Computer Animation

Michael Kazhdan

(601.457/657)

Overview

- Some early animation history
  - http://web.inter.nl.net/users/anima/index.htm
  - http://www.public.iastate.edu/~rllew/chrnearl.html
- Computer animation

Thaumatrope

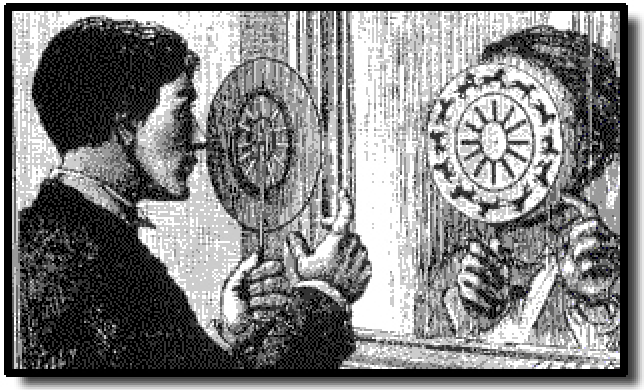
Q: Why does animation work?

A: Persistence of vision

- 1824 John Ayerton invents the *thaumatrope*
- Or, 1828 Paul Roget invents the *thaumatrope*

Phenakistoscope

- Invented independently by 2 people in 1832
- Disc mounted on spindle
- Viewed through slots with images facing mirror
- Turning disc animates images



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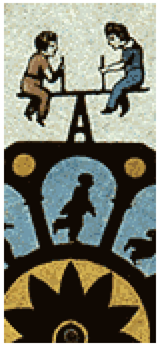

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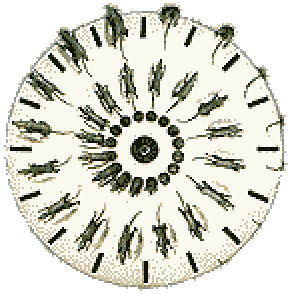

Zoetrope (1834)

- Images arranged on paper band inside a drum
- Slits cut in the upper half of the drum
- Opposite side viewed as drum rapidly spun
- Praxinoscope is a variation on this

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Mutoscope (1895)

- Coin-operated “flip-book” animation
- Picture cards attached to a drum
- Popular at sea-side resorts, etc.

Animation History

First known example of animation:

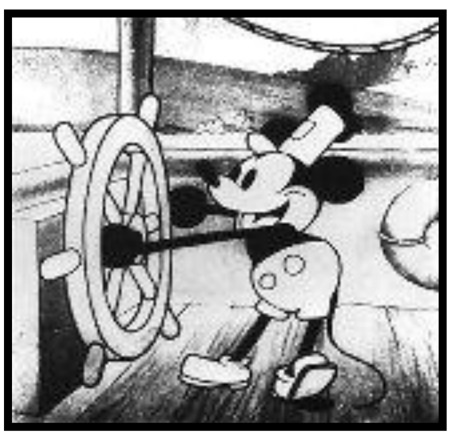
- "Humorous Phases of Funny Faces" (1906)

Humorous phases of funny faces

Key Developments

- Plot
- Creation of animation studios
- Inking on cels

“Felix the Cat”
Otto Messmer (1921)

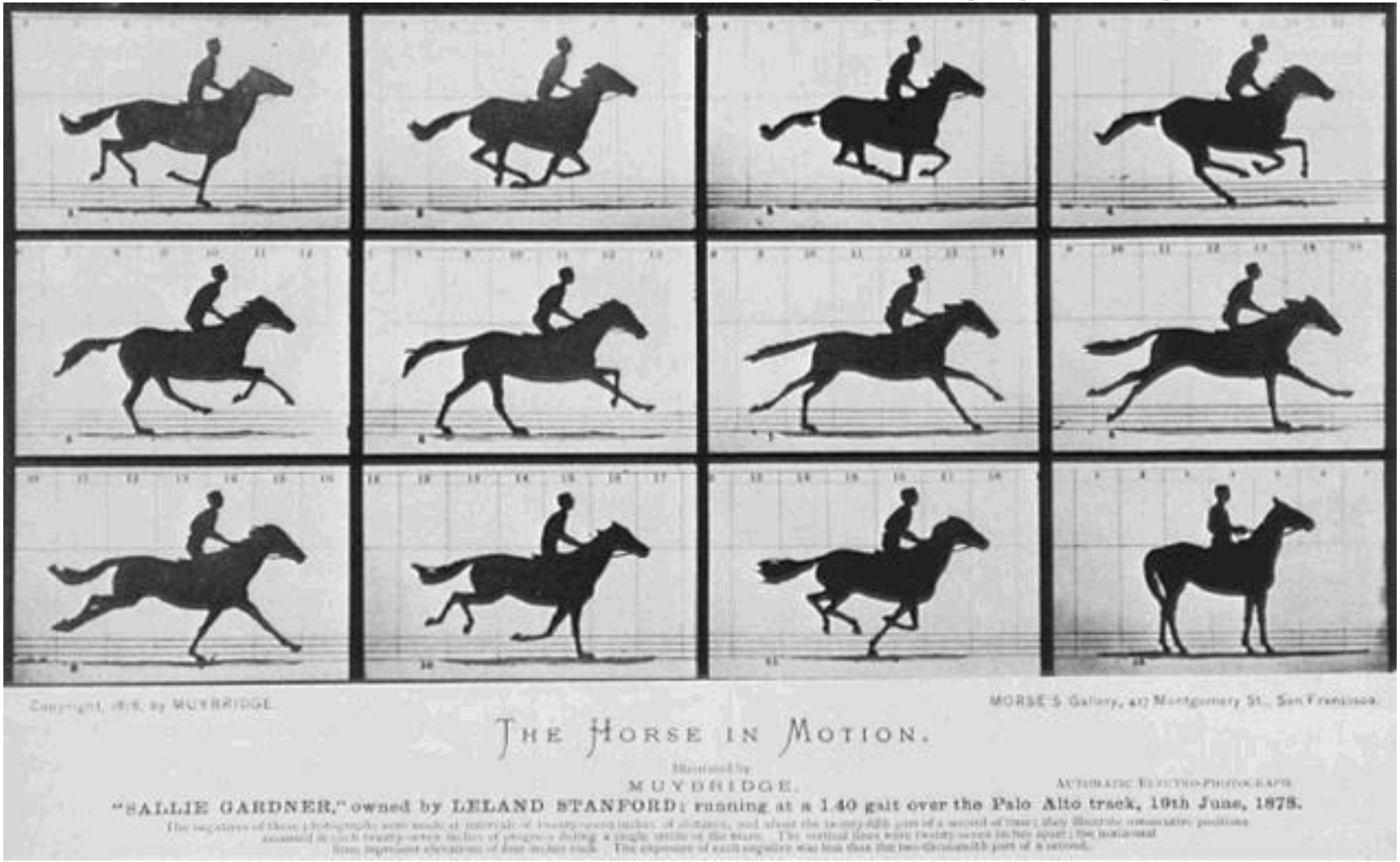


“Steamboat Willie”
Walt Disney (1928)

“Gertie the Dinosaur”
Windsor McCay (1914)

Key Developments

- Max Fleischer invents rotoscoping (1921)



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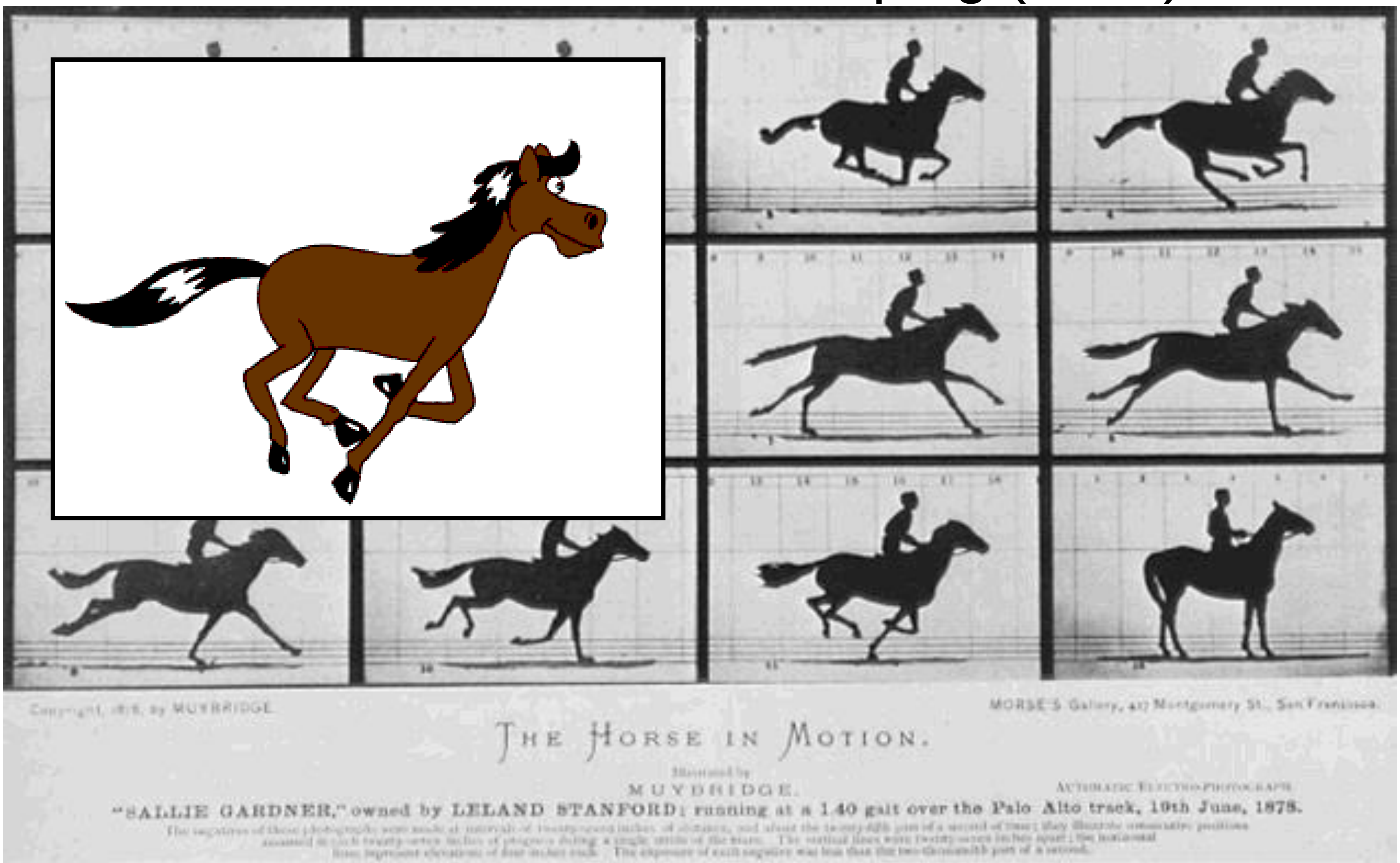


Key Developments

- “Flowers and Trees”, 1932:
  - Uses color, wins Academy Award
- “Snow White” (aka “Disney’s Folly”), 1937:
  - $1.4 million to make
  - 750 artists
  - Highest grossing ($8 million)

“Flowers and Trees”
Walt Disney

“Snow White”
Walt Disney

Animation Uses

- Entertainment
- Education
- Propaganda

Principles of Traditional Animation

How do we communicate aspects of the animation that are not strictly visual?

