

Computer Animation

Misha 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*



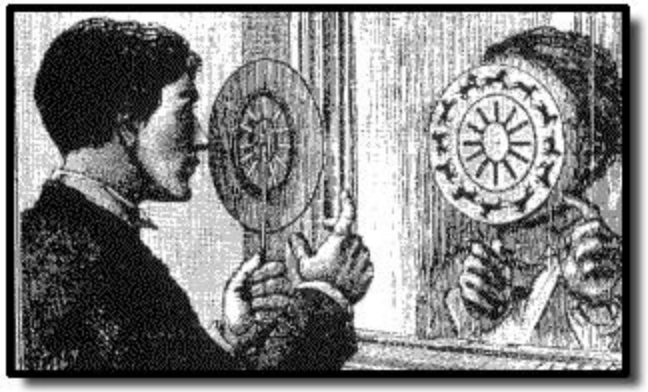
Phenakistoscope

Invented independently by 2 people in 1832

Disc mounted on spindle

Viewed through slots with images facing mirror

Turning disc animates images



Aliasing as a feature, not a bug

Phenakistoscope

Invented independently by 2 people in 1832

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Viewed through slots with images facing mirror

Turning disc animates images





Aliasing as a feature, not a bug

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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Slits cut in the upper half of the drum

Opposite side viewed as drum rapidly spun

Praxinoscope is a variation on this





Aliasing as a feature, not a bug

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**:

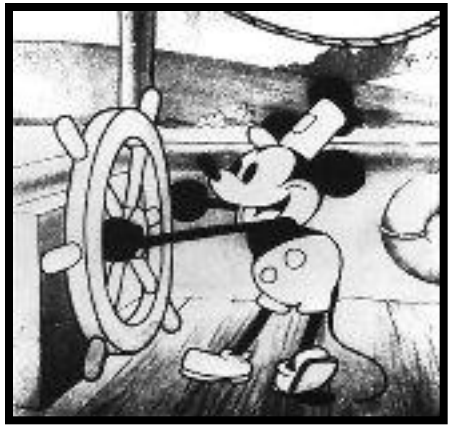
Humorous phases of funny faces (1906)

Key Developments

Plot

Creation of animation studios

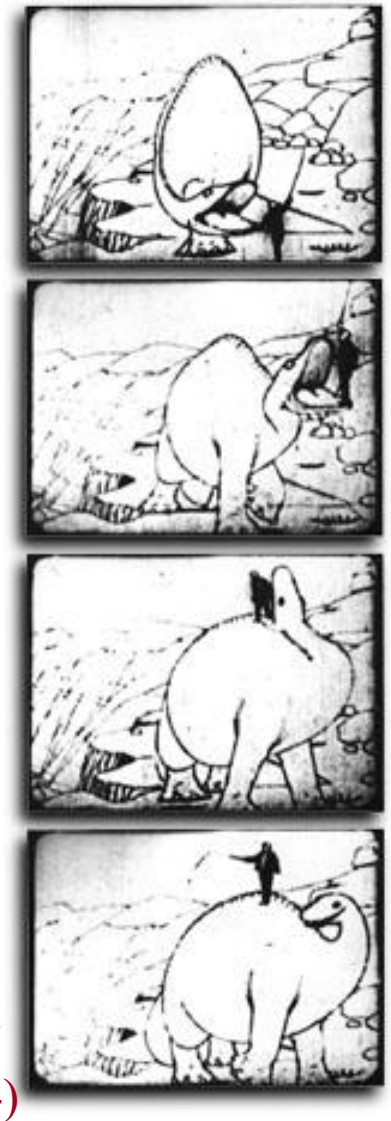
Inking on cels



"Steamboat Willie"
Walt Disney (1928)

"Felix the Cat"
Otto Messmer (1921)

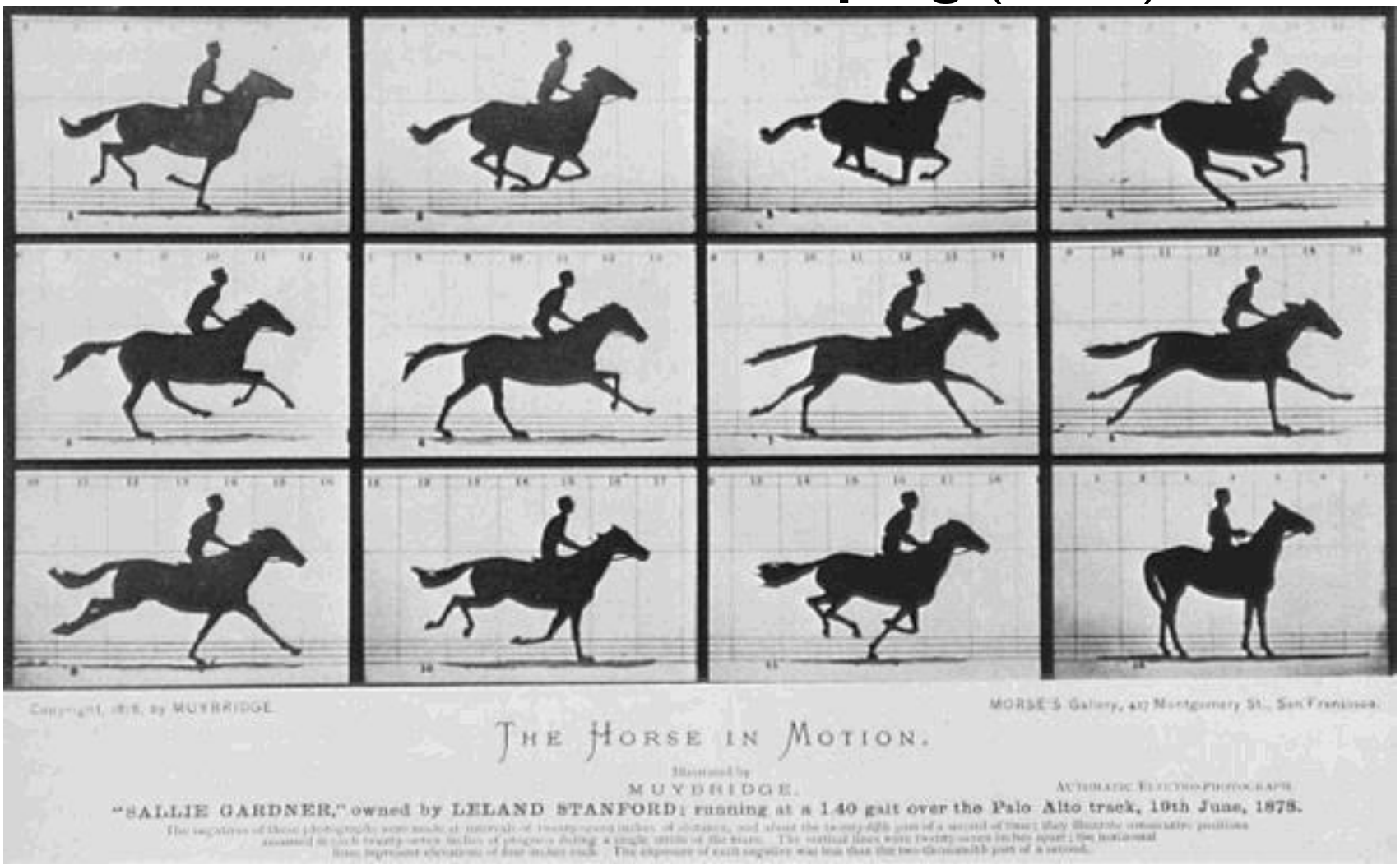




"Gertie the Dinosaur"
Windsor McCay (1914)

