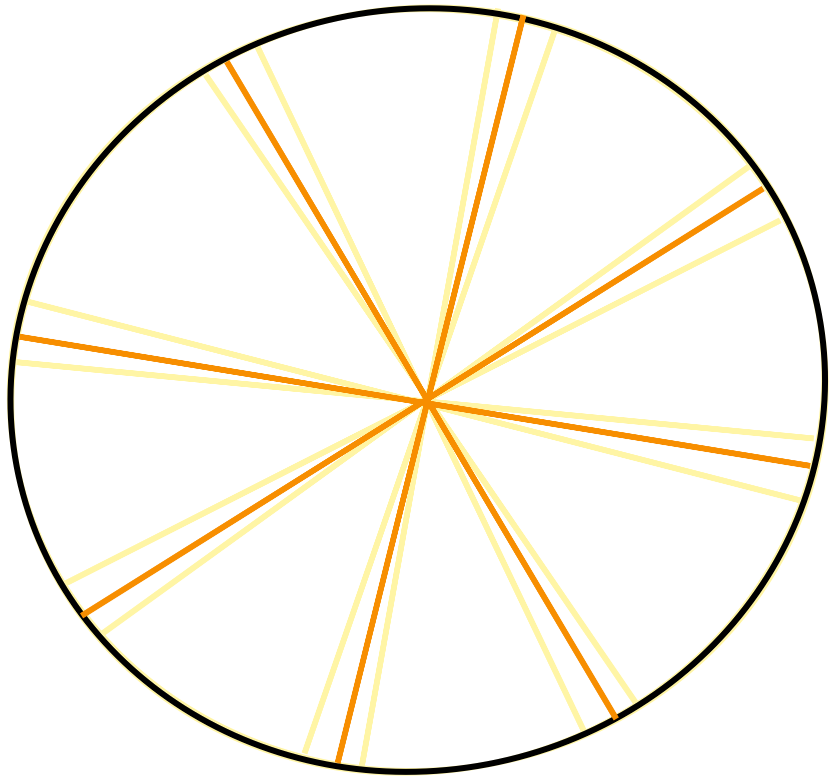
Temporal Aliasing

- Artifacts due to limited temporal resolution
  - Strobing
  - Flickering



Motion Blur

- Composite weighted images of adjacent frames
  - Remove parts of signal under-sampled in time



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