- Rigidity
- Weight
- Mood
- Intent
- Focus
- Etc.

See, for example, *The Illusion of Life: Disney Animation* for Disney's 12 basic principals of animation.

Luxo Junior

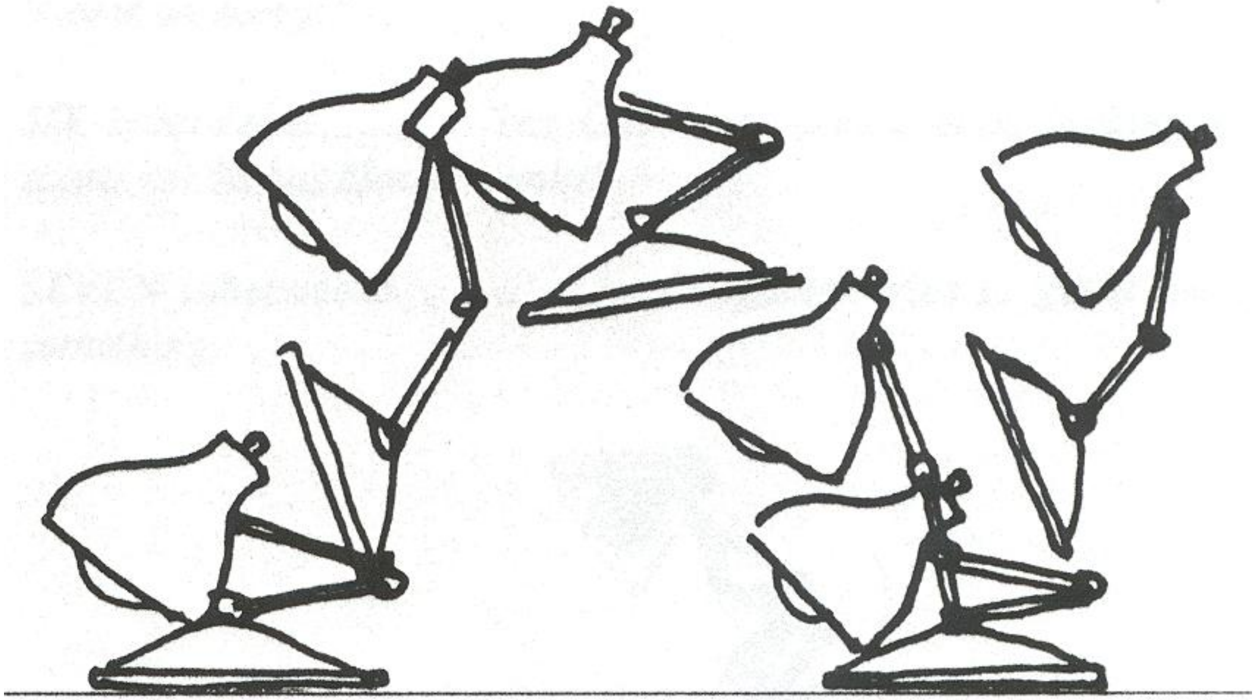
https://en.wikipedia.org/wiki/12_basic_principles_of_animation

Overview

- Some early animation history
- Computer animation
  - Keyframe animation
  - Articulated figures
  - Kinematics and dynamics

Keyframe Animation

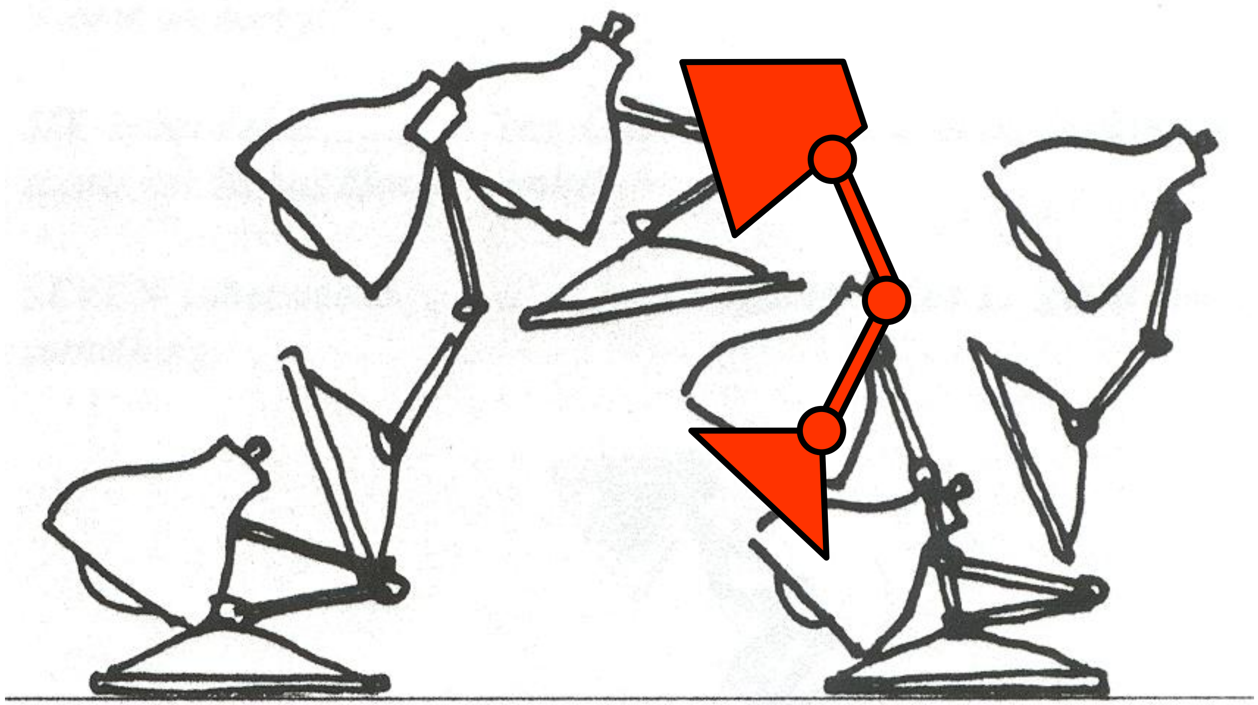
- Define character poses at specific time steps called “keyframes”



Lasseter `87

Keyframe Animation

- Define character poses at specific time steps called “keyframes”
- Interpolate/blend variables describing keyframes to determine poses for character “in-between”



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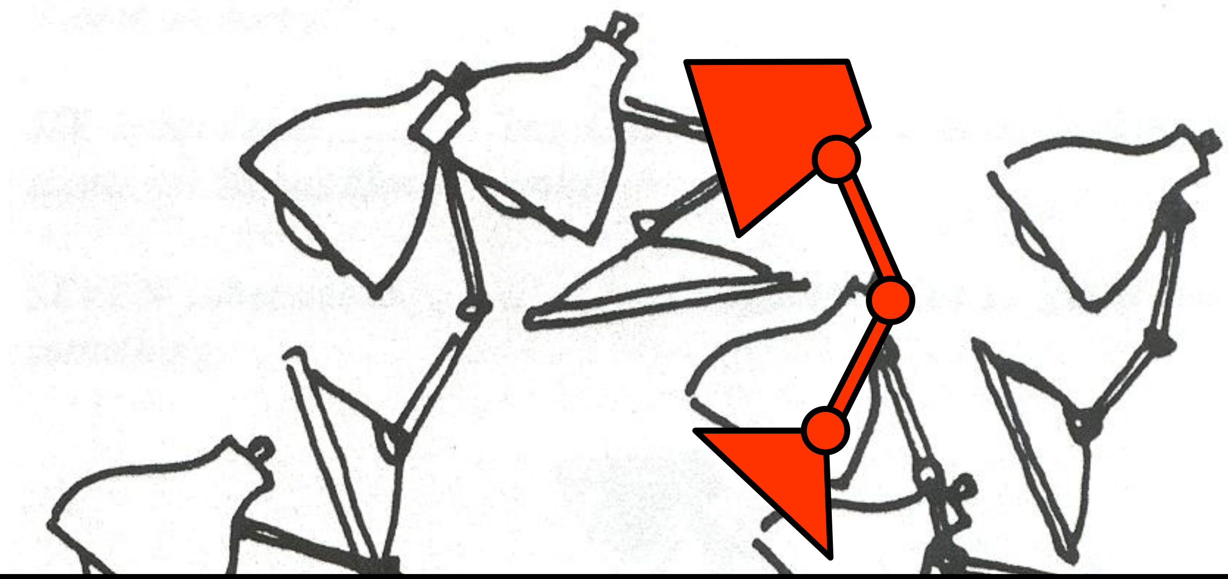
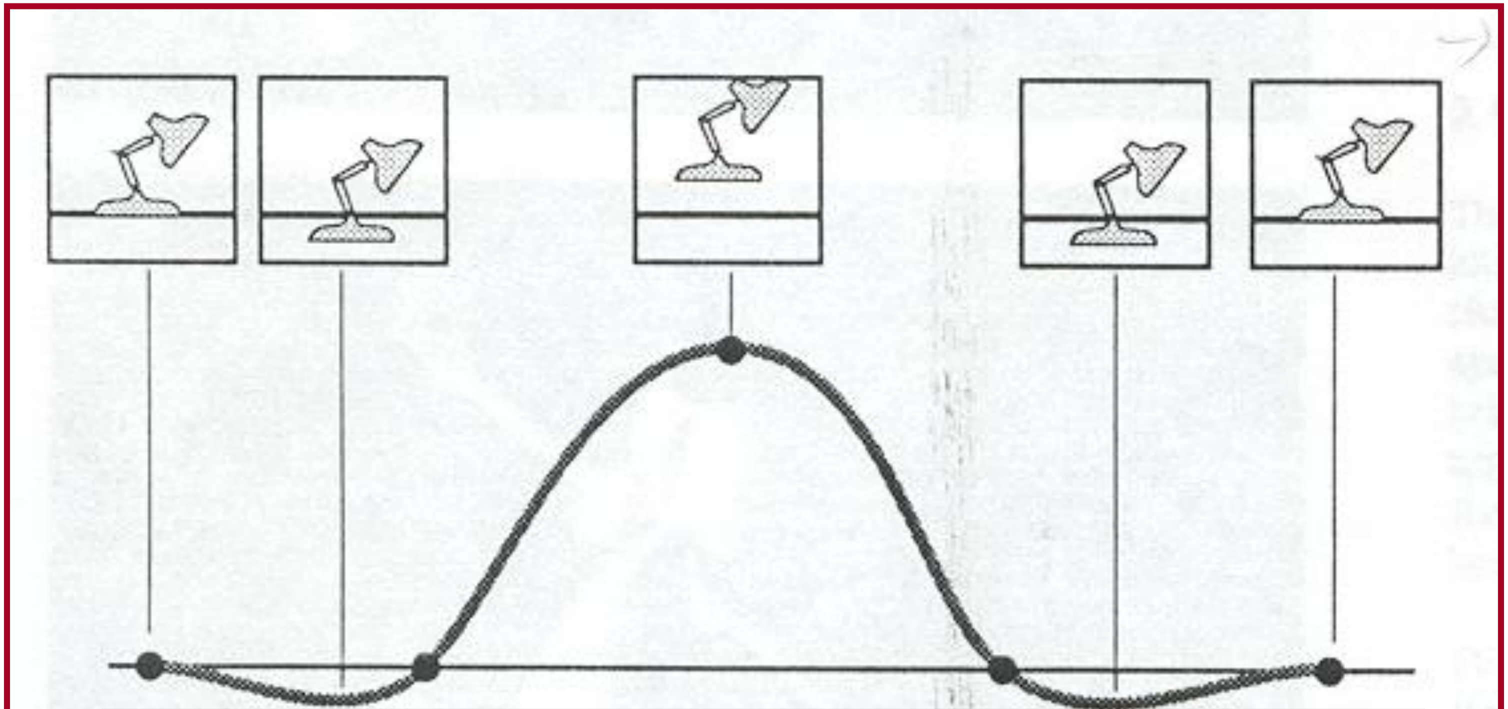