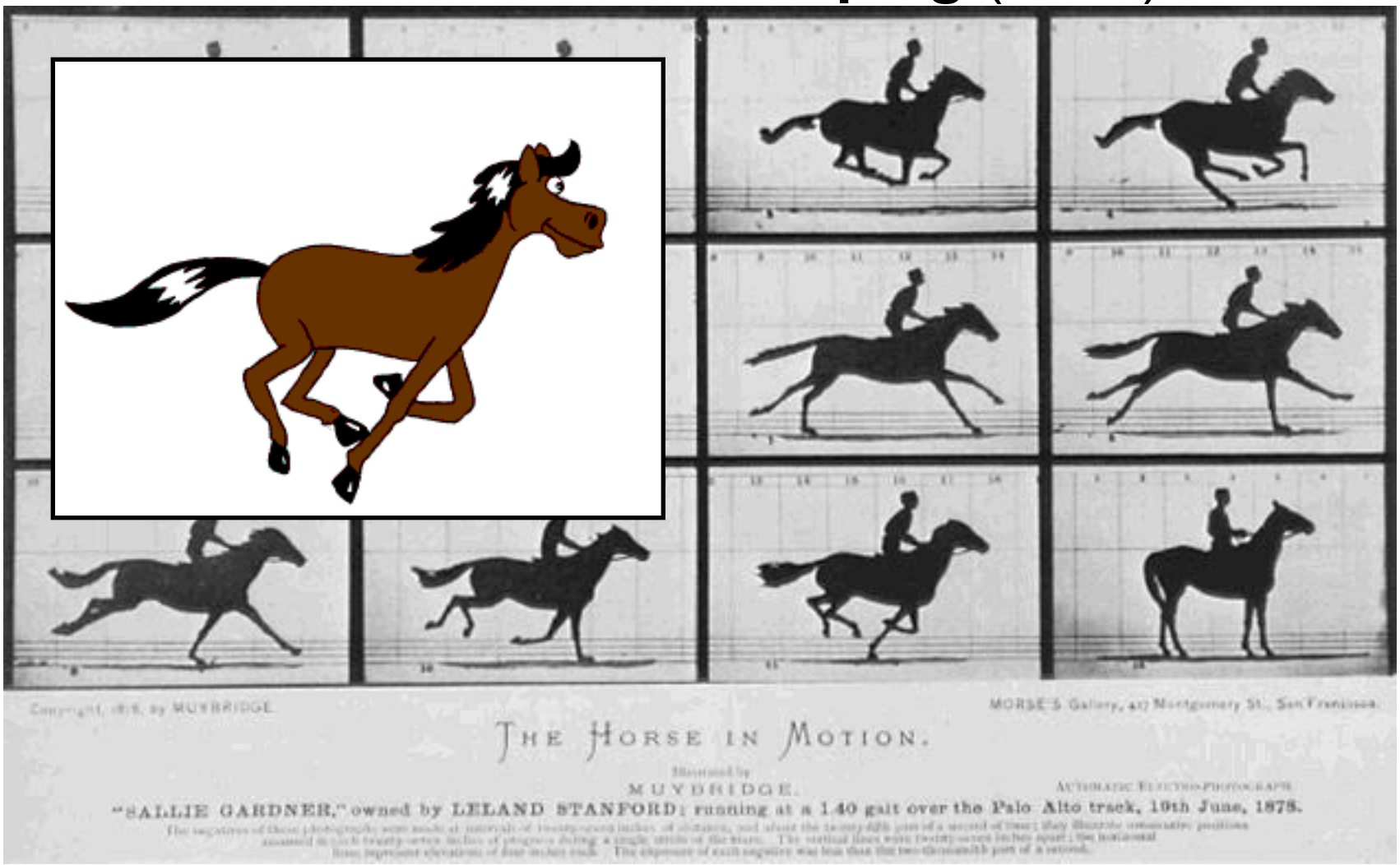
Key Developments

Max Fleischer invents **rotoscoping** (1921)



Key Developments

Max Fleischer invents **rotoscoping** (1921)



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.

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

Luxo Jr.

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

Overview



Some early animation history

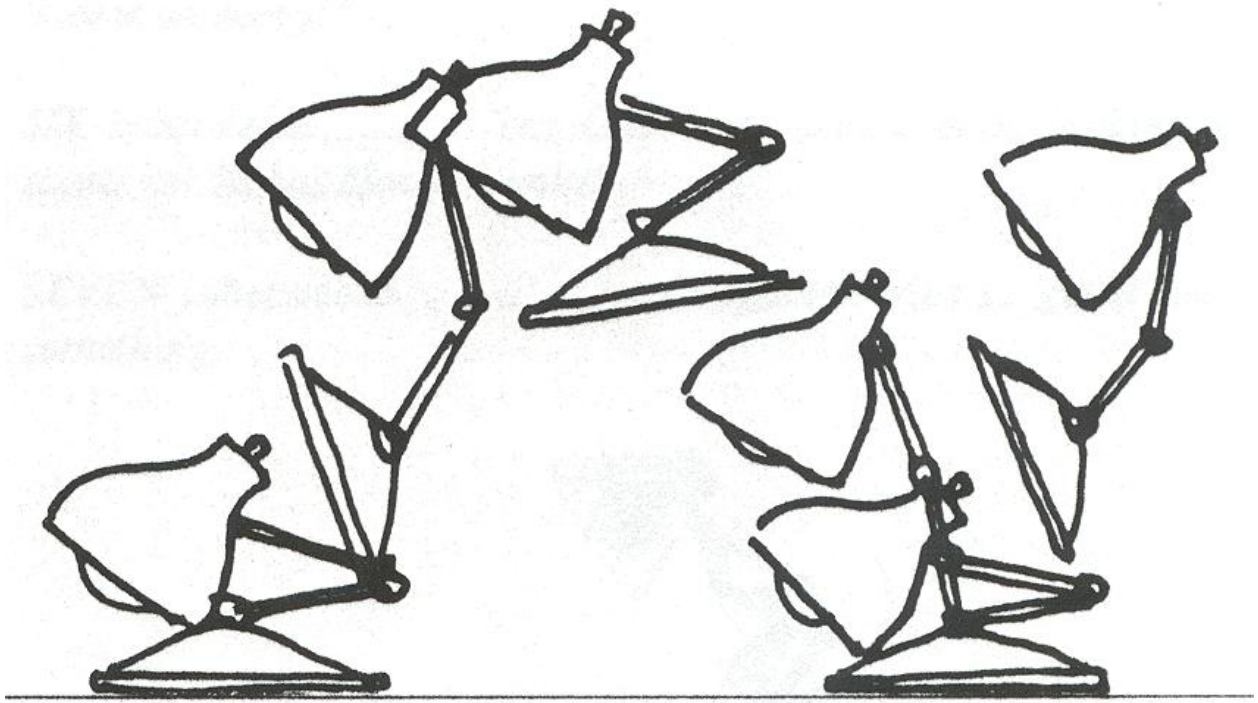
Computer animation

- Keyframe animation
- Articulated figures
- Kinematics and dynamics

Keyframe Animation



Define character poses at specific time steps called “keyframes”



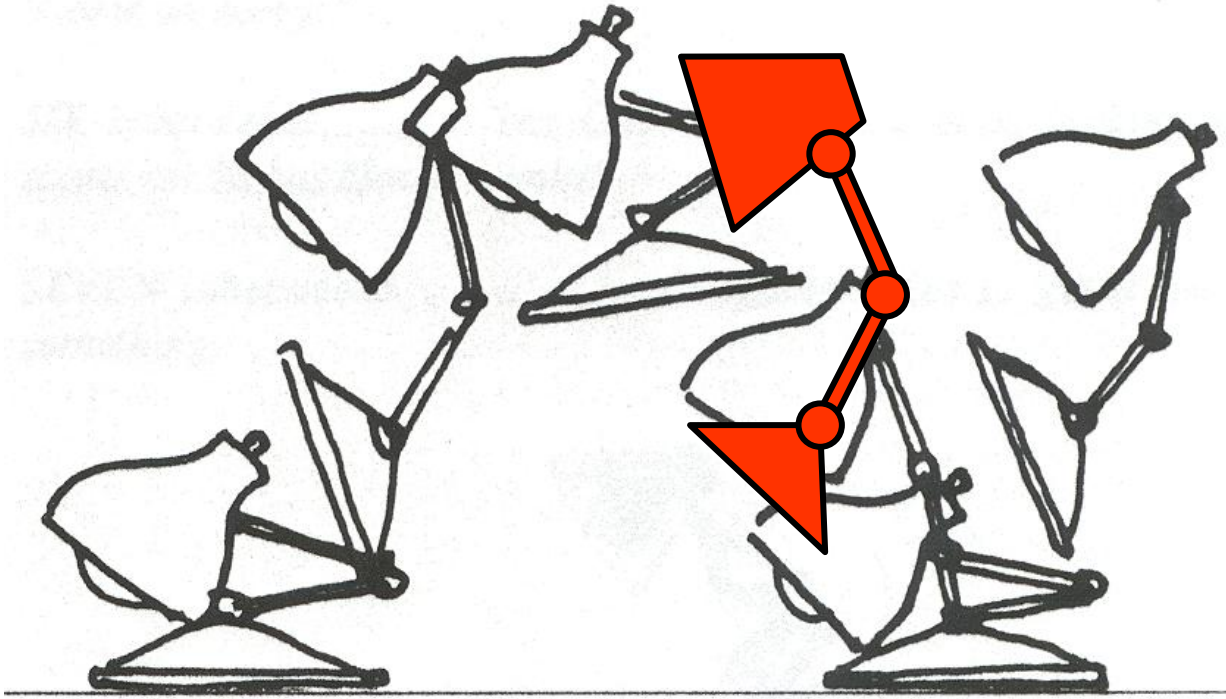
Lasseter `87

Keyframe Animation



Define character poses at specific time steps called “keyframes”

