Computer Animation

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CS 4810: Graphics

Acknowledgment: slides by Jason Lawrence, Misha Kazhdan, Allison Klein, Tom Funkhouser, Adam Finkelstein and David Dobkin

Overview

- Some early animation history
  - http://en.wikipedia.org/wiki/History_of_animation#Animation_before_film
- Computer animation

Thaumatrope

- Why does animation work?
- Persistence of vision
- 1824 John Ayerton invents the *thaumatrope*
- Or, 1828 Paul Roget invents the *thaumatrope*

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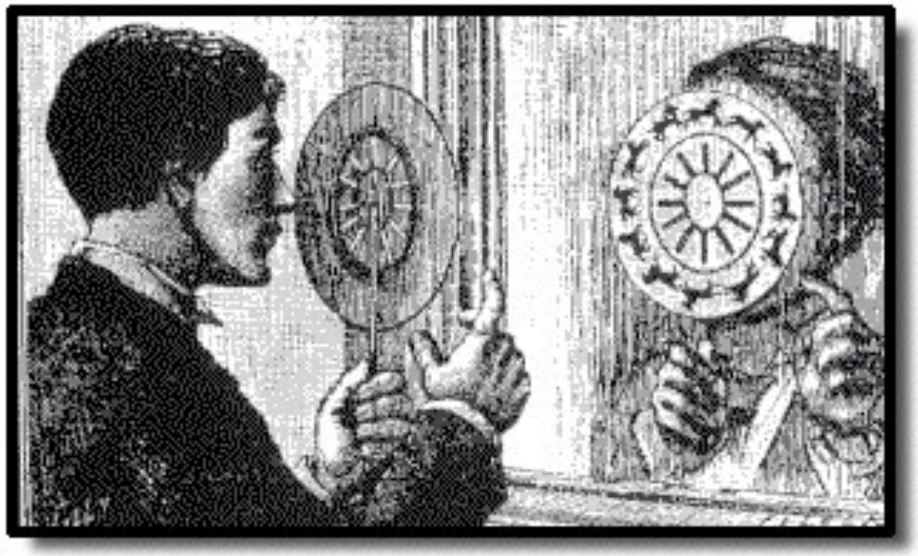
Thaumatrope

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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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.

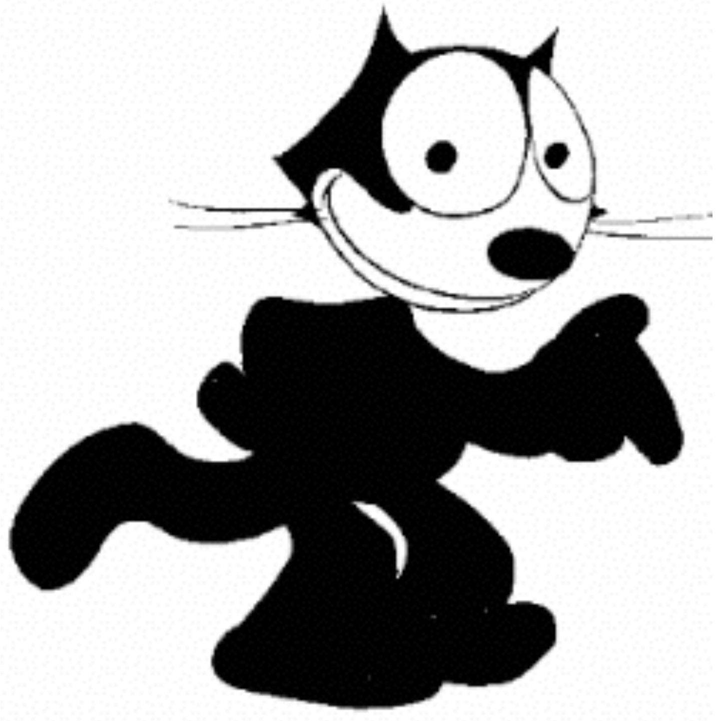
Animation History

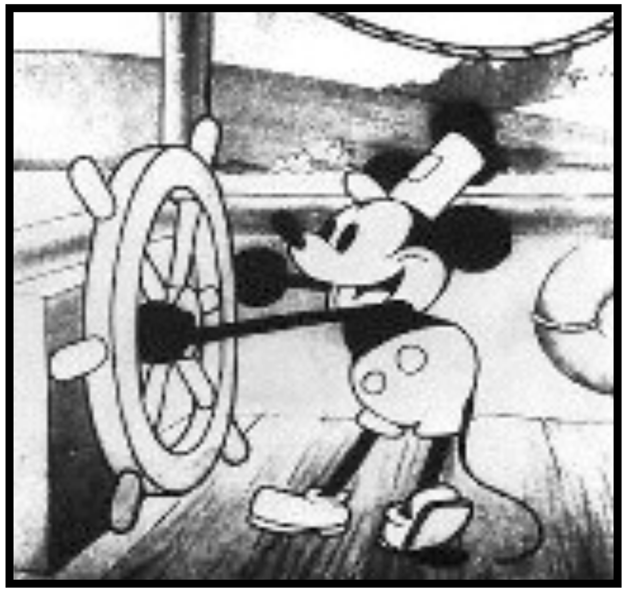
- Animation and technology have always gone together!
- Animation popular even before movies
- Movies were big step forward!
- "Humorous Phases of Funny Faces" (1906)

Key Developments

- Plot
- Creation of animation studios
- Getting rid of “rubber-hose” bodies
- Inking on cels

“Felix the Cat”
Pat Sullivan (1919)