Can use your favorite spline to blend (assuming it satisfies required conditions, smoothness/convex-hull-containment/etc.)

Keyframe Animation

<u>Note</u>:

If you don't choose the "right" spline for blending, you may get problematic results.



Recall: Convex hull containment

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Keyframe Animation

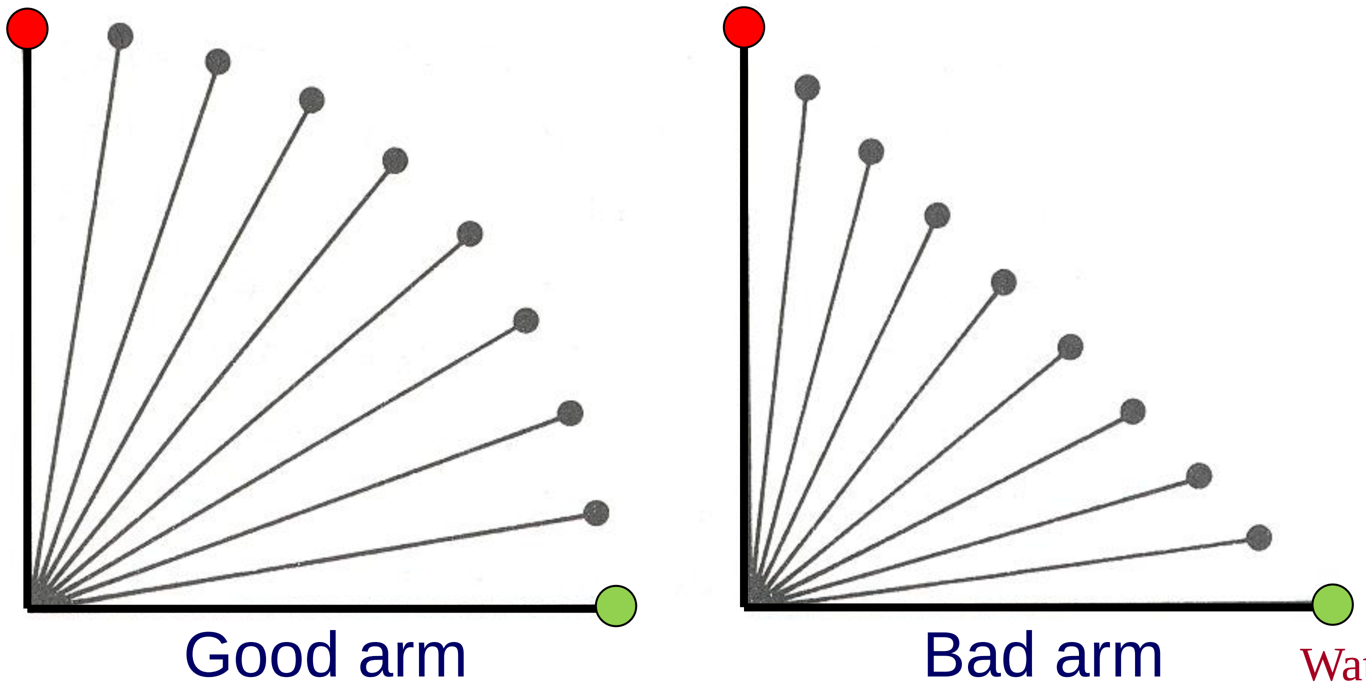
Q: Why interpolate/blend joint parameters instead of interpolating/blending vertices directly?

A: For translations, it doesn't make a difference (assuming the blend is translation equivariant).

Keyframe Animation

Q: Why interpolate/blend joint parameters instead of interpolating/blending vertices directly?

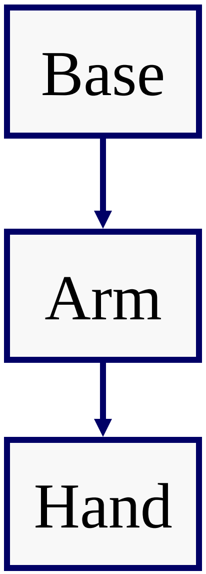
A: For rotations, it could lead to geometric distortion.