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



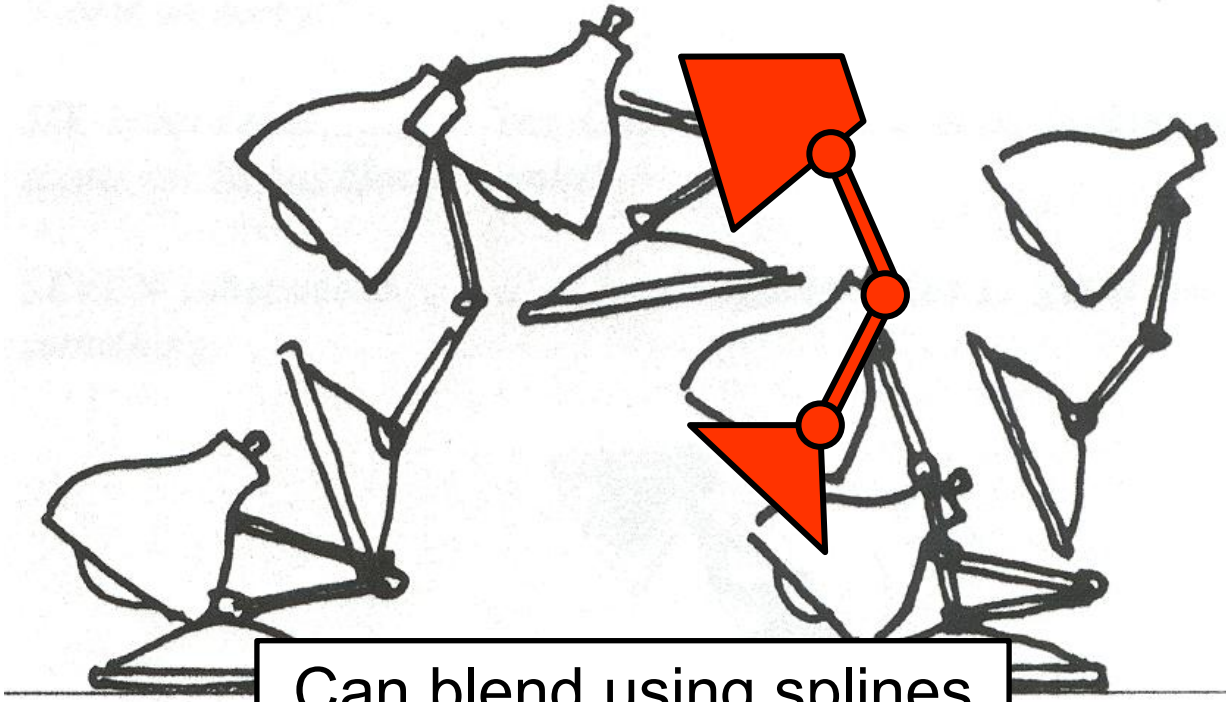
Lasseter `87

Keyframe Animation



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Lasseter `87

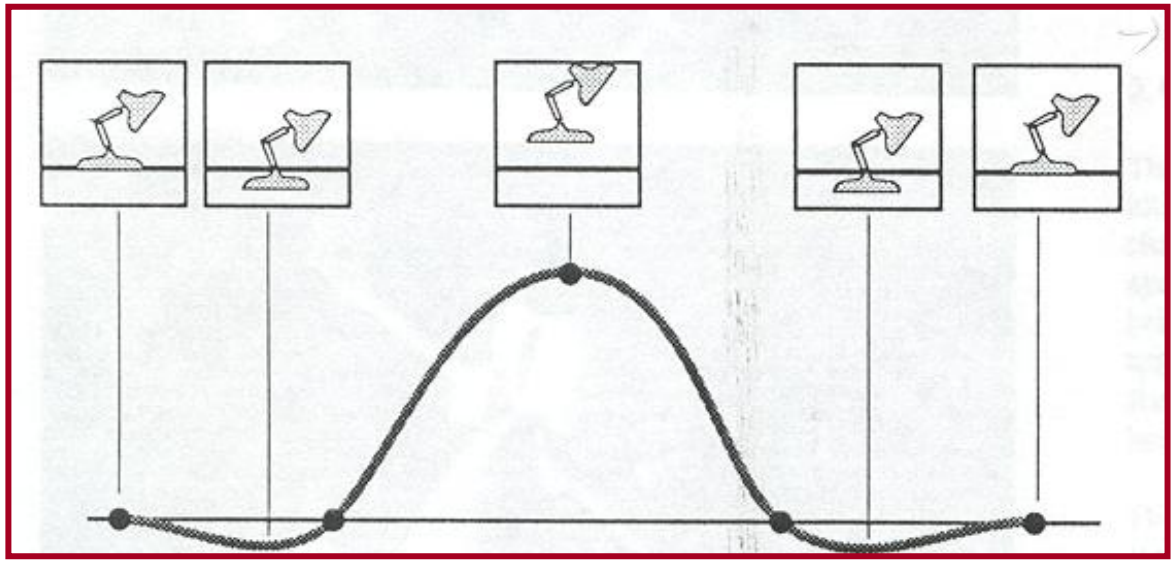
Can blend using splines

Keyframe Animation



Define character poses at specific time steps called “keyframes”

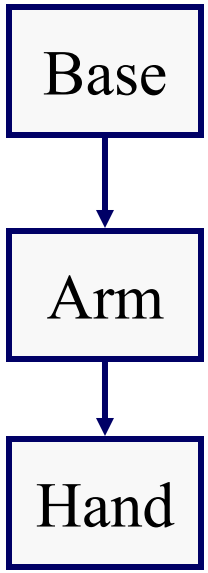
Interpolate/blend variables describing keyframes to determine poses for character “in-between”



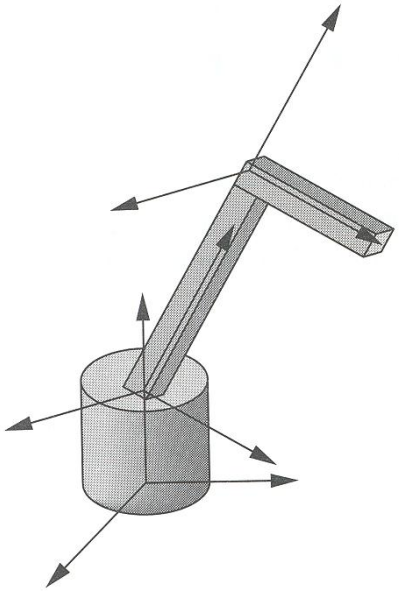
Choose a spline with the properties the application demands (e.g. convex hull containment)