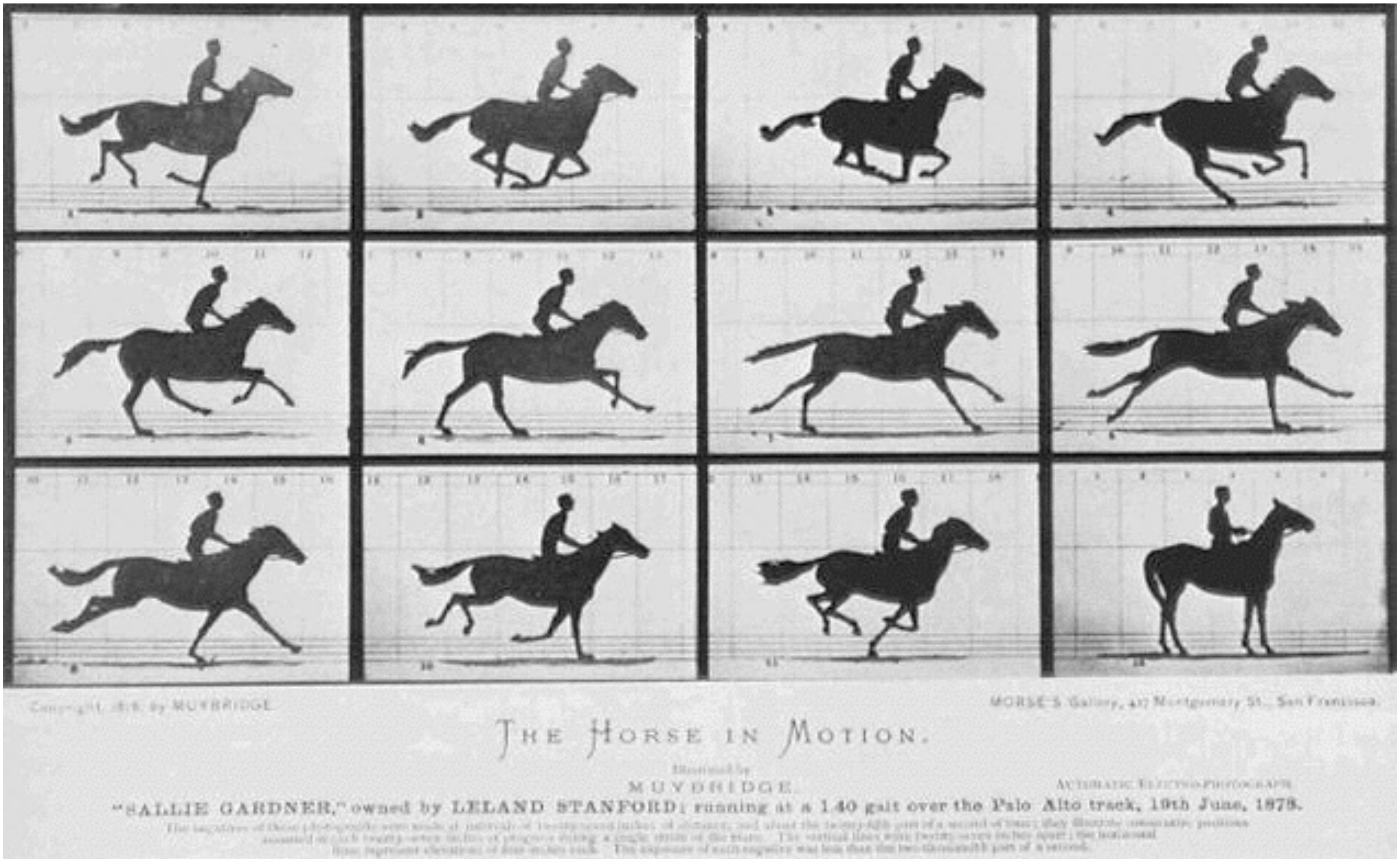


“Steamboat Willie”
Walt Disney (1928)

“Gertie the Dinosaur”
Windsor McCay (1914)

Key Developments

- Max Fleischer invents rotoscoping (1921)



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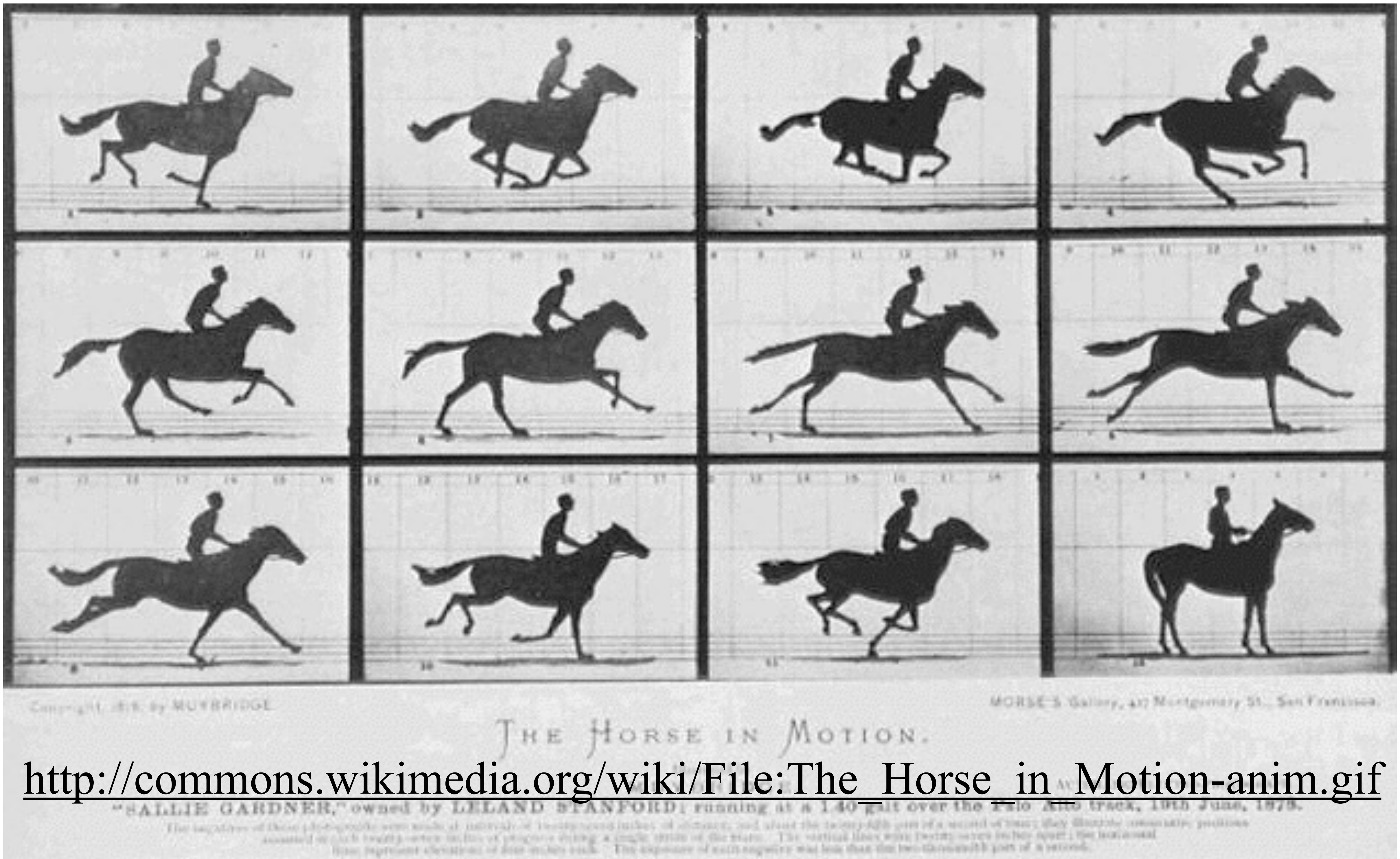