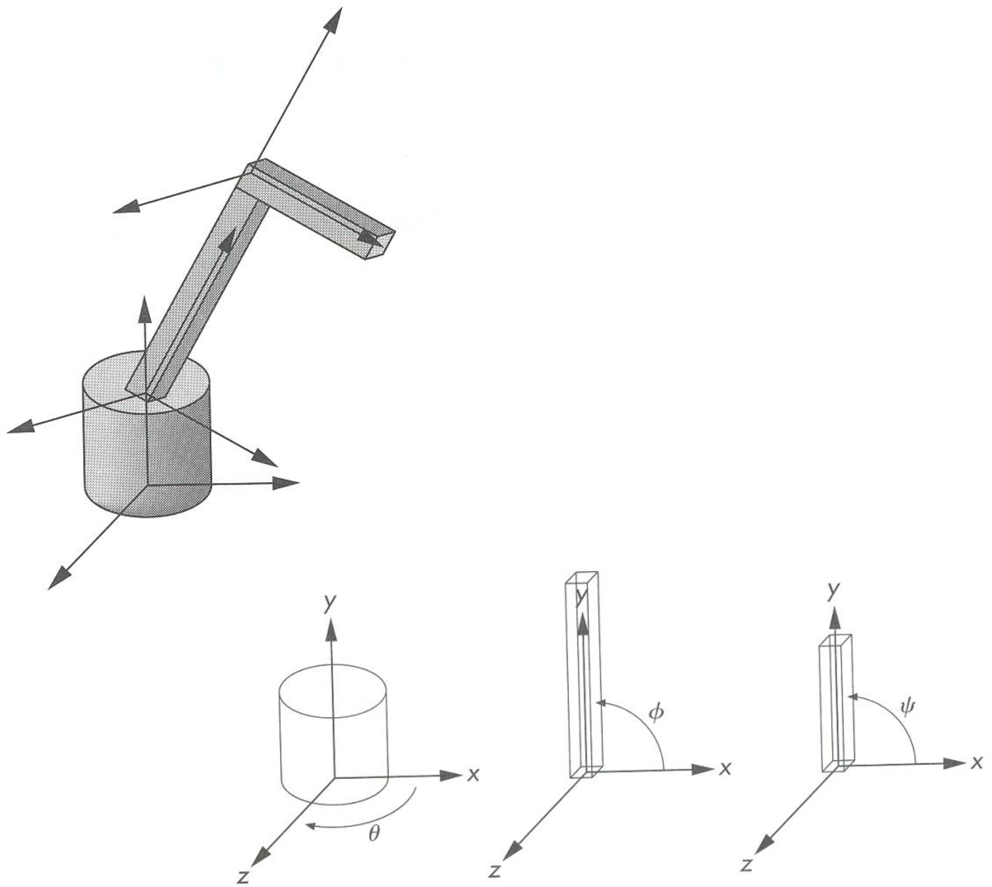
Watt & Watt

Articulated Figures

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



Scene Graph



Angel Figures 8.8 & 8.9

Articulated Figures

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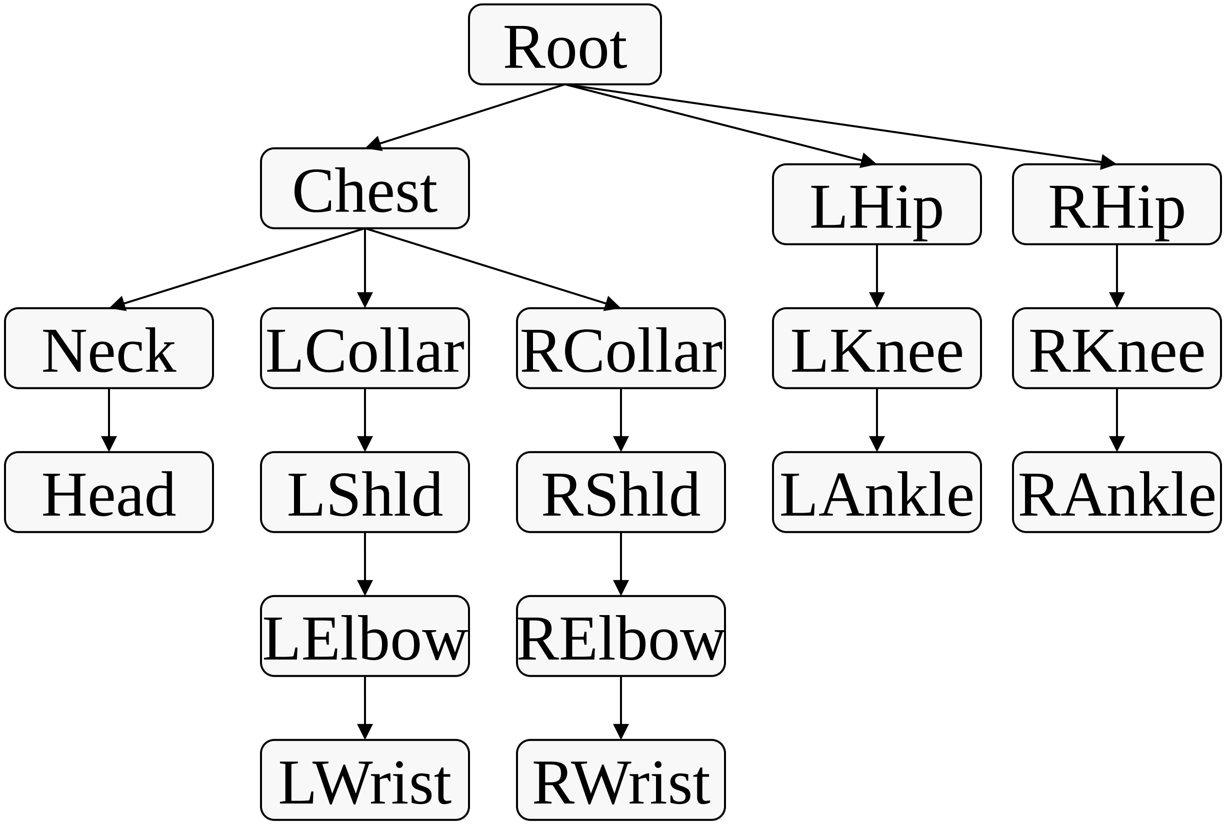
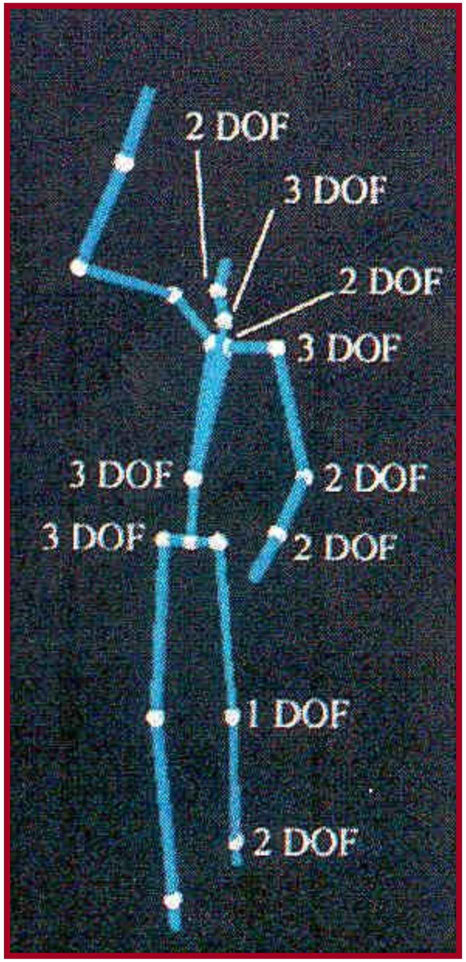
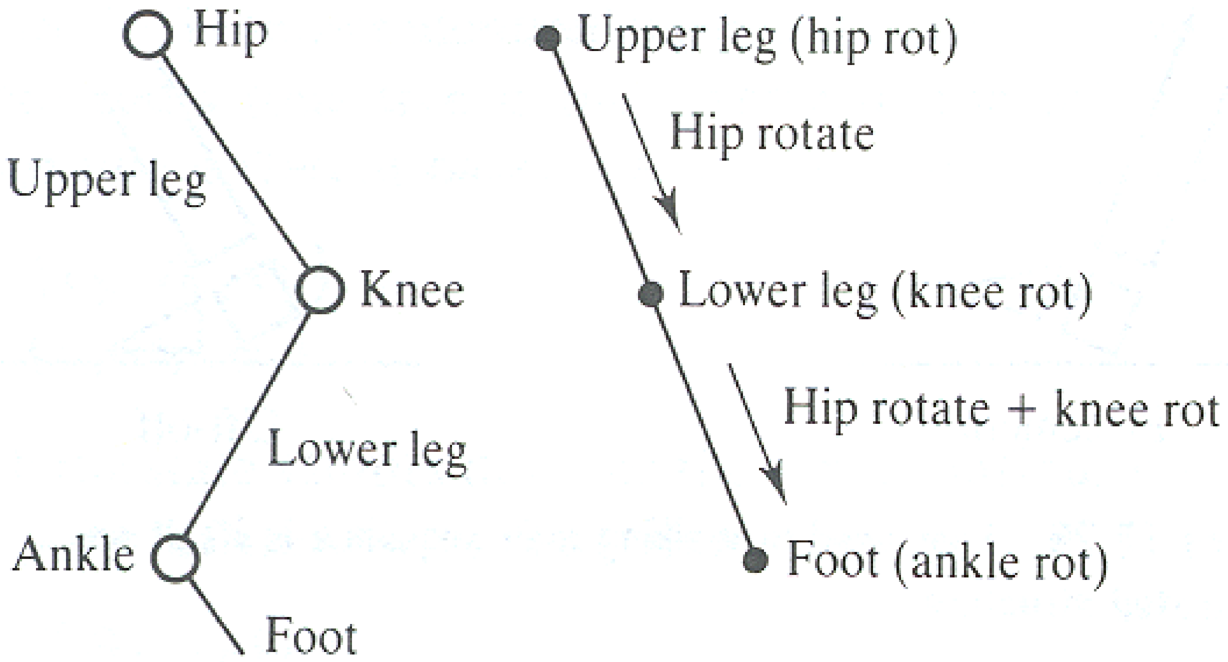




Rose et al. `96

Example: Walk Cycle

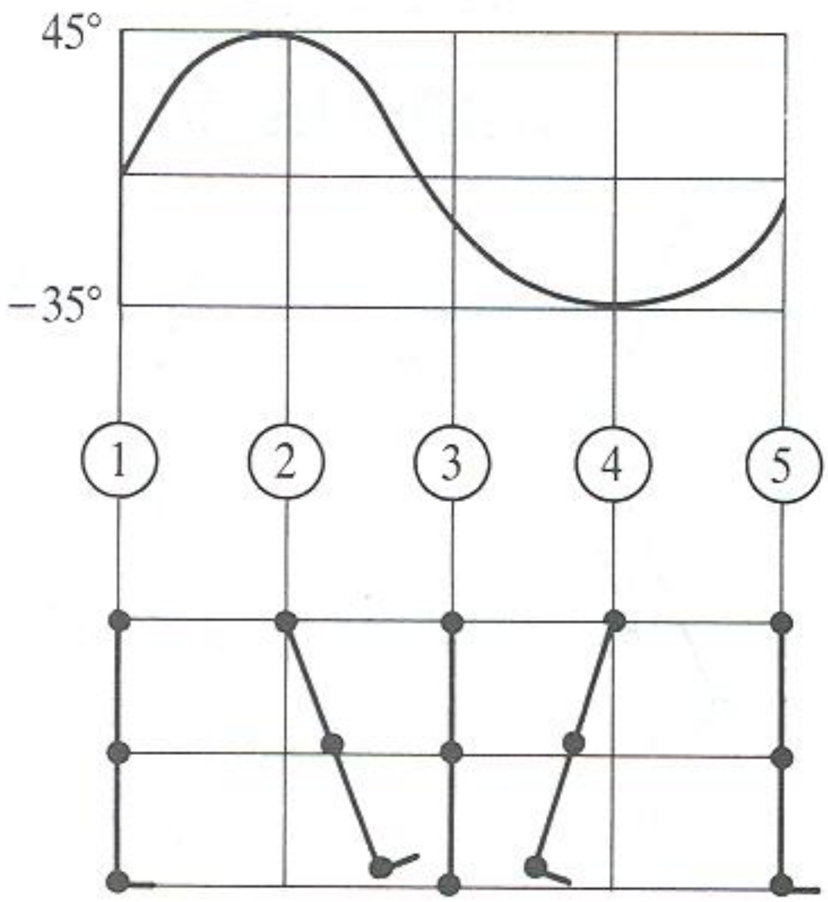
- Articulated figure:



Watt & Watt

Example: Walk Cycle

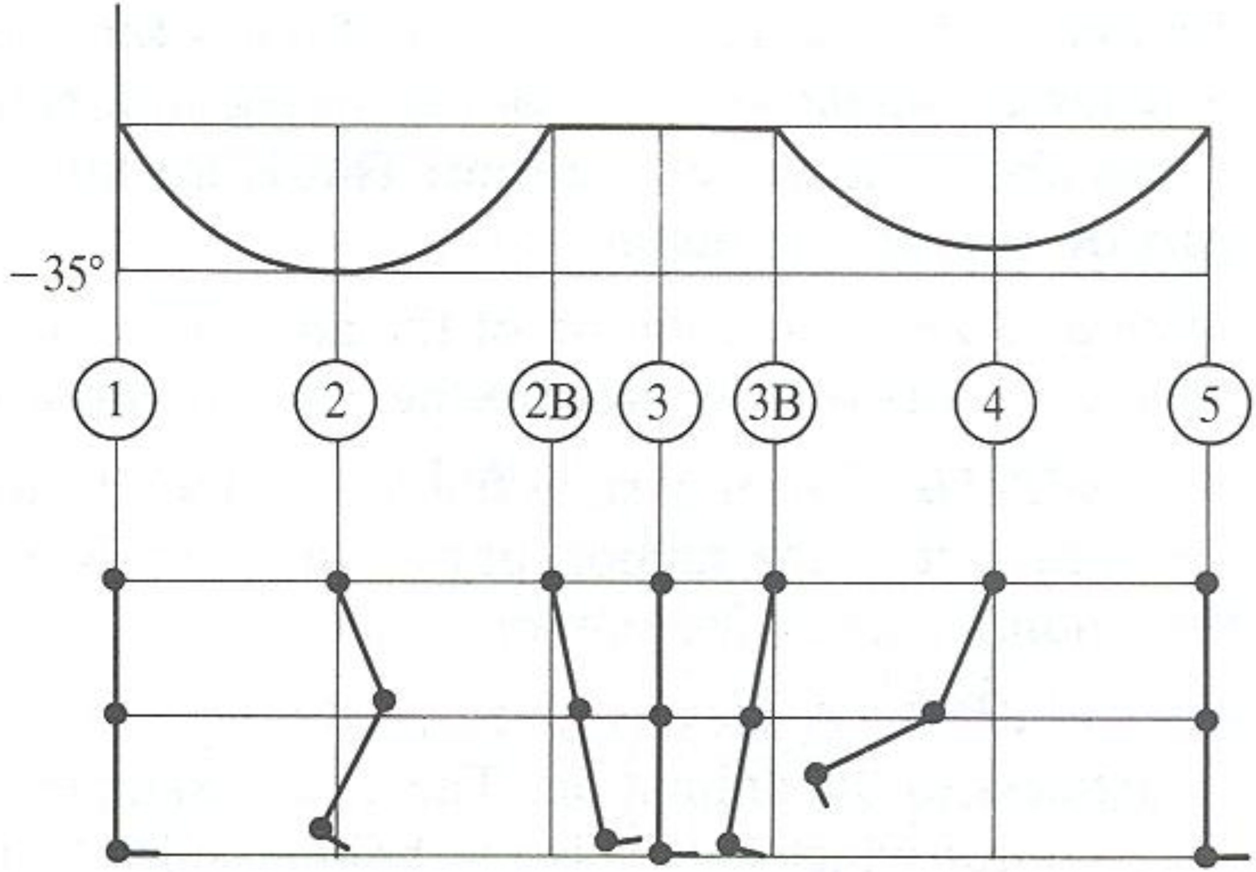
- Hip joint orientation:



Watt & Watt

Example: Walk Cycle

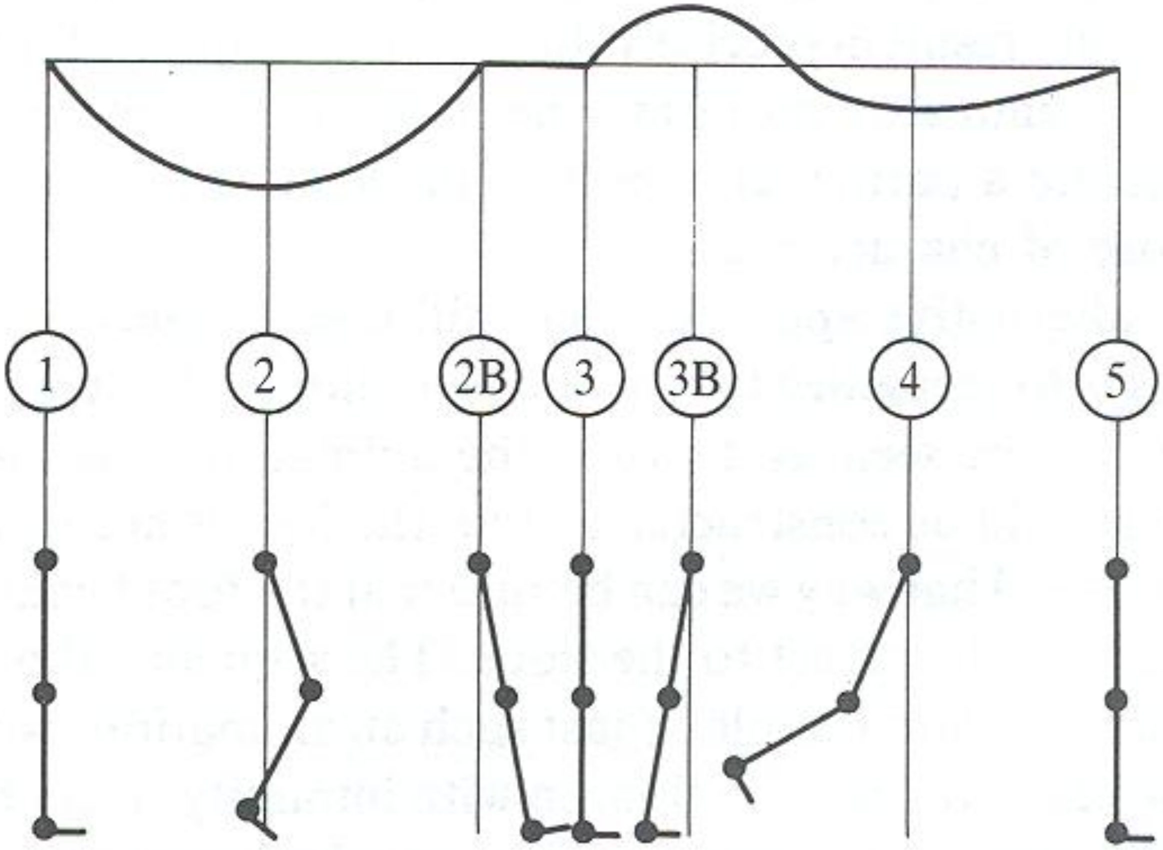
- Knee joint orientation:



Watt & Watt

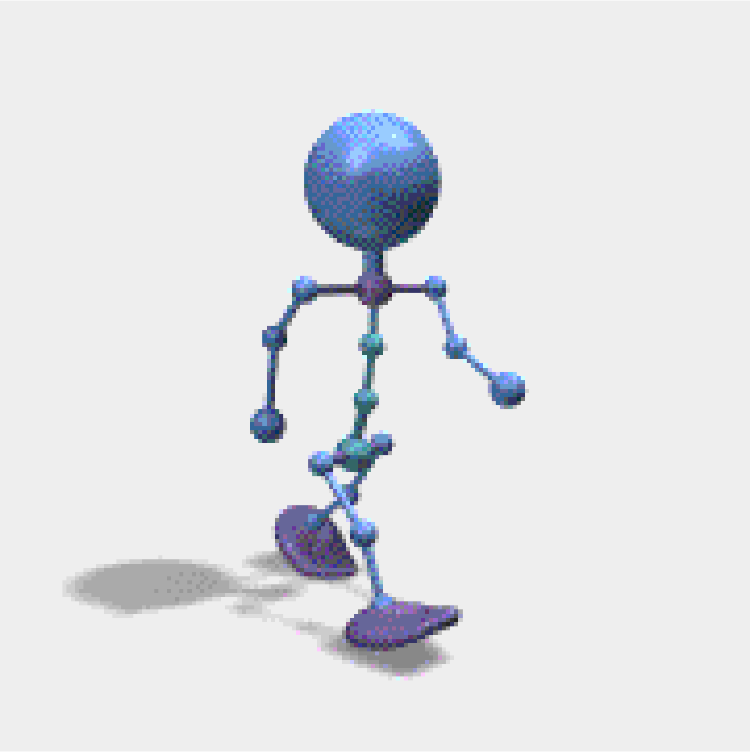
Example: Walk Cycle

- Ankle joint orientation:



Watt & Watt

Example: Walk Cycle



http://www.ischool.utexas.edu/~luna73/architecture/

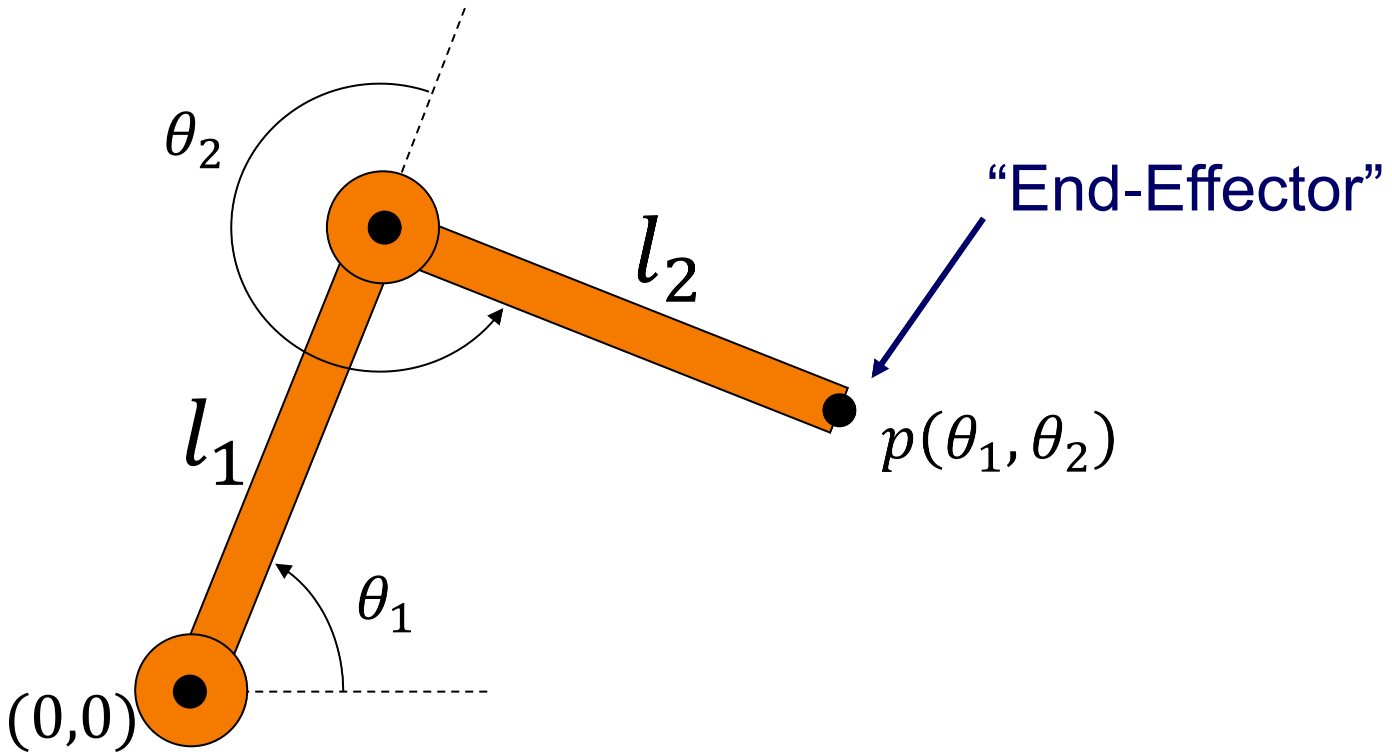
Will discuss the <u>how</u> of blending joint parameters next time.