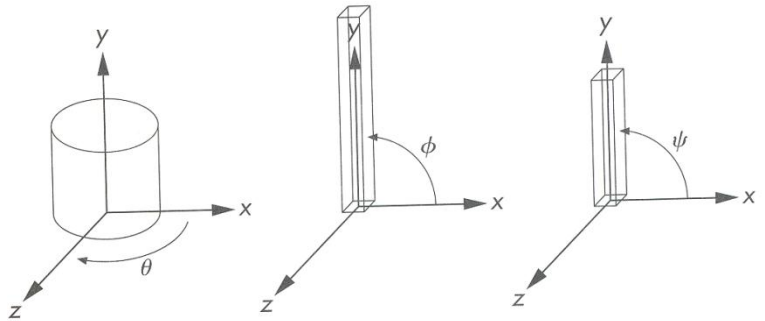
Articulated Figures

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



Scene Graph

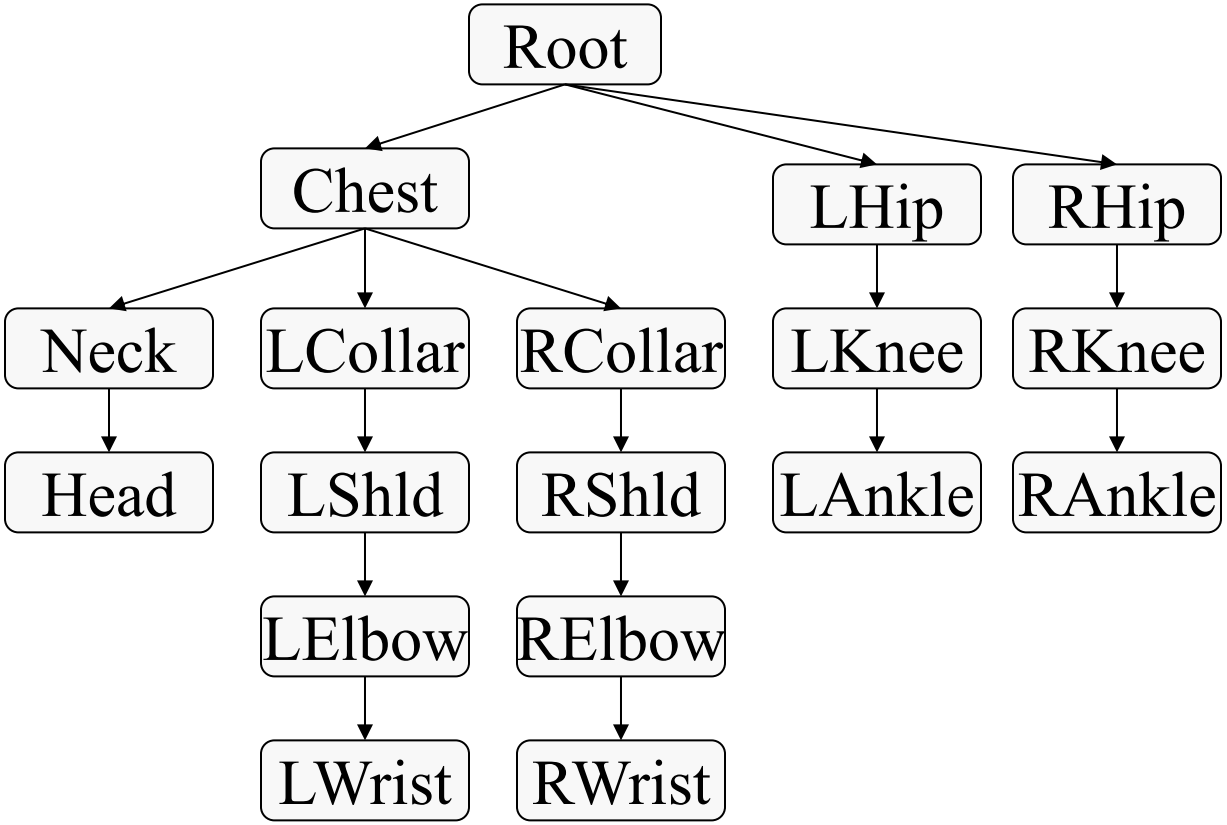


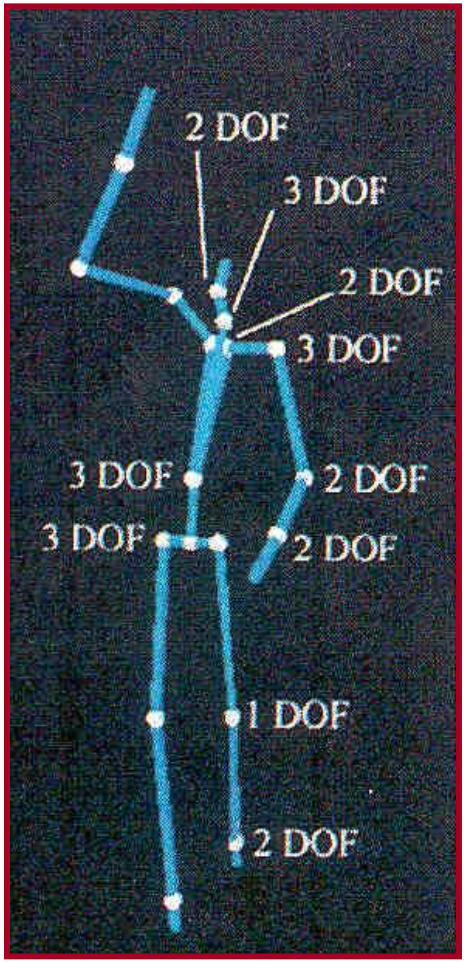


Angel Figures 8.8 & 8.9

Articulated Figures

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

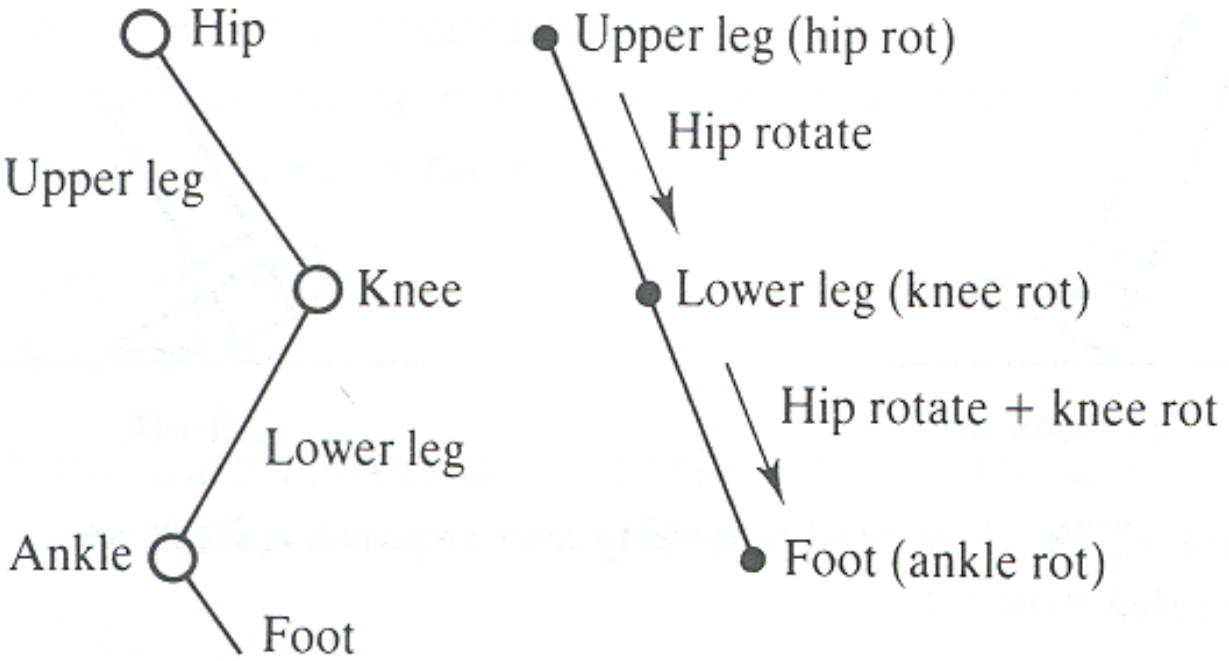




Rose et al. `96

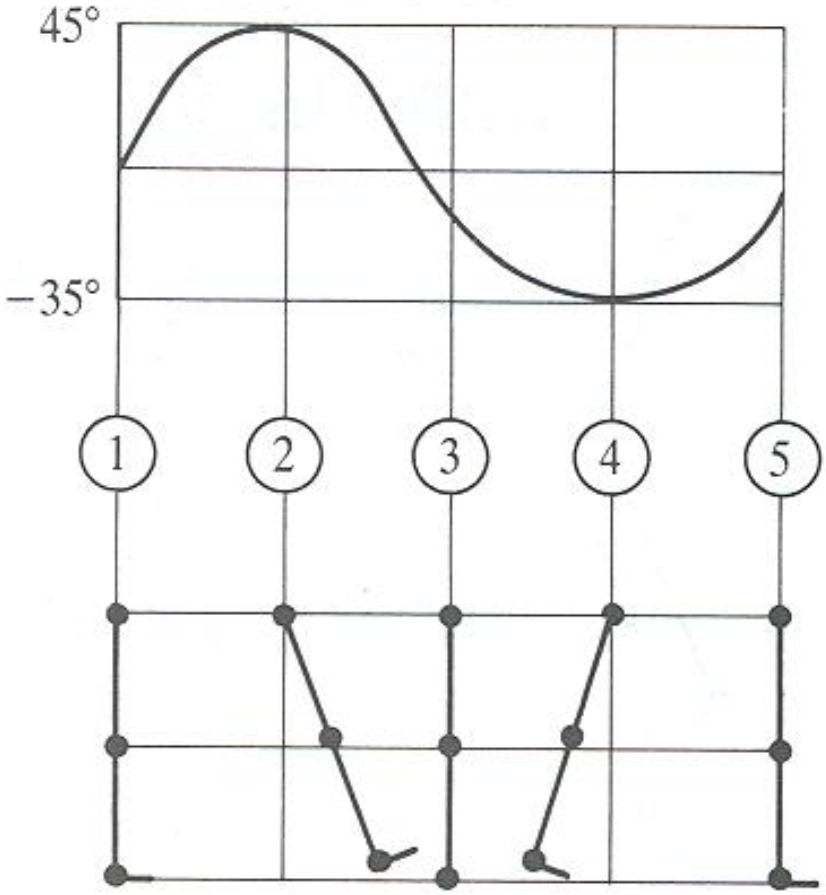
Example: Walk Cycle

Articulated figure:



Example: Walk Cycle

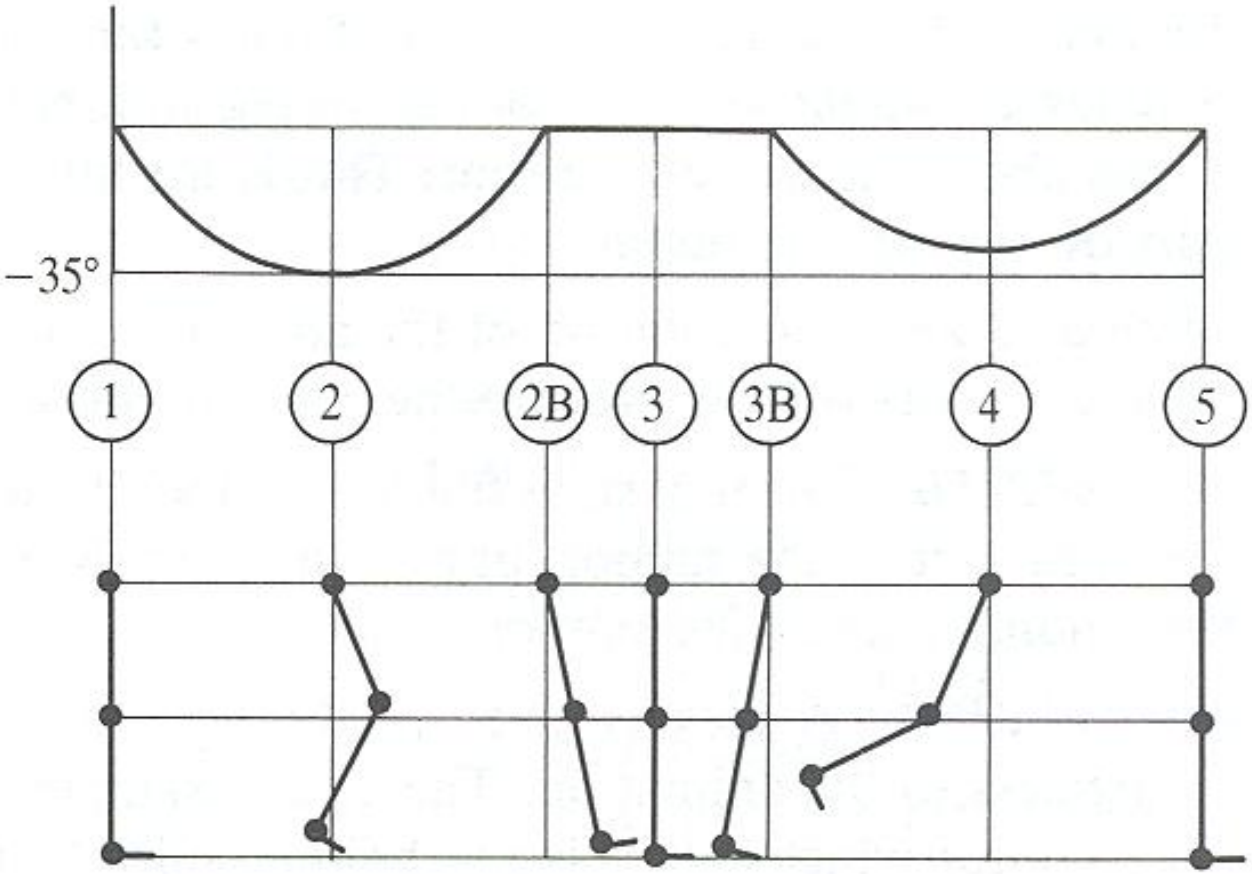
Hip joint orientation:



Watt & Watt

Example: Walk Cycle

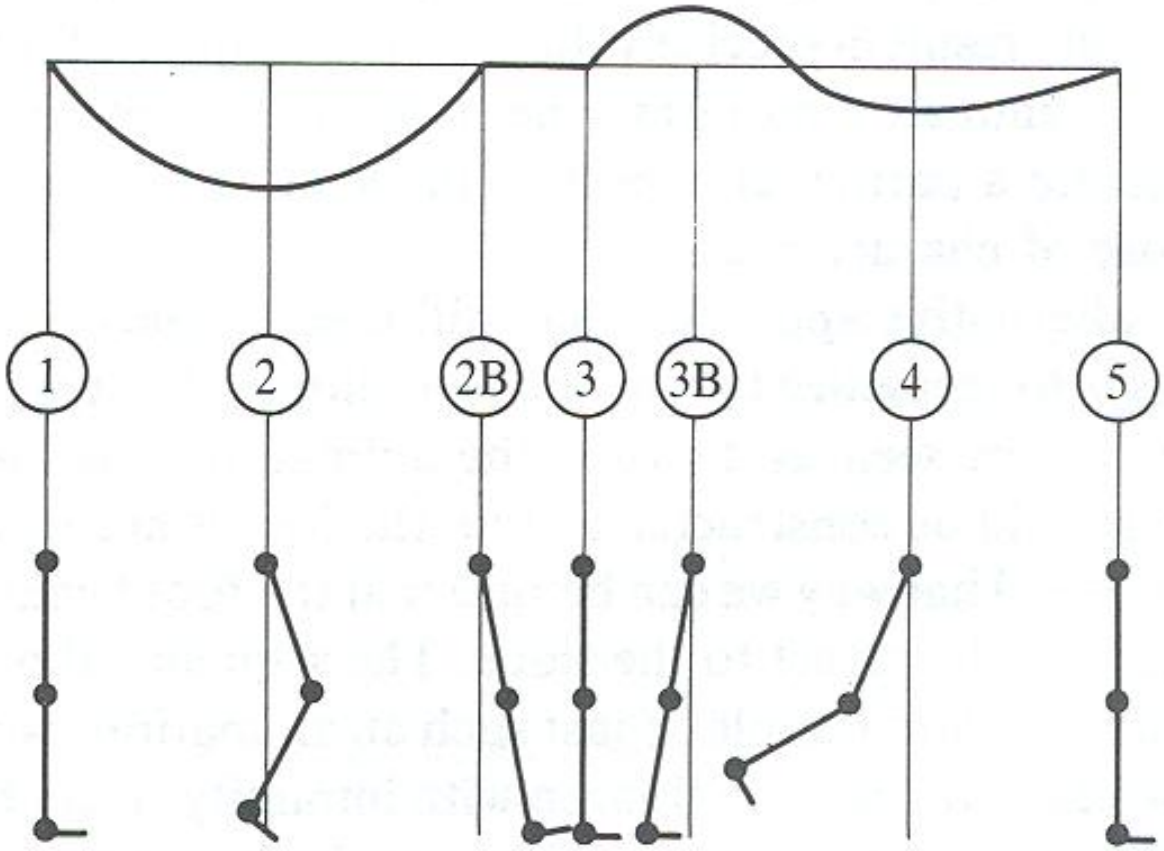
Knee joint orientation:



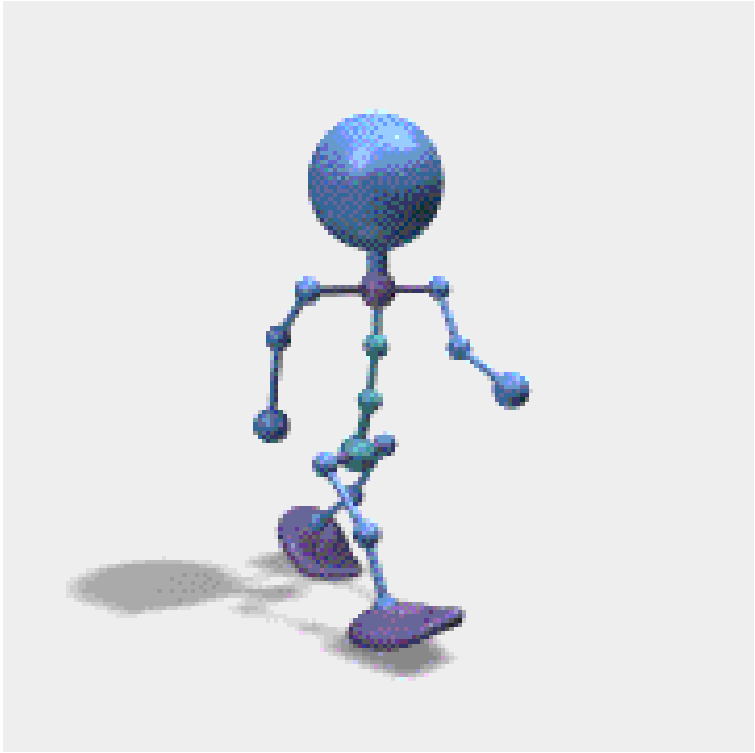
Watt & Watt

Example: Walk Cycle

Ankle joint orientation:



Example: Walk Cycle



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

Will discuss the how of blending joint parameters next time.

Keyframe Animation



Q: Why interpolate/blend joint parameters rather than vertex positions?

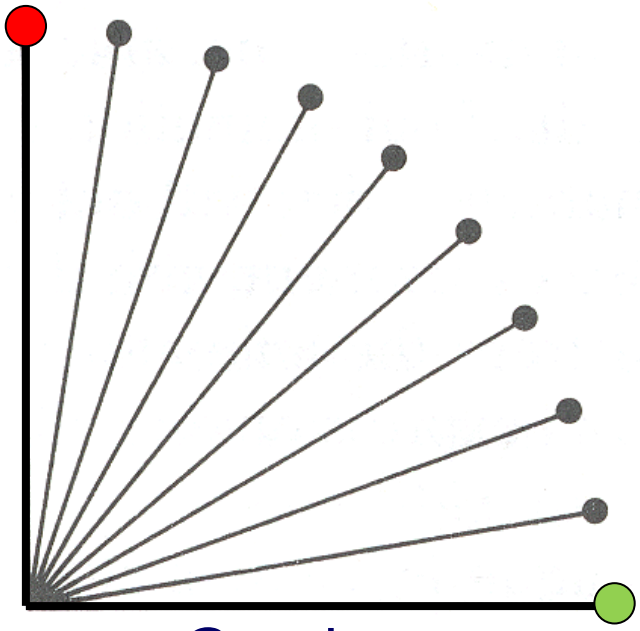
A: For translations, it doesn't make a difference (assuming the blend is translation equivariant).

Keyframe Animation

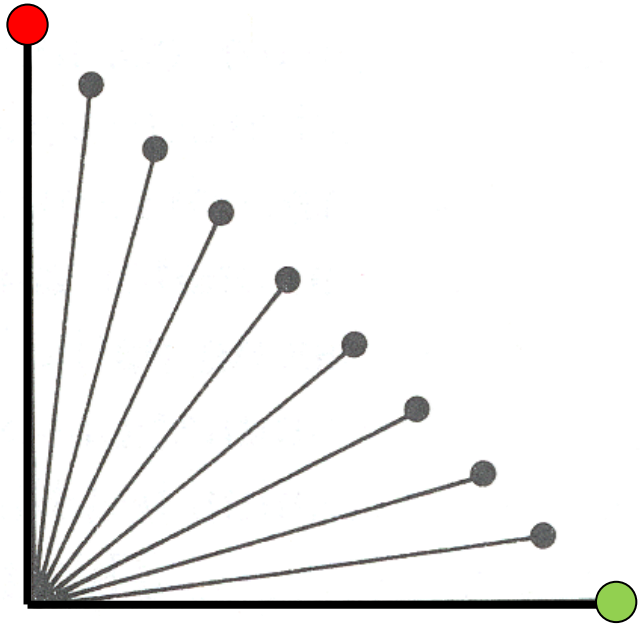


Q: Why interpolate/blend joint parameters rather than vertex positions?

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



Good arm



Bad arm

Watt & Watt

Kinematics and Dynamics



Kinematics: *Study of motion w/o regard for the cause*

- Considers only motion
- Determined by positions, velocities, accelerations

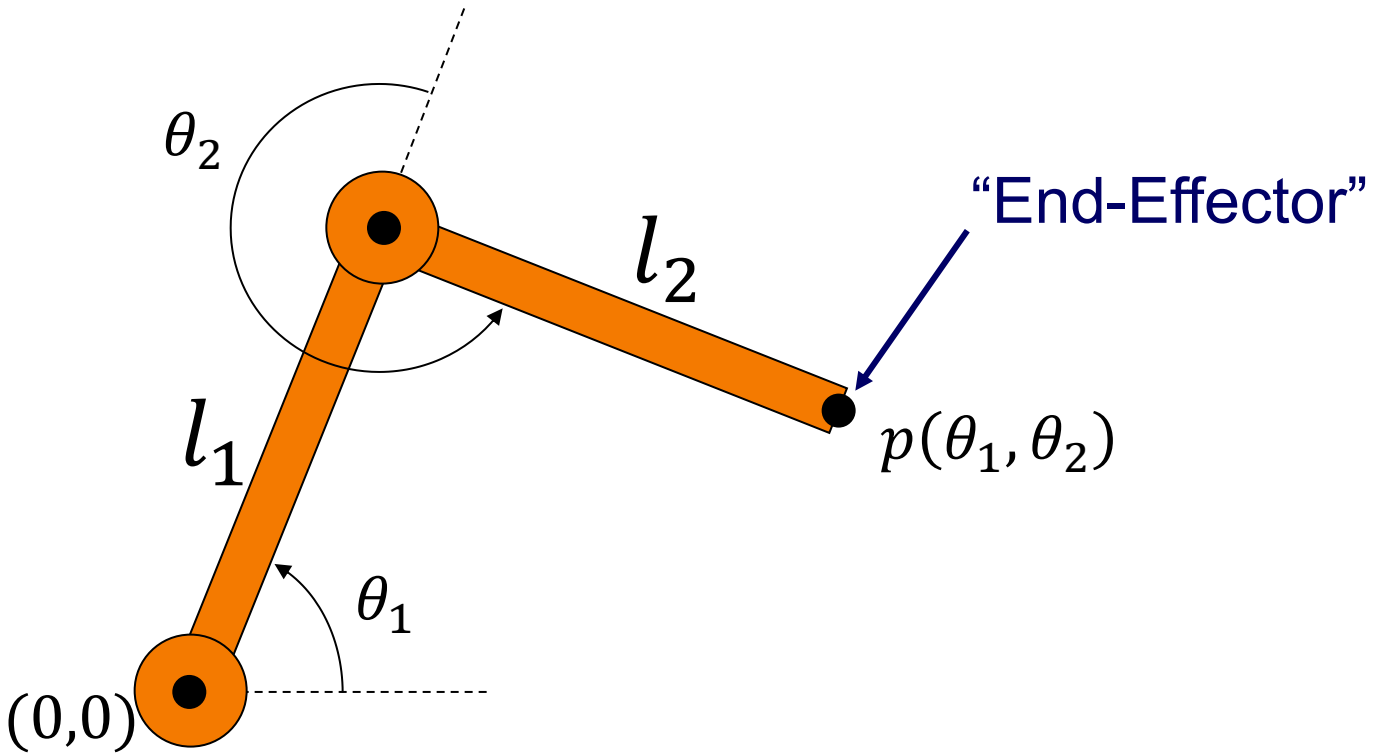
Dynamics: *Study of the cause of motion*