http://commons.wikimedia.org/wiki/File:The_Horse_in_Motion-anim.gif

Fleischer's Rotoscope

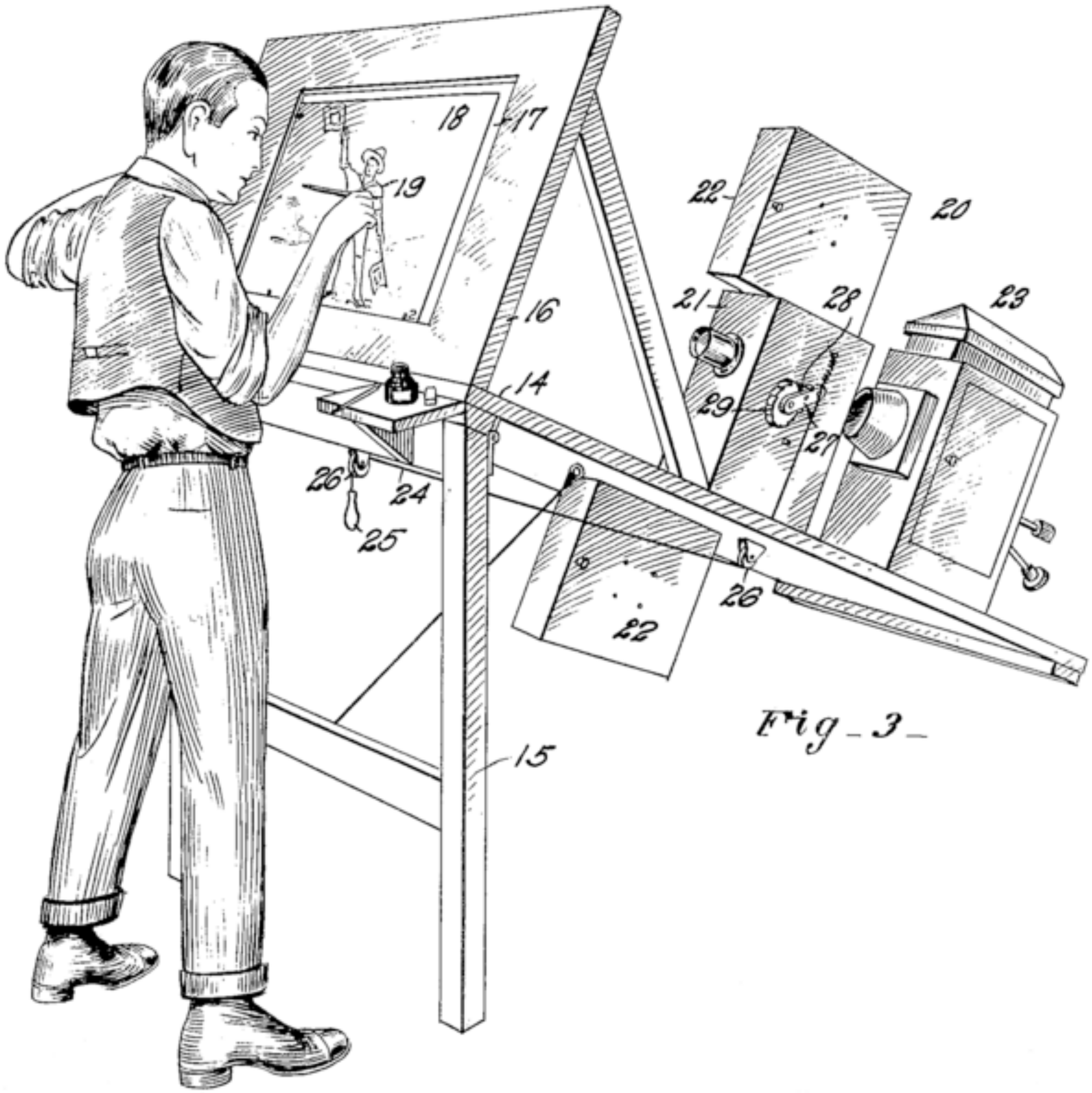

Fig_3_

Key Developments

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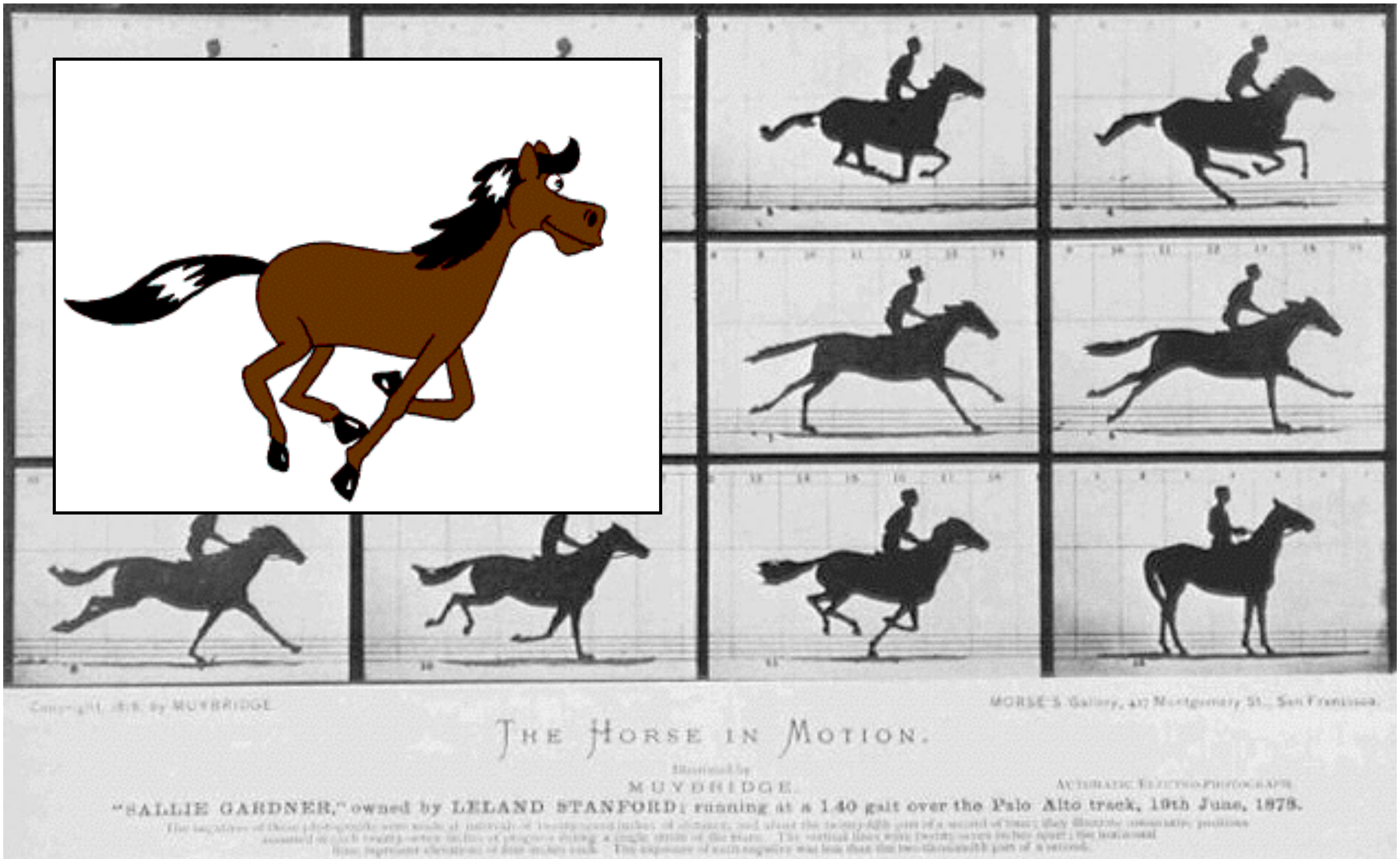
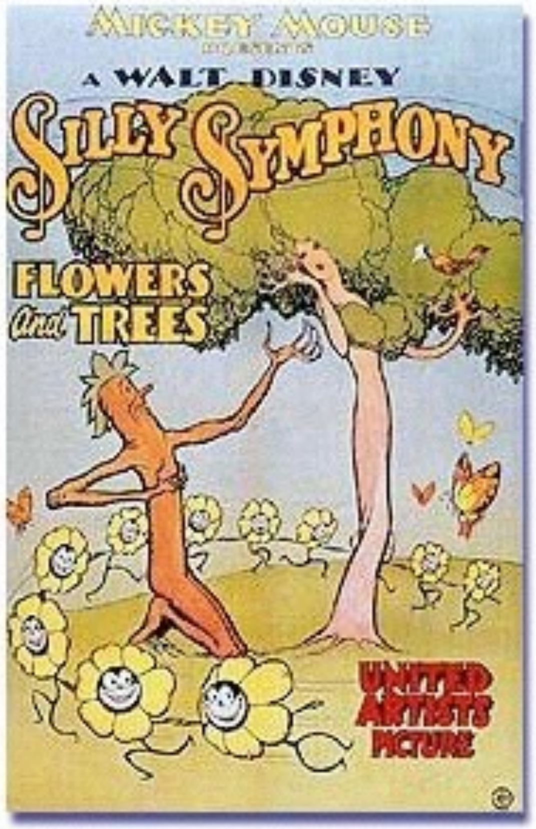


Key Developments

- "Flowers and Trees" (1932) uses color!
- "Snow White" (aka "Disney's Folly") released 1937