Kinematics and Dynamics

- Kinematics: *Study of motion w/o regard for the cause*
  - Considers only motion
  - Determined by positions, velocities, accelerations
- Dynamics: *Study of the cause of motion*
  - Considers underlying forces and interactions
  - Compute motion from initial conditions and physics

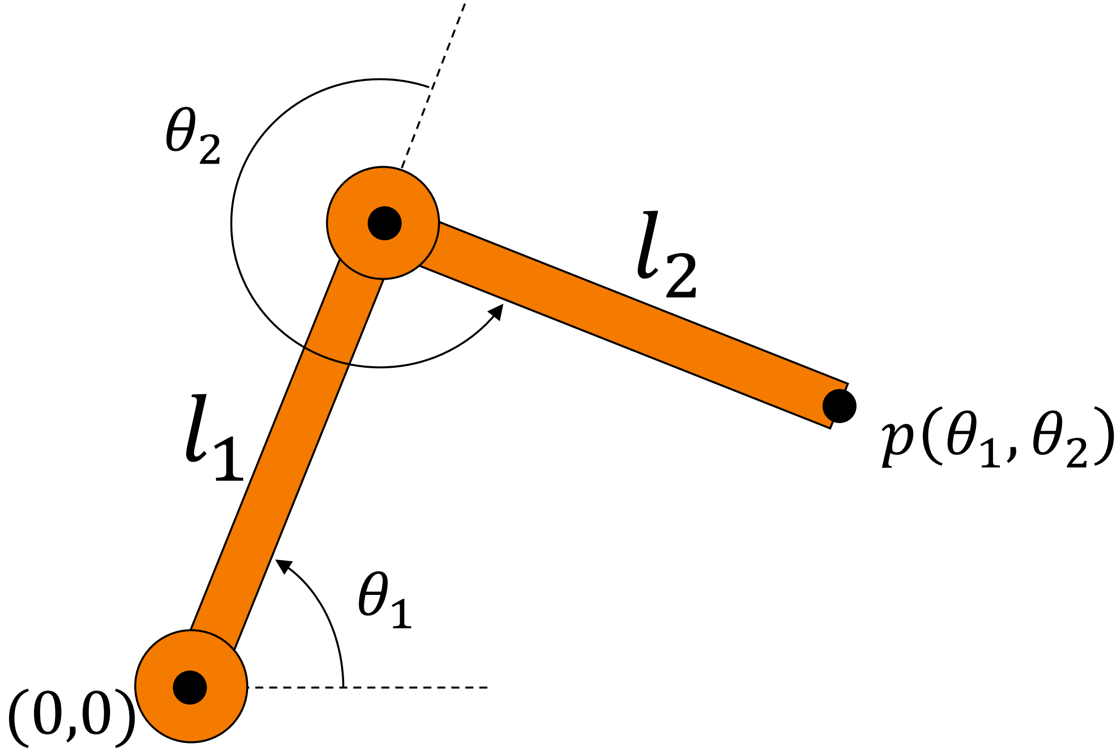
Example: 2-Link Structure

- Two links connected by rotational joints



Forward Kinematics

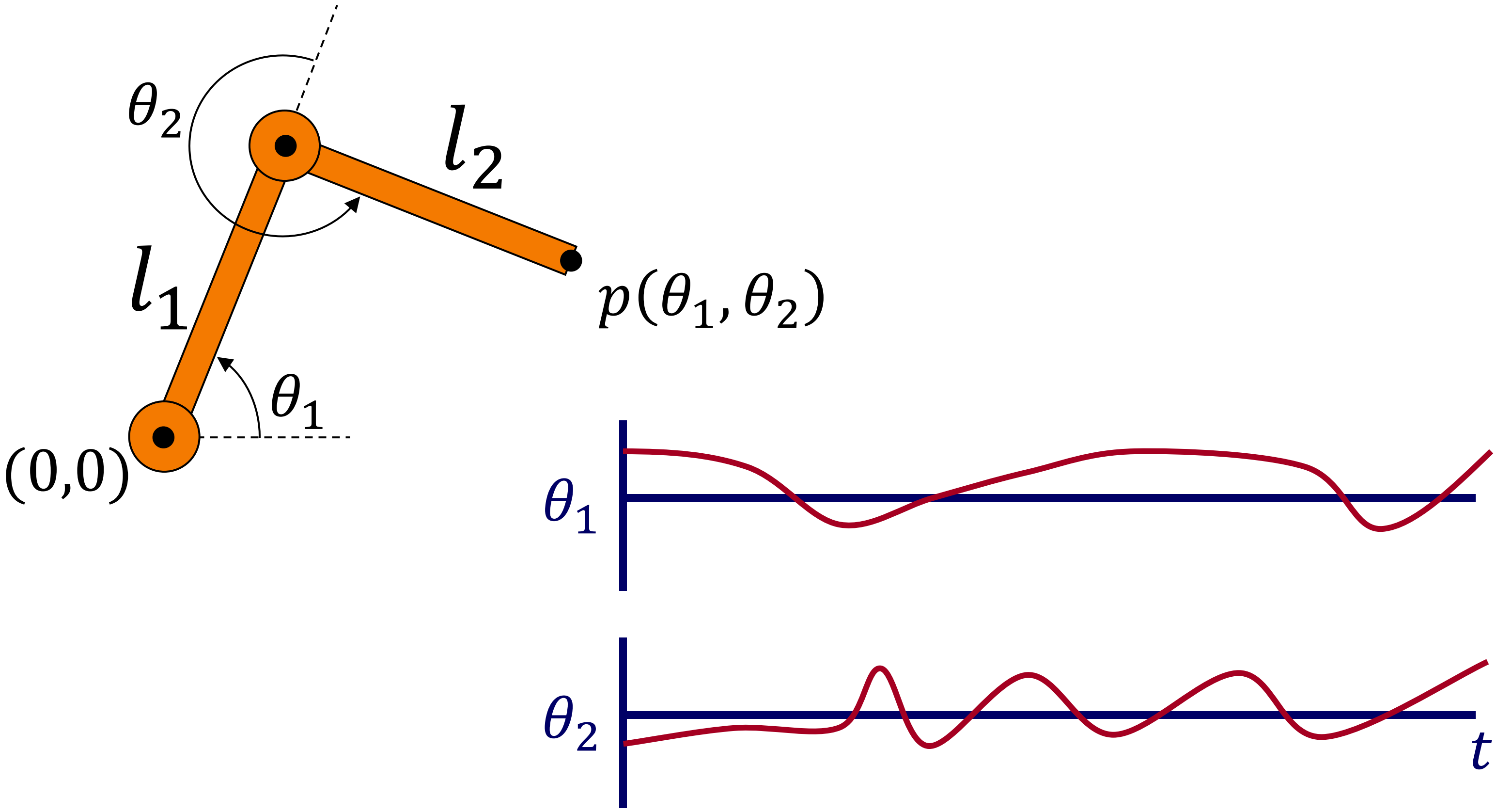
- Animator specifies joint angles: θ_1 and θ_2
- Computer finds positions of end-effector: $p(\theta_1, \theta_2)$



$$p(\theta_1, \theta_2) = (l_1 \cos\theta_1 + l_2(\cos(\theta_1 + \theta_2)\,, l_1 \sin\theta_1 + l_2 \sin(\theta_1 + \theta_2))$$