- Considers underlying forces and interactions
- Compute motion from initial conditions and physics

Forward Kinematics

Example:

Two links connected by rotational joints

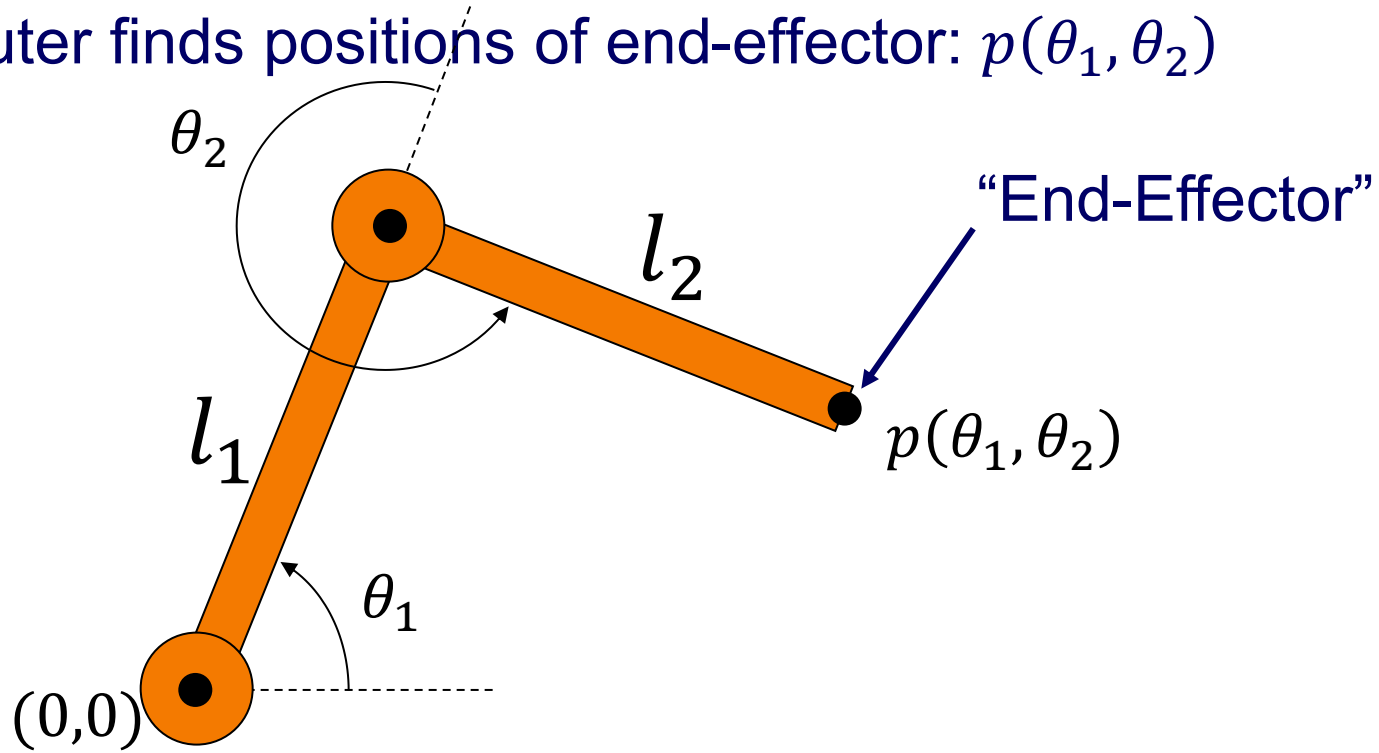


Forward Kinematics



Example:

- Two links connected by rotational joints
- Animator specifies joint angles: θ_1 and θ_2
- Computer finds positions of end-effector: $p(\theta_1, \theta_2)$



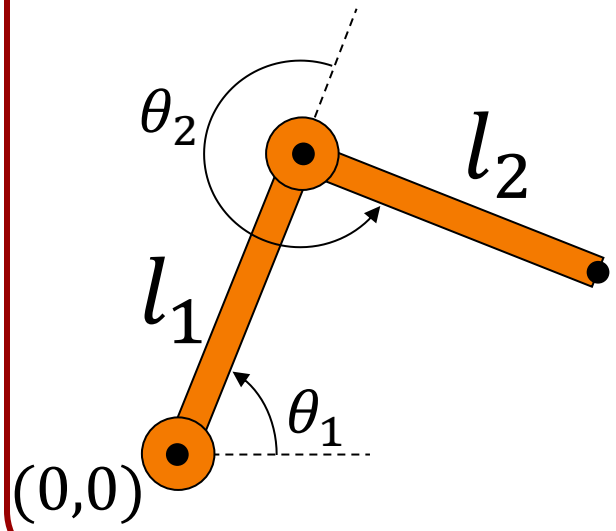
$$p(\theta_1, \theta_2) = (l_1 \cos\theta_1 + l_2(\cos(\theta_1 + \theta_2), l_1 \sin\theta_1 + l_2 \sin(\theta_1 + \theta_2))$$

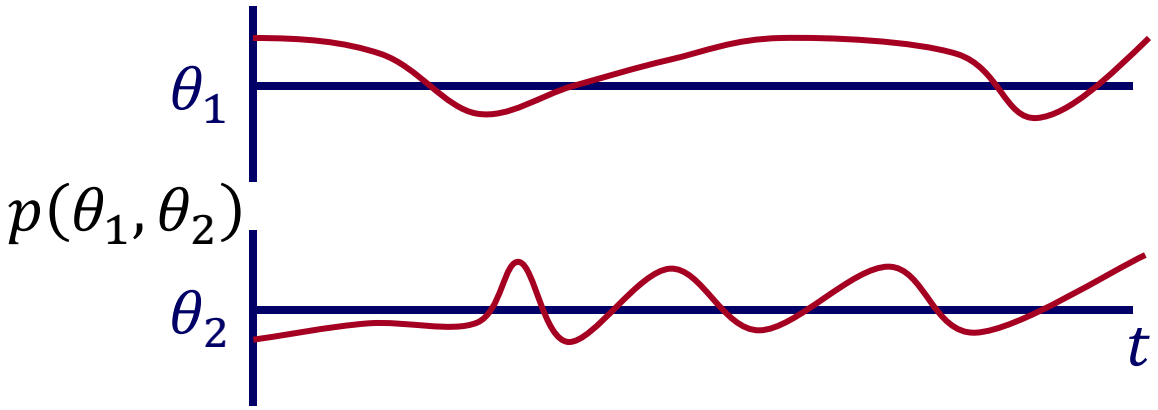
Forward Kinematics



Example:

- Two links connected by rotational joints
- Animator specifies joint angles: θ_1 and θ_2
- Computer finds positions of end-effector: $p(\theta_1, \theta_2)$
- Joint motions can be specified by spline curves





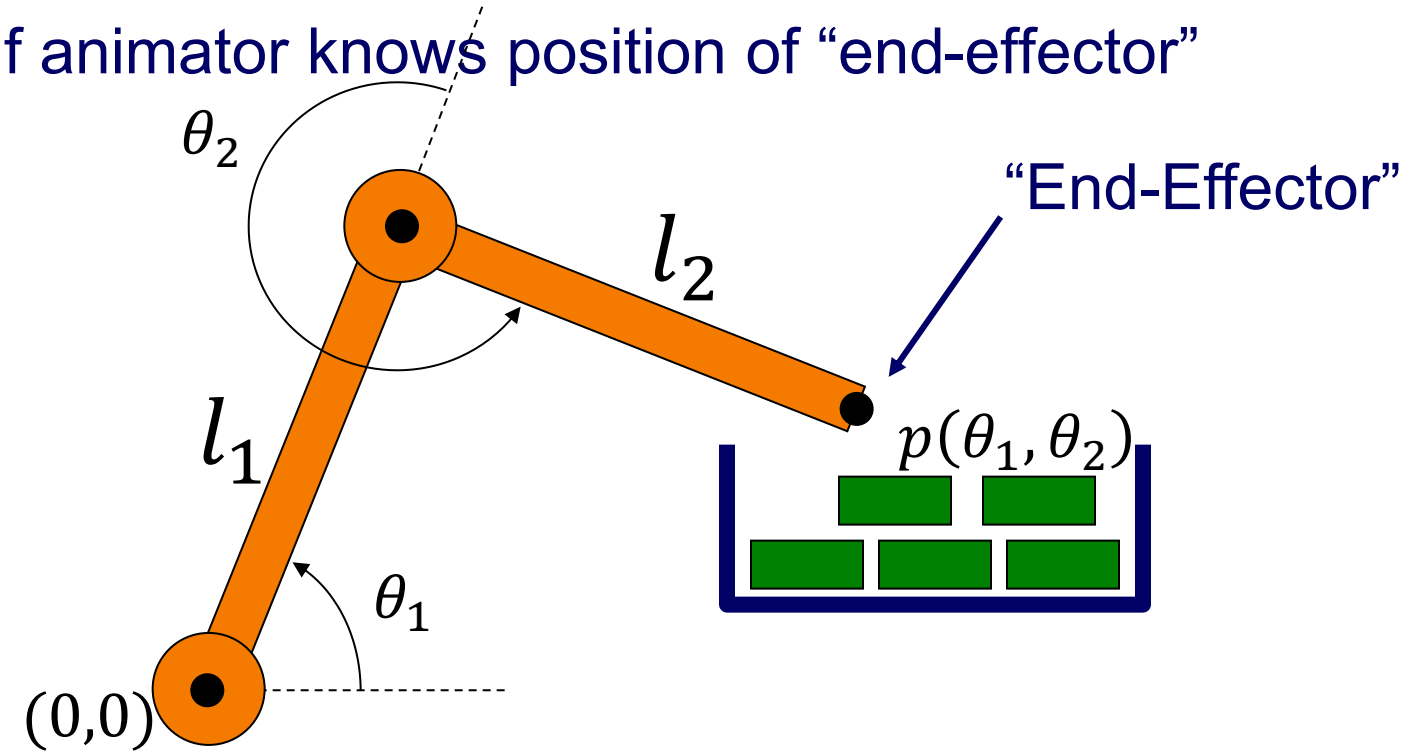
Inverse Kinematics

Example:

Two links connected by rotational joints

Question:

What if animator knows position of “end-effector”

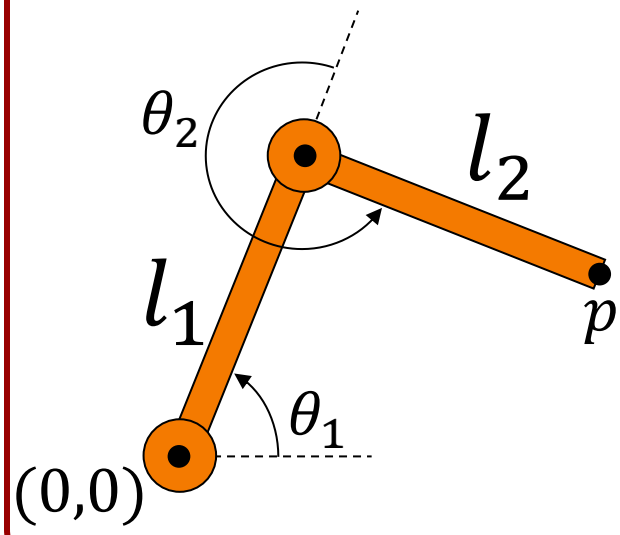


Inverse Kinematics



Example:

- Two links connected by rotational joints
- Animator specifies end-effector positions: p
- Computer finds joint angles: θ_1 and θ_2



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

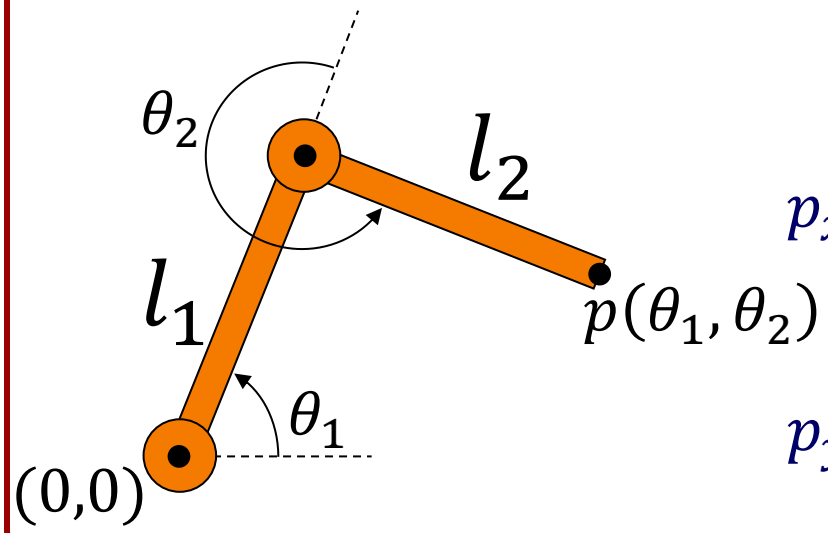
$$\theta_1 = \tan^{-1}\left(\frac{p_y}{p_x}\right) - \tan^{-1}\left(\frac{l_2 \sin\theta_2}{l_1 + l_2 \cos\theta_2}\right)$$

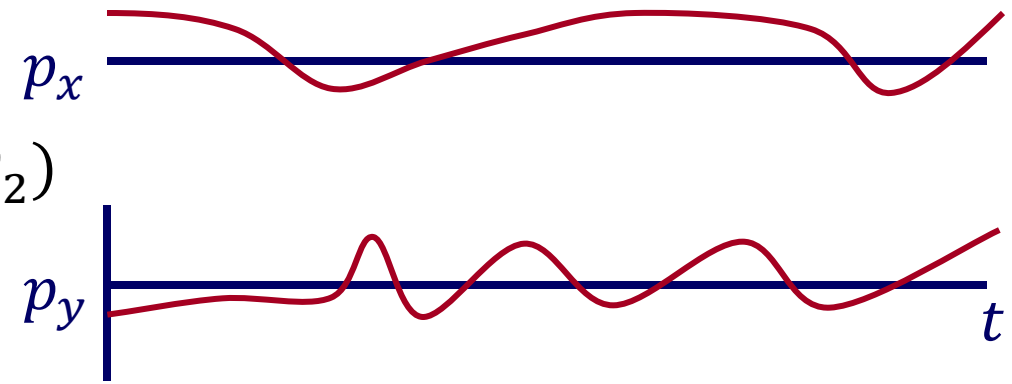
Inverse Kinematics



Example:

- Two links connected by rotational joints
- Animator specifies end-effector positions: p
- Computer finds joint angles: θ_1 and θ_2
- End-effector positions can be specified by splines

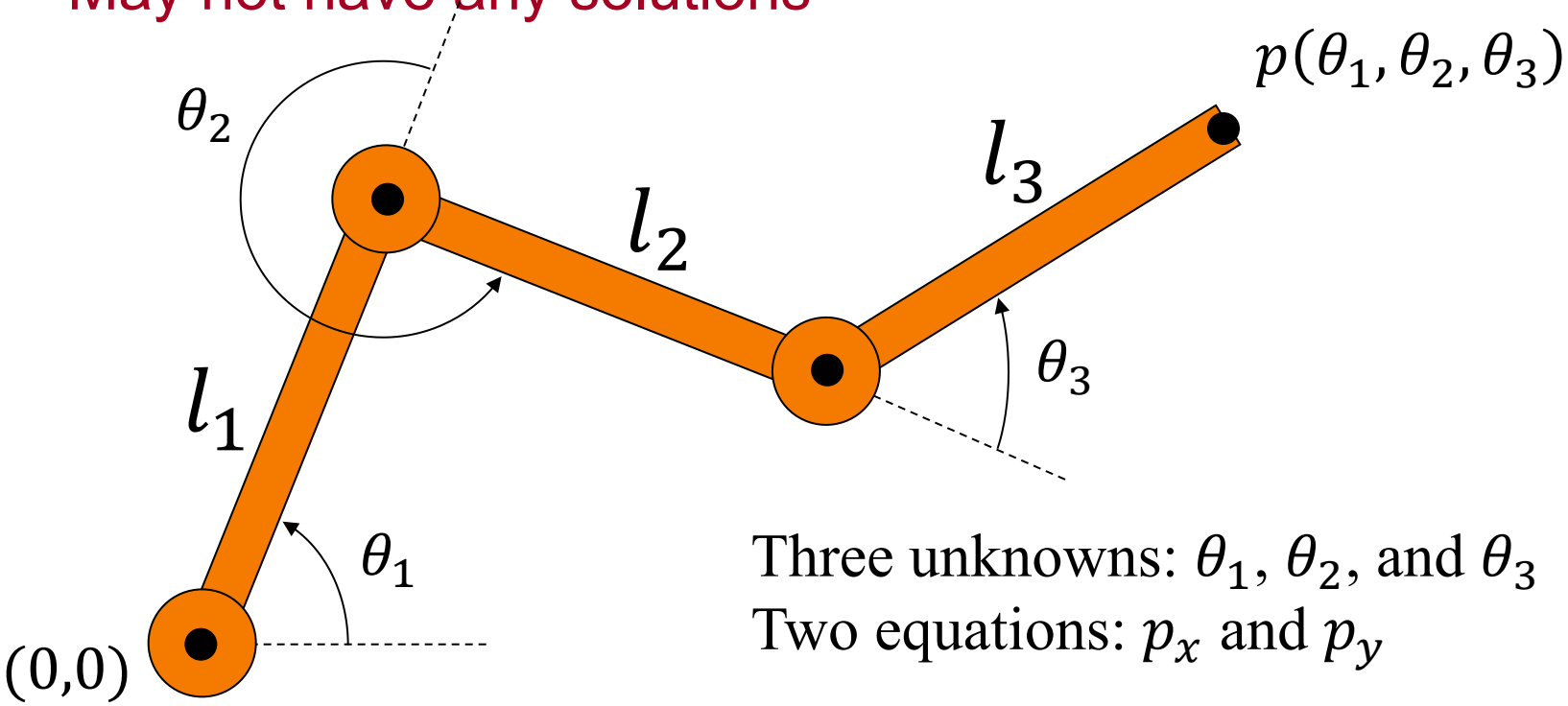




Inverse Kinematics

Challenges for more complex structures

- System can be non-linear (i.e. hard to solve)
  - May have multiple solutions
    - May be able to find best/closest solution
  - May not have any solutions