"Flowers and Trees"
Walt Disney

"Snow White"
Walt Disney

Animation Uses

- Entertainment
- Education
- Propaganda

Overview

- Some early animation history
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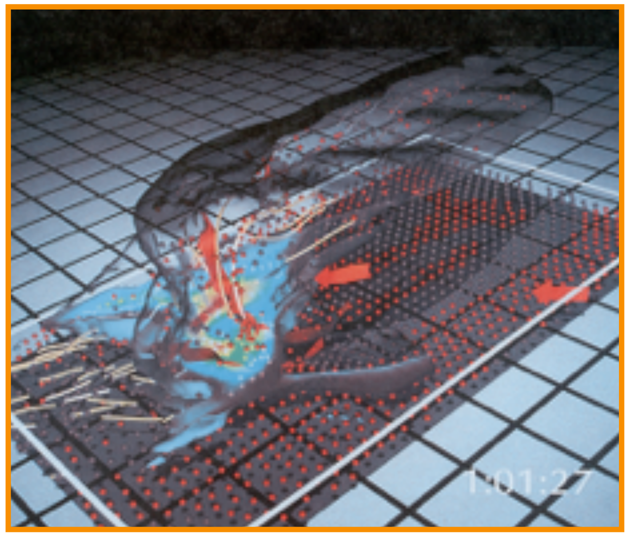
- Computer animation

Computer Animation

- What is animation?
  - Make objects change over time according to scripted actions