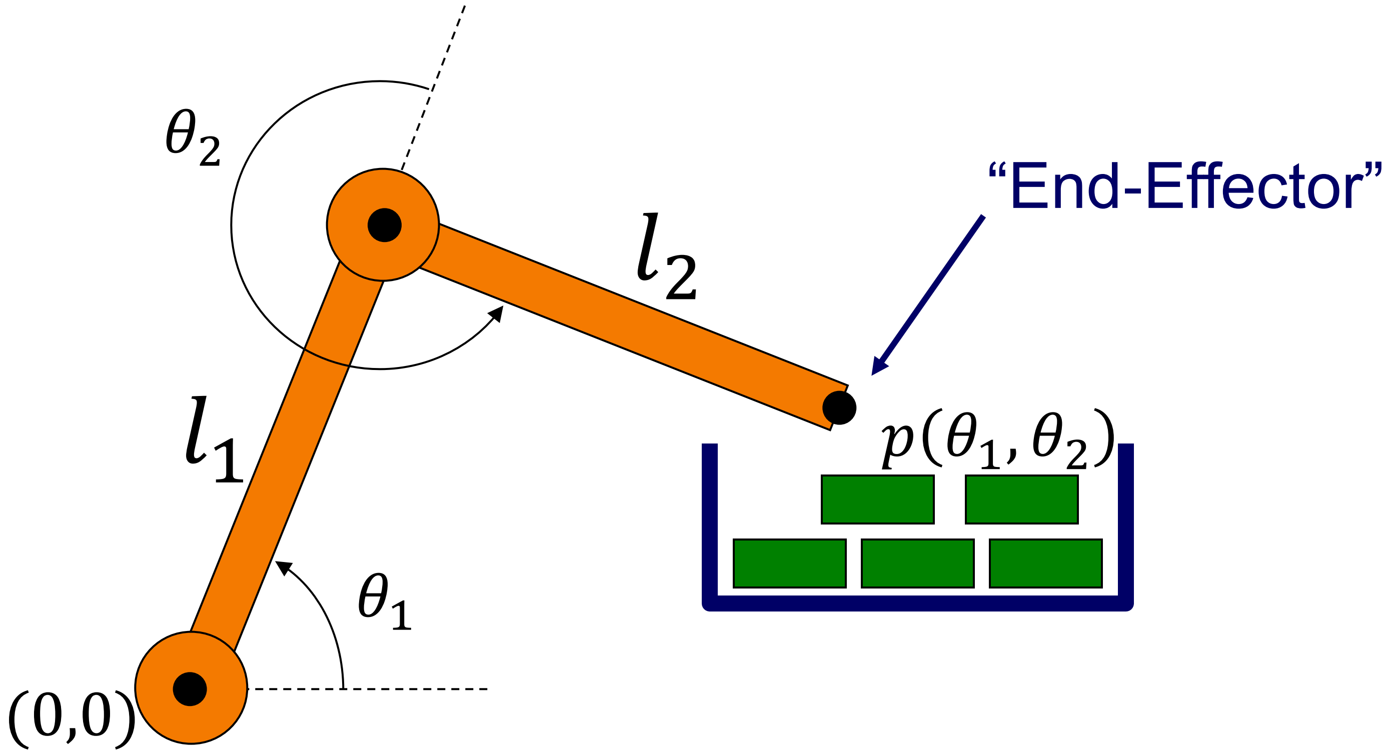
Forward Kinematics

- Joint motions can be specified by spline curves



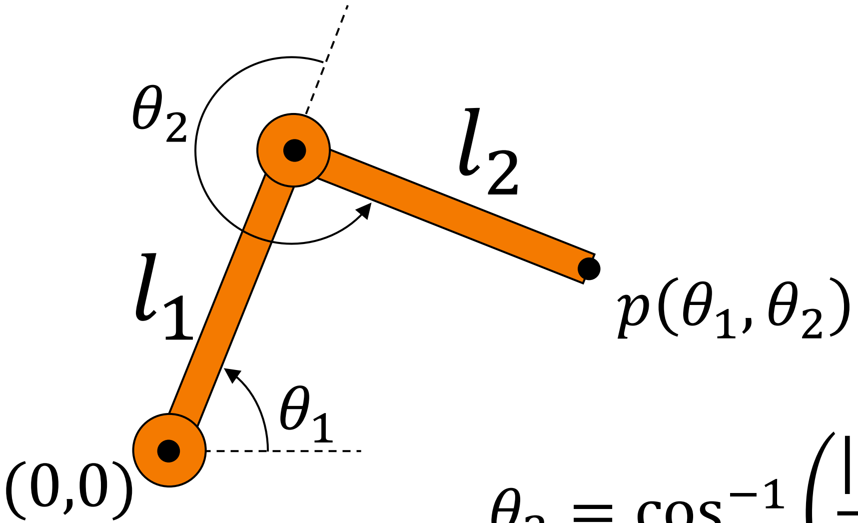
Example: 2-Link Structure

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



Inverse Kinematics

- Animator specifies end-effector positions: p
- Computer finds joint angles: θ_1 and θ_2

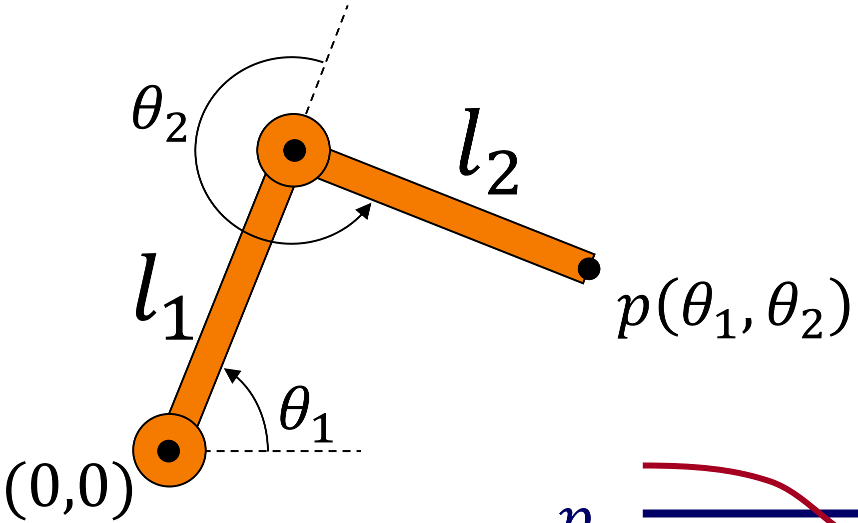


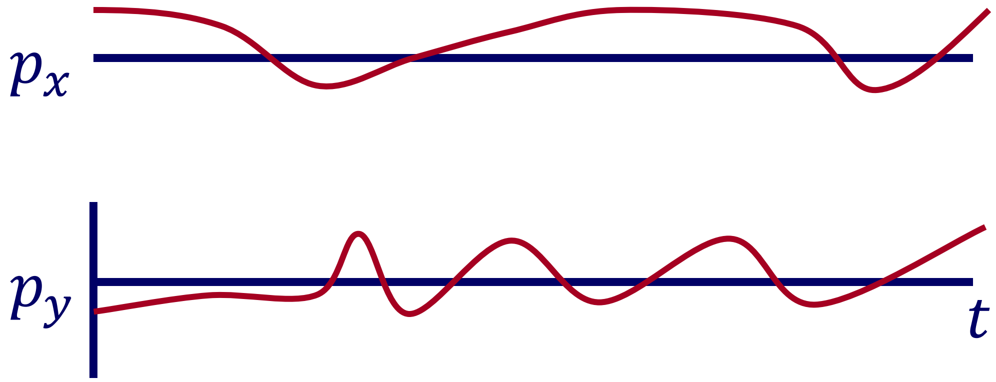
$$\theta_2 = \cos^{-1}\left(\frac{|p|^2 - l_1^2 - l_2^2}{2 l_1 l_2}\right)$$

$$\theta_1 = \tan^{-1}\left(\frac{p_y}{p_x}\right) - \tan^{-1}\left(\frac{l_2 \sin\theta_2}{l_1 + l_2 \cos\theta_2}\right)$$

Inverse Kinematics

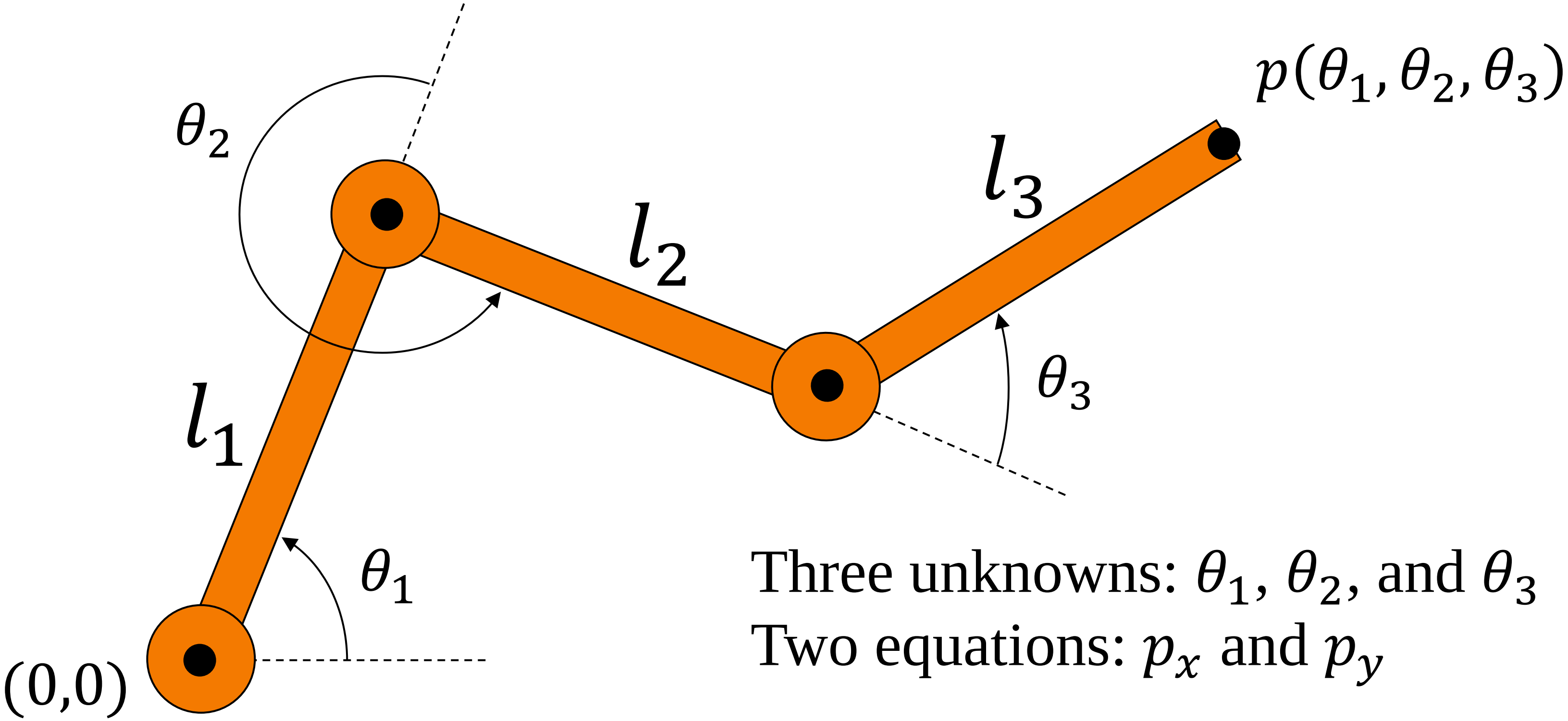
- End-effector postions can be specified by splines





Inverse Kinematics

- Challenges for more complex structures
  - Not guaranteed to have one solution
    - » May be able to find best/closest solution
  - System can be non-linear (i.e. hard to solve)