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

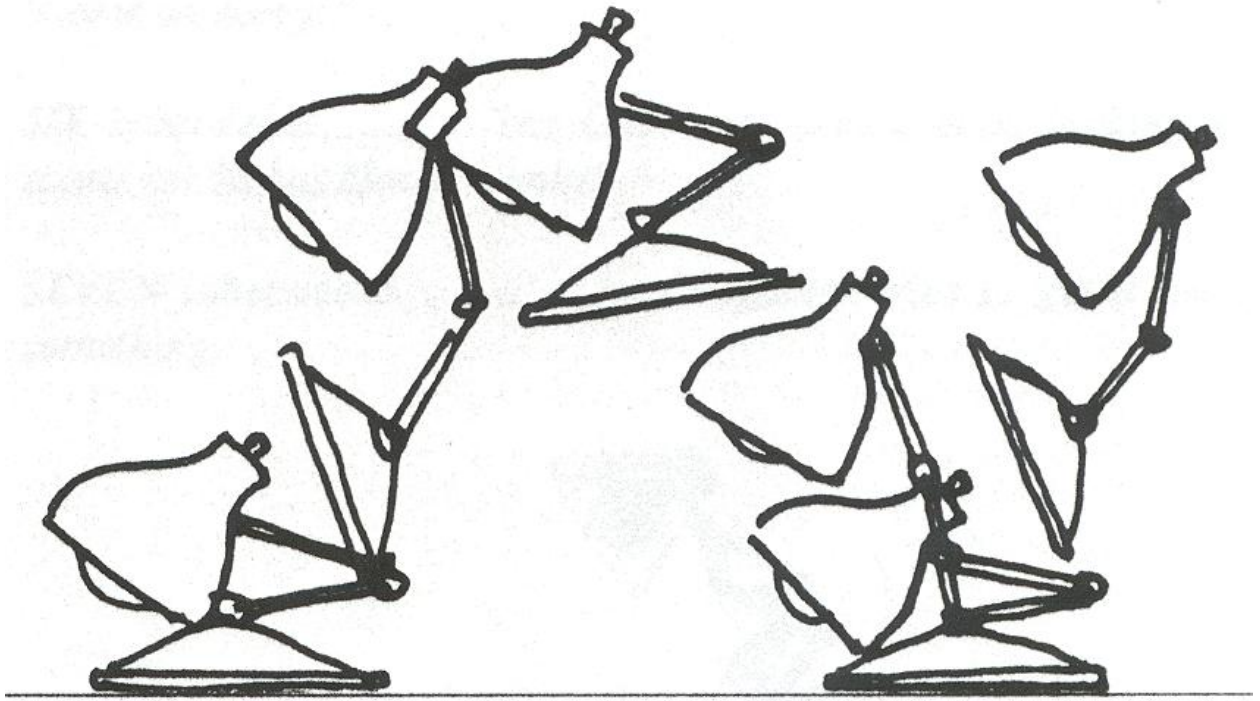
Inverse kinematics

- “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

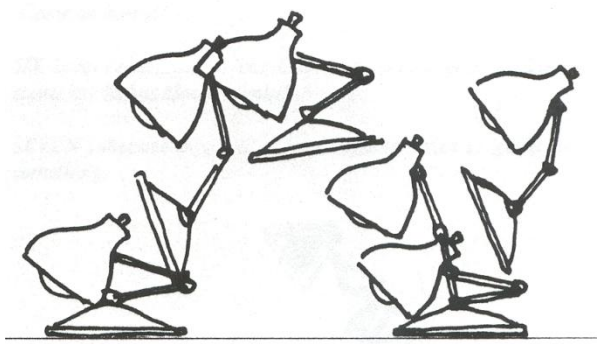


Lasseter `87

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 specific time
- 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)

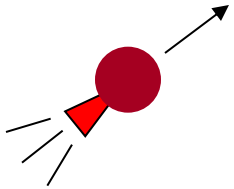
Example: particle with jet propulsion

$\mathbf{x}(t)$ 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



Discretize time into N uniform intervals (of size $h = \frac{1}{N}$)

Solve for discrete positions $\{\mathbf{x}_0, \cdots, \mathbf{x}_N\}$, w/ $\mathbf{x}_i = \mathbf{x}(i \cdot h)$

Compute discrete velocities:

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

Compute discrete acceleration:

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

Compute discrete force:

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

Dynamics

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

Optimization ⇒ minimizing a quadratic energy:

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

$$\Downarrow$$

$$E(\{\mathbf{x}_0, \ldots, \mathbf{x}_n\}) = h\sum_i \|m(\ddot{\mathbf{x}}_i - \mathbf{g})\|^2$$

$$= hm^2 \sum_i \left\| \frac{\mathbf{x}_{i+1} - 2\mathbf{x}_i + \mathbf{x}_{i-1}}{h^2} - \mathbf{g} \right\|^2$$

with $\mathbf{x}_0 = \mathbf{a}$, $\mathbf{x}_N = \mathbf{b}$, $\mathbf{x}_{-1} = \mathbf{x}_1$ and $\mathbf{x}_{N+1} = \mathbf{x}_{N-1}$.

Dynamics

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

Optimization ⇒ minimizing a quadratic energy:

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

$$\Downarrow$$

$$E(\{\mathbf{x}_0, \ldots, \mathbf{x}_n\}) = h \sum_i \|m(\ddot{\mathbf{x}}_i - \mathbf{g})\|^2$$

$$\approx h \sum \left\| \frac{\mathbf{x}_{i+1} - 2\mathbf{x}_i + \mathbf{x}_{i-1}}{h^2} - \mathbf{g} \right\|^2$$

To minimize, need to find where the gradient is zero.

Energy is quadratic ⇒ the gradient is linear.

with

Reduces to a *linear* system of equations.

Dynamics

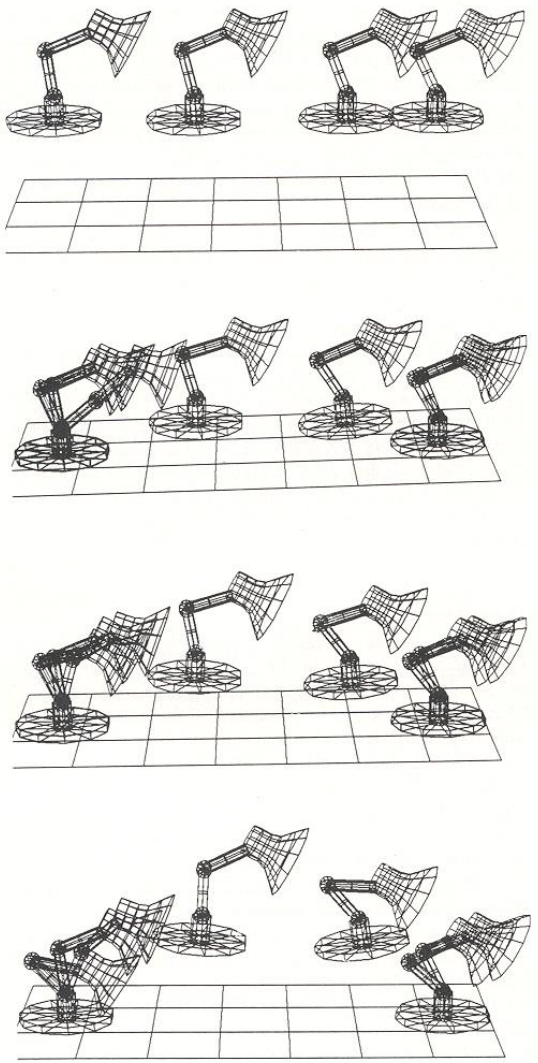
For simple scenarios:

Solve a linear system

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

For complex scenarios:

Solve using iterative optimization techniques

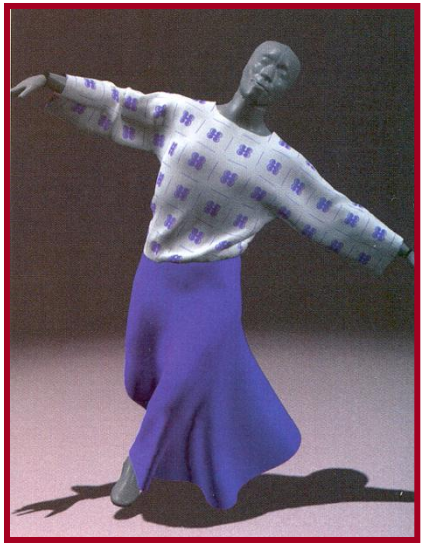


Witkin & Kass `88

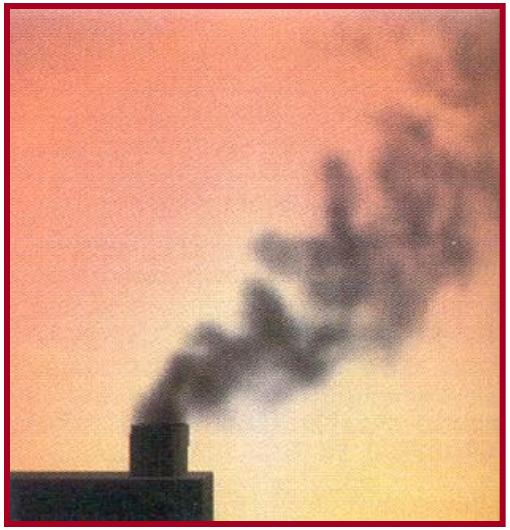
Dynamics

Other physical simulations:

- Rigid bodies
- Soft bodies
- Cloth
- Liquids
- Gases
- etc.



Cloth
(Baraff & Witkin `98)



Hot Gases
(Foster & Metaxas `97)

Demo

Dynamics



Properties:

- ✓ Free animator from specifying details of physically realistic motion
- ✓ Easy to adapt motions to new parameters and/or new constraints
- ✗ Specifying constraints and objective functions
- ✗ Avoiding local minima during optimization