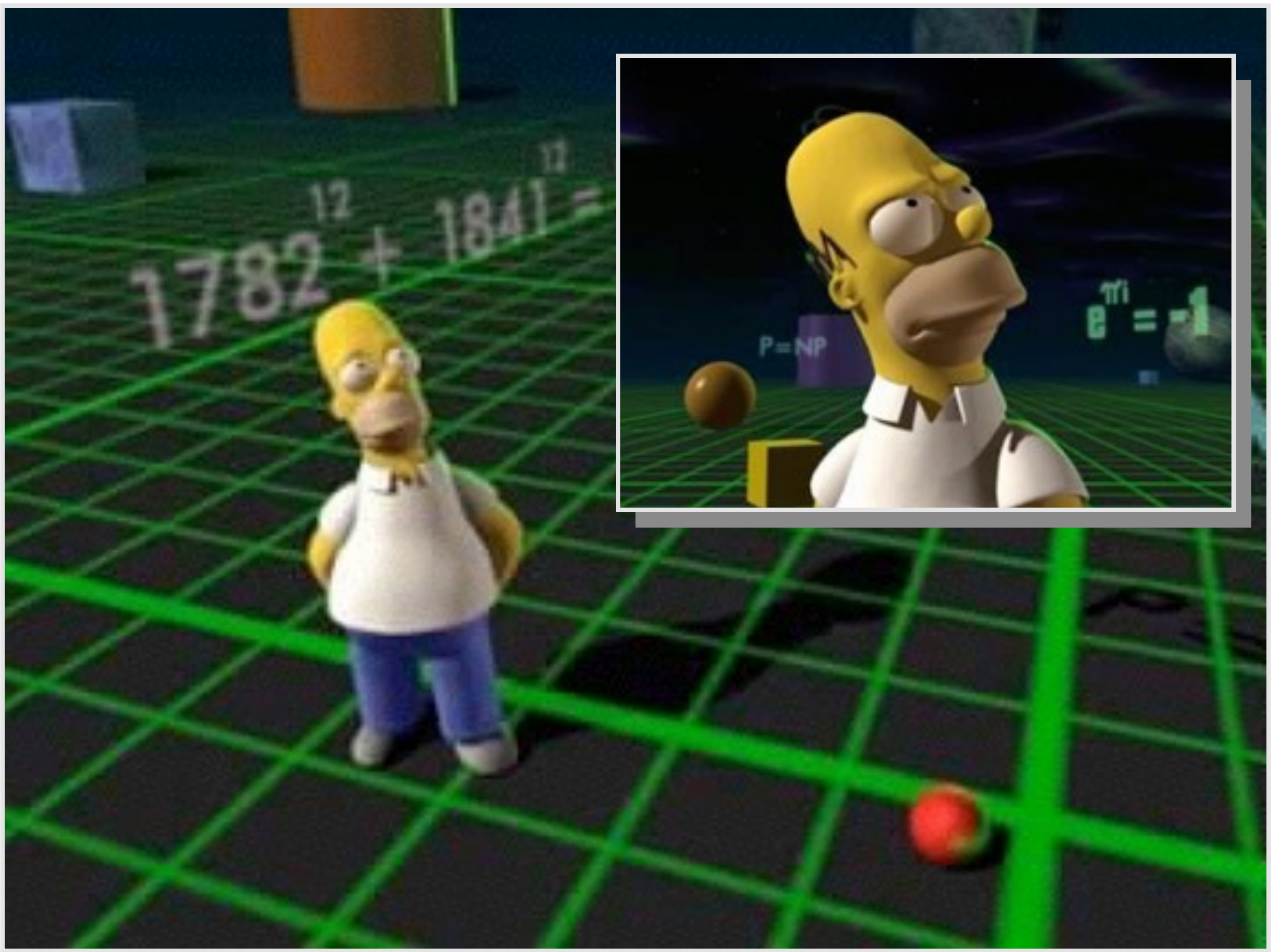
Pixar

- What is simulation?
  - Predict how objects change over time according to physical laws



University of Illinois

3-D and 2-D animation

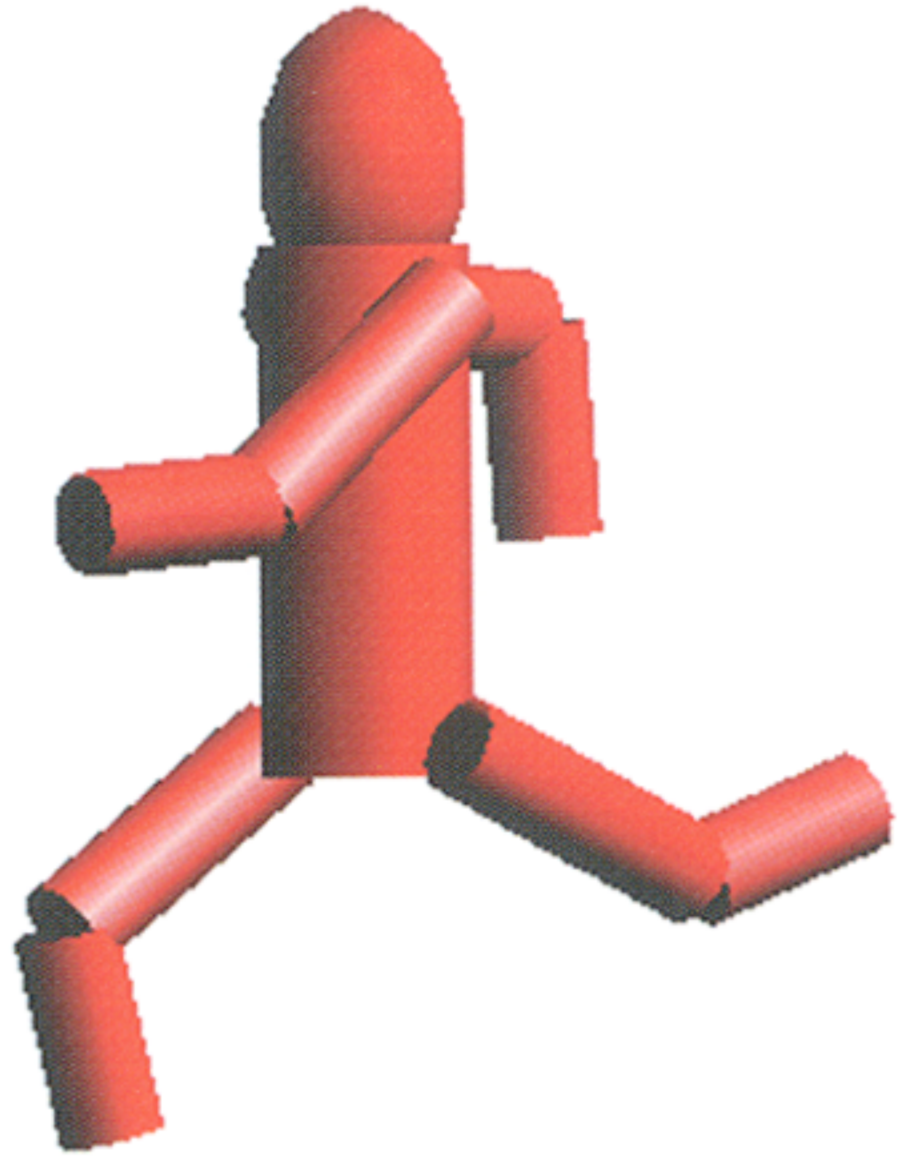


Homer 3-D

Homer 2-D

Outline

- Principles of animation
- Keyframe animation
- Articulated figures



Angel Plate 1

Principles of Traditional Animation

- Squash and Stretch
- Timing
- Anticipation
- Staging
- Follow Through and Overlapping Action
- Straight Ahead Action and Pose-to-Pose Action
- Slow In and Out
- Arcs
- Exaggeration
- Secondary action
- Appeal