Three unknowns: θ_1, θ_2, and θ_3
Two equations: p_x and p_y

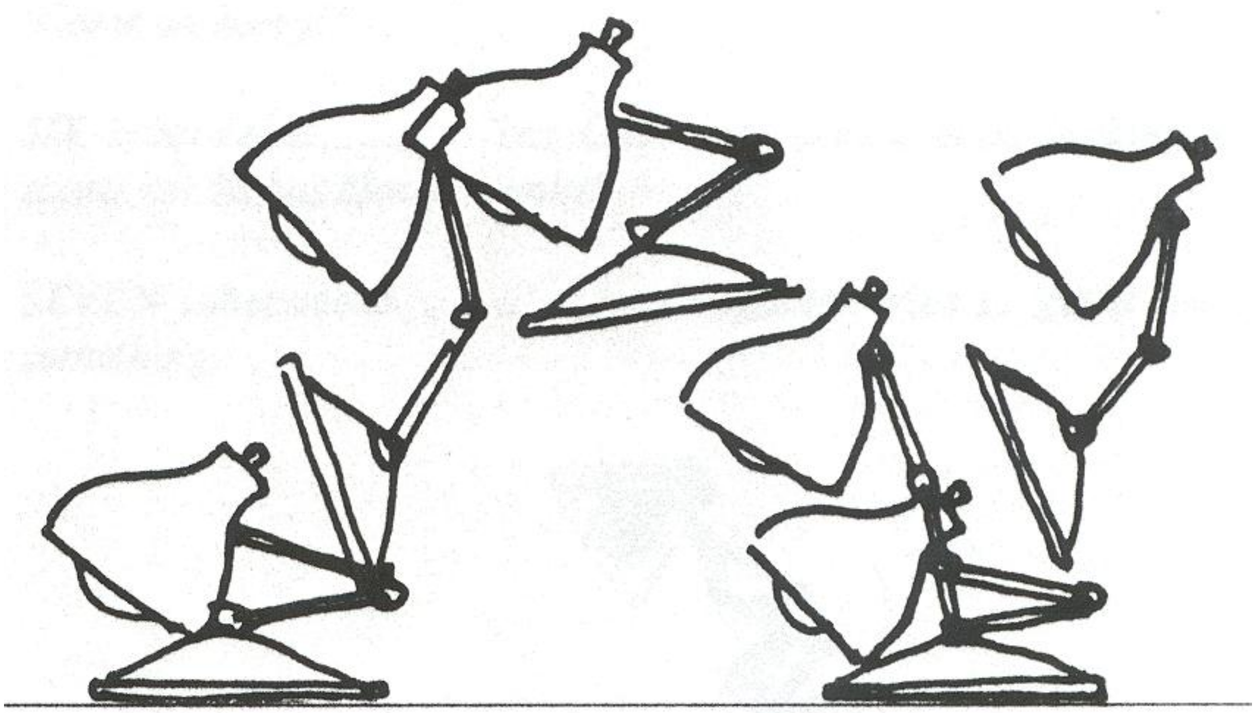
Summary of Kinematics

- 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

Dynamics

- Simulate physics to obtain motion that is responsive / realistic



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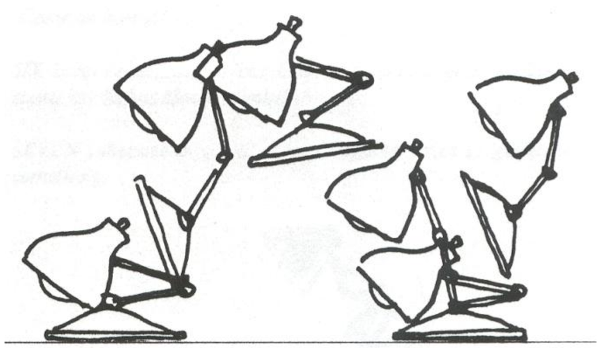
Dynamics

- 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



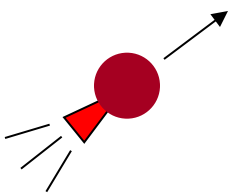
Dynamics

Computer finds the "best" physical motion satisfying the constraints (e.g. by minimizing some objective)

Example: particle with jet propulsion

- $\mathbf{x}(t)$ is position of particle at time t
- $\mathbf{f}(t)$ is the directional force of jet propulsion at time t
- Particle's equation of motion is:

$$0 = m(\ddot{\mathbf{x}} - \mathbf{g}) - \mathbf{f}$$



- In a unit of time, move from $\mathbf{a}$ to $\mathbf{b}$ minimizing

$$E(\mathbf{x}) = \int_0^1 \|\mathbf{f}(t)\|^2 dt = \int_0^1 \|m(\ddot{\mathbf{x}} - \mathbf{g})(t)\|^2 dt$$

$$\dot{\mathbf{x}} = \frac{\partial \mathbf{x}}{\partial t}$$

$$\ddot{\mathbf{x}} = \frac{\partial^2 \mathbf{x}}{\partial t^2}$$

Such that:

$$\mathbf{x}(0) = \mathbf{a},\ \dot{\mathbf{x}}(0) = \mathbf{0},\ \mathbf{x}(1) = \mathbf{b}, \text{ and } \dot{\mathbf{x}}(1) = \mathbf{0}$$

Dynamics

Turn into a discrete problem by partitioning time into N uniform intervals (of size $h=\frac{1}{N}$) giving discrete positions $\{\mathbf{x}_0,\cdots,\mathbf{x}_N\}$, with $\mathbf{x}_i=\mathbf{x}(i\cdot h)$:

$$\dot{\mathbf{x}}_i=\frac{\mathbf{x}_i-\mathbf{x}_{i-1}}{h}$$

$$\ddot{\mathbf{x}}_i=\frac{\dot{\mathbf{x}}_{i+1}-\dot{\mathbf{x}}_i}{h}=\frac{\mathbf{x}_{i+1}-2\mathbf{x}_i+\mathbf{x}_{i-1}}{h^2}$$

$$\mathbf{f}_i=m(\ddot{\mathbf{x}}_i-\mathbf{g})=m\left(\frac{\mathbf{x}_{i+1}-2\mathbf{x}_i+\mathbf{x}_{i-1}}{h^2}-\mathbf{g}\right)$$

Dynamics

Turn into a discrete problem…

$$\mathbf{f}_i = m\left(\frac{\mathbf{x}_{i+1} - 2\mathbf{x}_i + \mathbf{x}_{i-1}}{h^2} - \mathbf{g}\right)$$

Optimization ⇒ minimizing a quadratic energy:

$$\begin{aligned} E(\mathbf{x}) &= \int_0^1 \|m(\ddot{\mathbf{x}} - \mathbf{g})\|^2 dt \\ &\approx h \sum_i \|m(\ddot{\mathbf{x}}_i - \mathbf{g})\|^2 \\ &= hm^2 \sum_i \left\|\frac{\mathbf{x}_{i+1} - 2\mathbf{x}_i + \mathbf{x}_{i-1}}{h^2} - \mathbf{g}\right\|^2 \end{aligned}$$

subject to $\mathbf{x}_{-1} = \mathbf{x}_0 = \mathbf{a}$ and $\mathbf{x}_N = \mathbf{x}_{N+1} = \mathbf{b}$.

Dynamics

Turn into a discrete problem…

$$\mathbf{f}_i = m\left(\frac{\mathbf{x}_{i+1} - 2\mathbf{x}_i + \mathbf{x}_{i-1}}{h^2} - \mathbf{g}\right)$$

Optimization ⇒ minimizing a quadratic energy:

$$E(\mathbf{x}) = \int_0^1 \|m(\ddot{\mathbf{x}} - \mathbf{g})\|^2 dt$$

$$\approx h \sum_i \|m(\ddot{\mathbf{x}}_i - \mathbf{g})\|^2$$

$$\approx hm^2 \sum \left\| \mathbf{x}_{i+1} - 2\mathbf{x}_i + \mathbf{x}_{i-1} \quad \ldots \right\|^2$$

To minimize, need to find where the gradient is zero. Since the energy is quadratic, the gradient is linear.

Reduces to solving a *linear* system of equations.

Dynamics

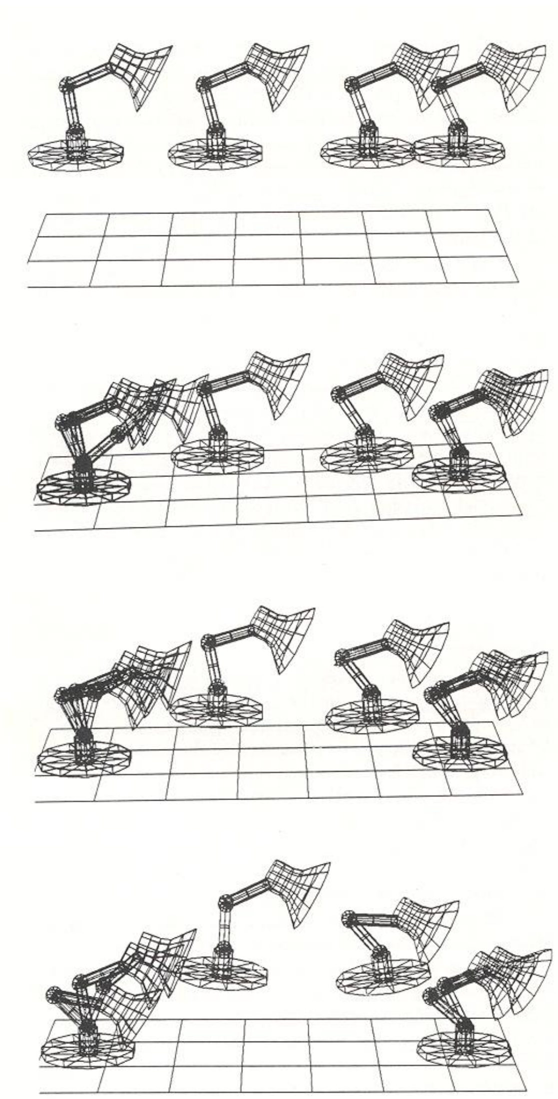
For simple scenarios:

- Solve a linear system

$$\mathbf{Ax} = \mathbf{b}$$

For complex scenarios:

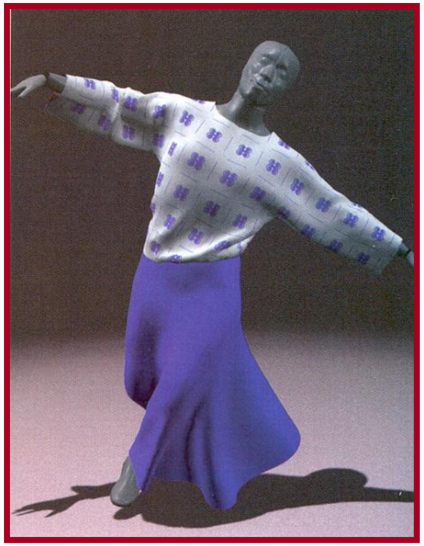
- Solve using iterative optimization techniques



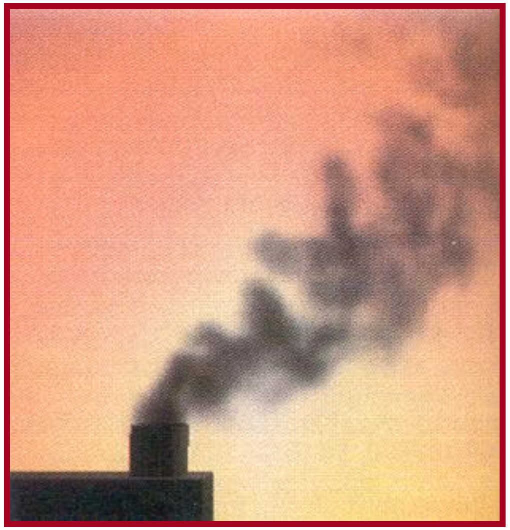
Witkin & Kass `88

Dynamics

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



Cloth
(Baraff & Witkin `98)



Hot Gases
(Foster & Metaxas `97)

Demo

Dynamics

- 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