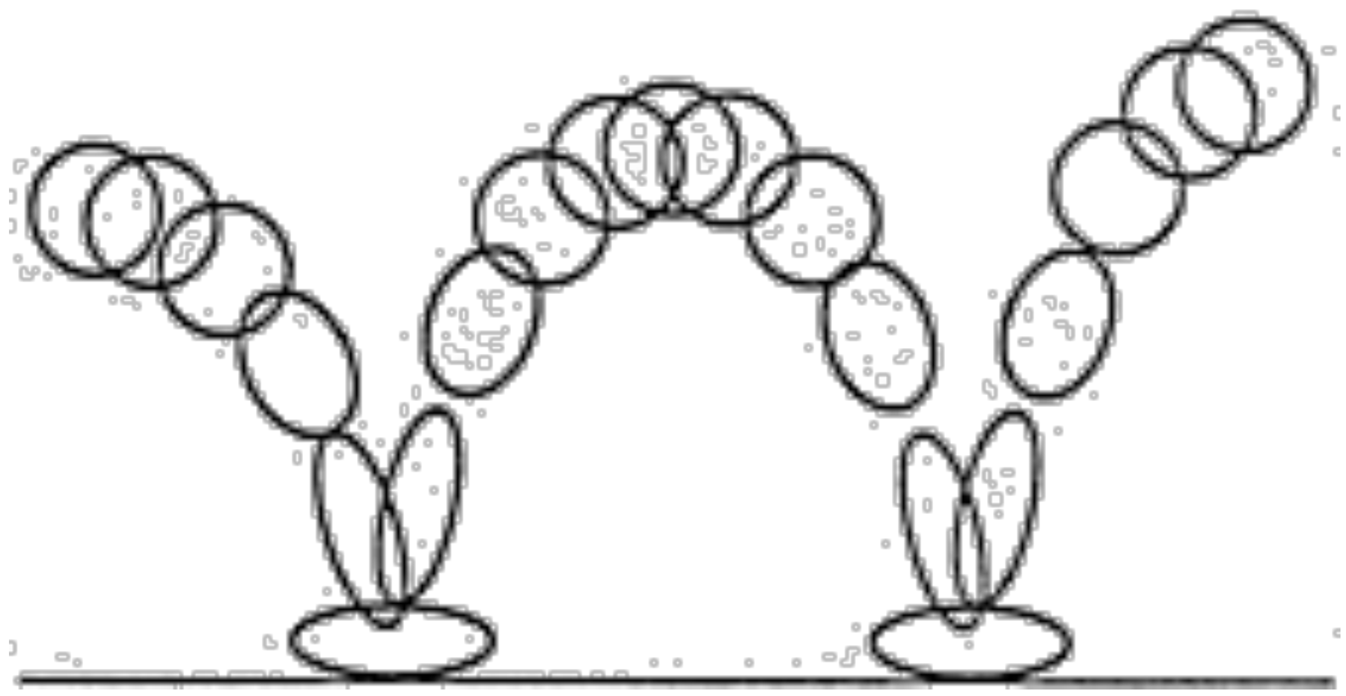
Luxo Junior Short Film

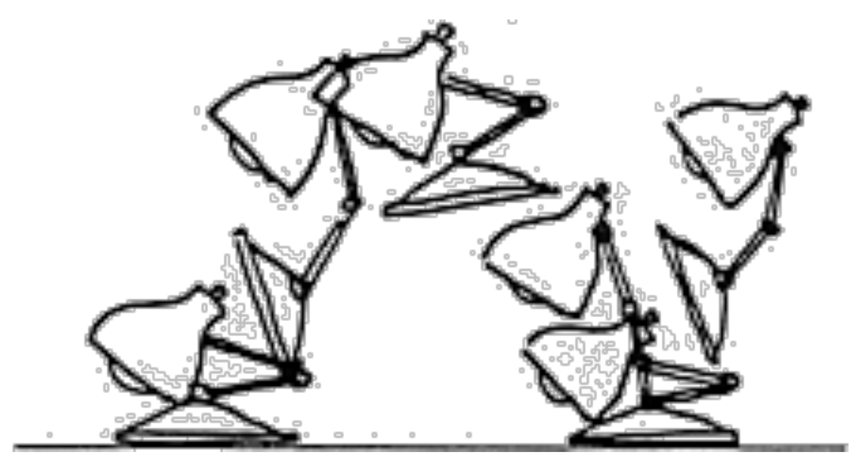
http://www.anticipation.info/texte/lasseter/principles.html

Principles of Traditional Animation

Squash and Stretch

- Defining the rigidity and mass of an object by distorting its shape during an action.





http://www.anticipation.info/texte/lasseter/principles.html

Principles of Traditional Animation

Timing

- Spacing actions to define the weight and size of objects and the personality of characters.
  - Heavier objects accelerate slower
  - Lethargic characters move slower
  - Etc.

http://www.anticipation.info/texte/lasseter/principles.html

Principles of Traditional Animation

Anticipation

- The preparation for an action.
  - Muscle contraction prior to extension
  - Bending over to lift a heavy object
  - Luxo's dad responds to Luxo Jr. off screen before Luxo Jr. appears.

http://www.anticipation.info/texte/lasseter/principles.html

Principles of Traditional Animation

<u>Staging</u>

- Presenting an idea so that it is unmistakably clear.
  - Keeping the viewer's attention focused on a specific part of the scene.
  - Luxo Jr. moves faster than his dad, and so we focus on him.

http://www.anticipation.info/texte/lasseter/principles.html

Principles of Traditional Animation

<u>Follow Through and Overlapping Action</u>

- The termination of an action and establishing its relationship to the next action.
  - Loose clothing will "drag" and continue moving after the character has stopped moving.
  - The way in which an object slows down indicates its weight/mood.

http://www.anticipation.info/texte/lasseter/principles.html

Principles of Traditional Animation

<u>Straight Ahead Action and Pose-to-Pose Action</u>

- The two contrasting approaches to the creation of movement.
  - **o** Straight Ahead Action:
    - » Action is drawn from the first frame through to the last one.
    - » Wild, scrambling actions where spontaneity is important.
  - **o** Pose-to-Pose Action:
    - » Poses are pre-conceived and animator fills in the in-betweens.
    - » Good acting, where the poses and timing are all important.

http://www.anticipation.info/texte/lasseter/principles.html

Principles of Traditional Animation

Slow In and Out

- The spacing of in-between frames to achieve subtlety of timing and movements.

http://www.anticipation.info/texte/lasseter/principles.html

Principles of Traditional Animation

Arcs

- The visual path of action for natural movement.
  - Make animation much smoother and less stiff than a straight line for the path of action

http://www.anticipation.info/texte/lasseter/principles.html

Principles of Traditional Animation

Exaggeration

- Accentuating the essence of an idea via the design and the action.

http://www.anticipation.info/texte/lasseter/principles.html

Principles of Traditional Animation

Secondary Action

- The Action of an object resulting from another action.
  - The rippling of Luxo Jr.'s cord as he bounces around the scene.

http://www.anticipation.info/texte/lasseter/principles.html

Principles of Traditional Animation

Appeal

- Creating a design or an action that the audience enjoys watching.
  - Charm
  - Pleasing design
  - Simplicity
  - Communication
  - Magnetism
  - Etc.

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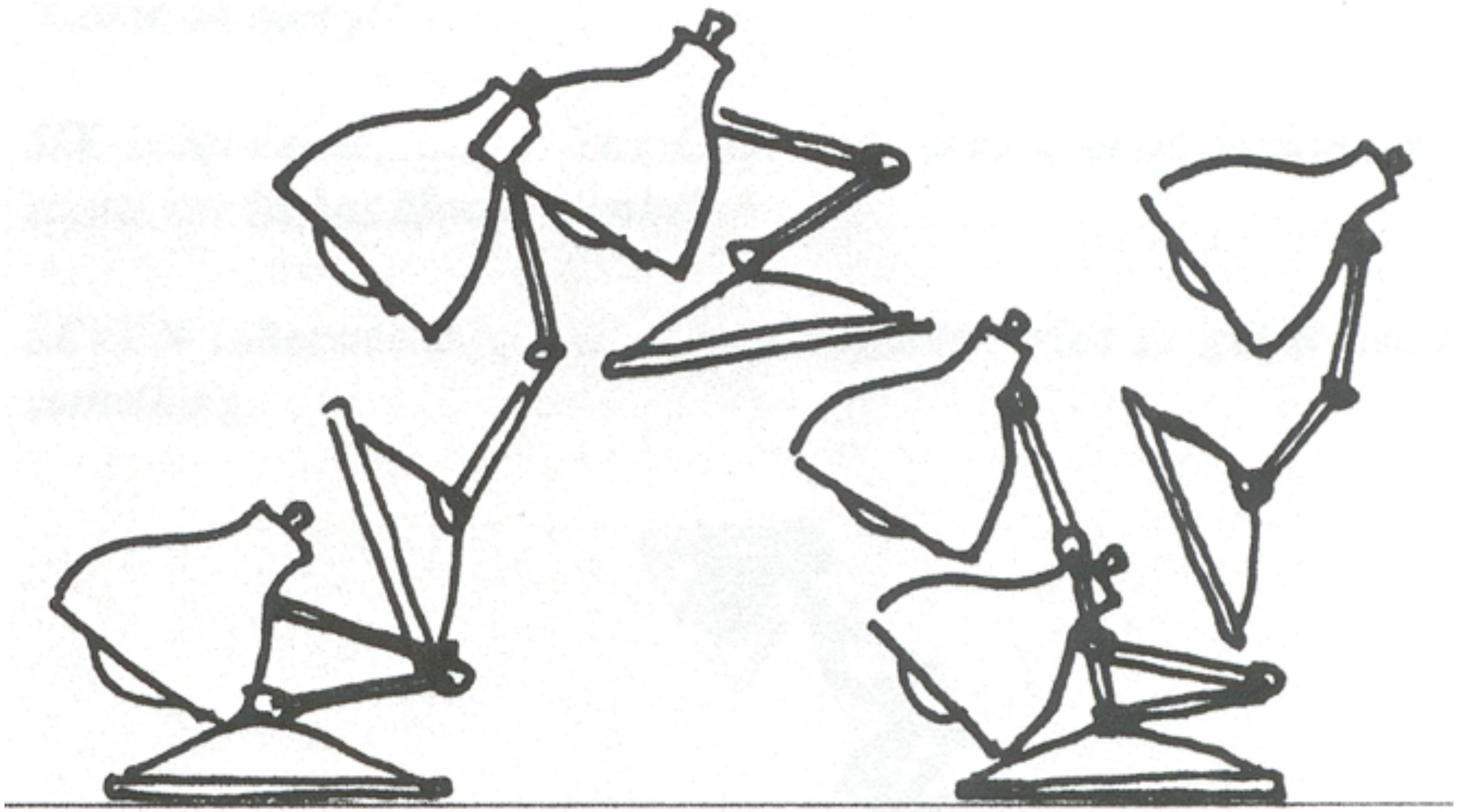
Keyframe Animation

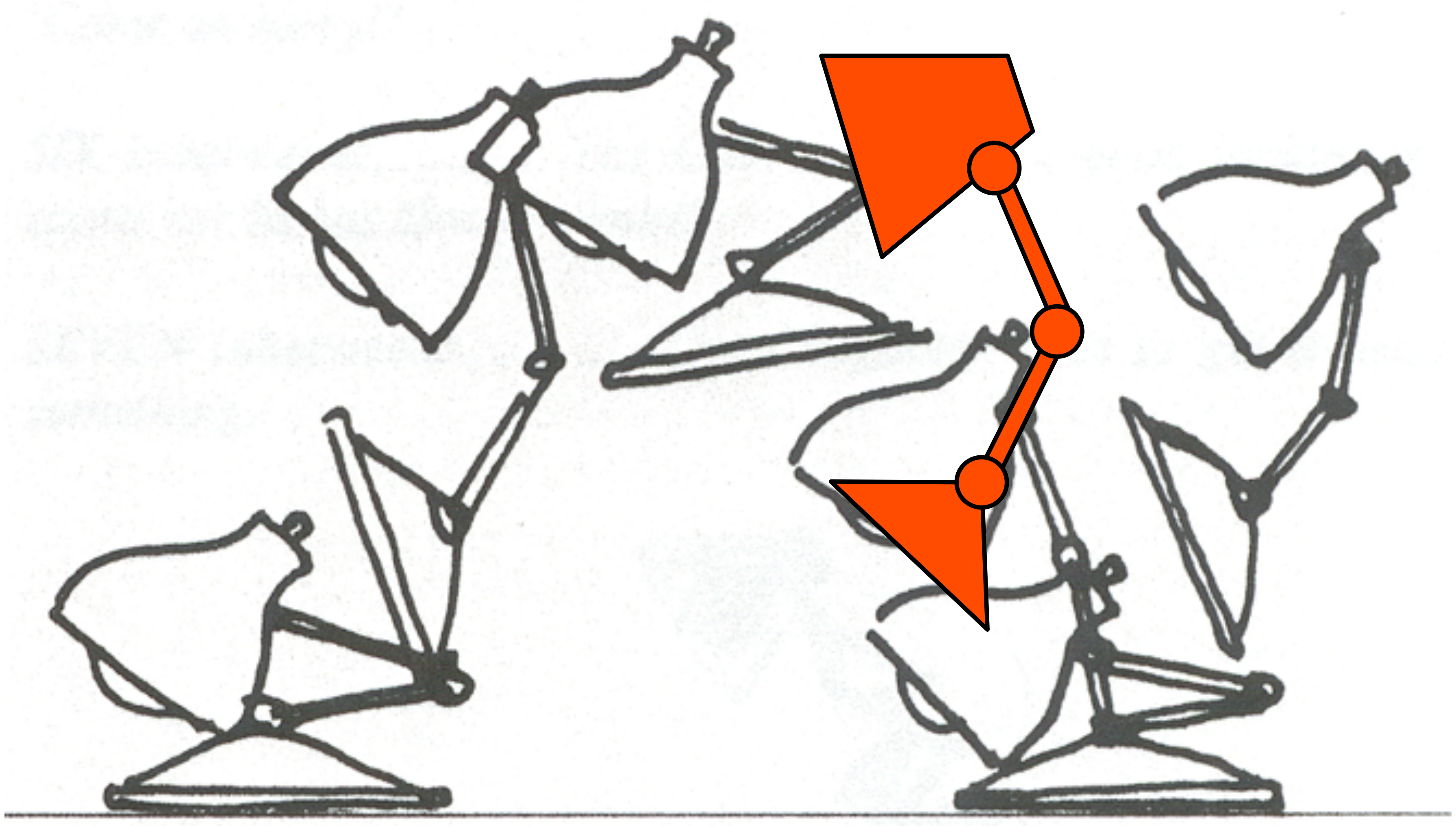
- Define character poses at specific time steps called “keyframes”



Lasseter `87

Keyframe Animation

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



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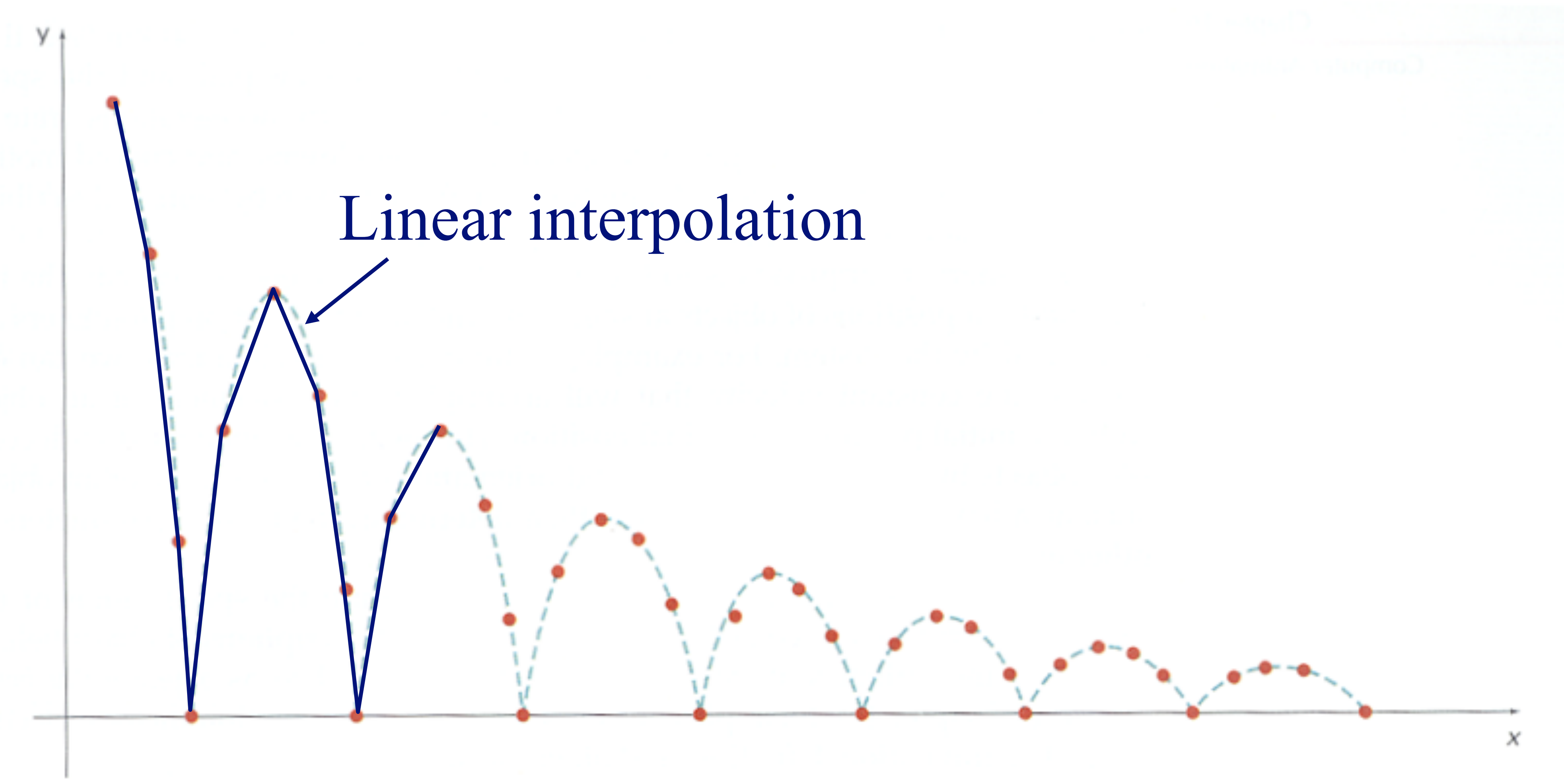
Keyframe Animation

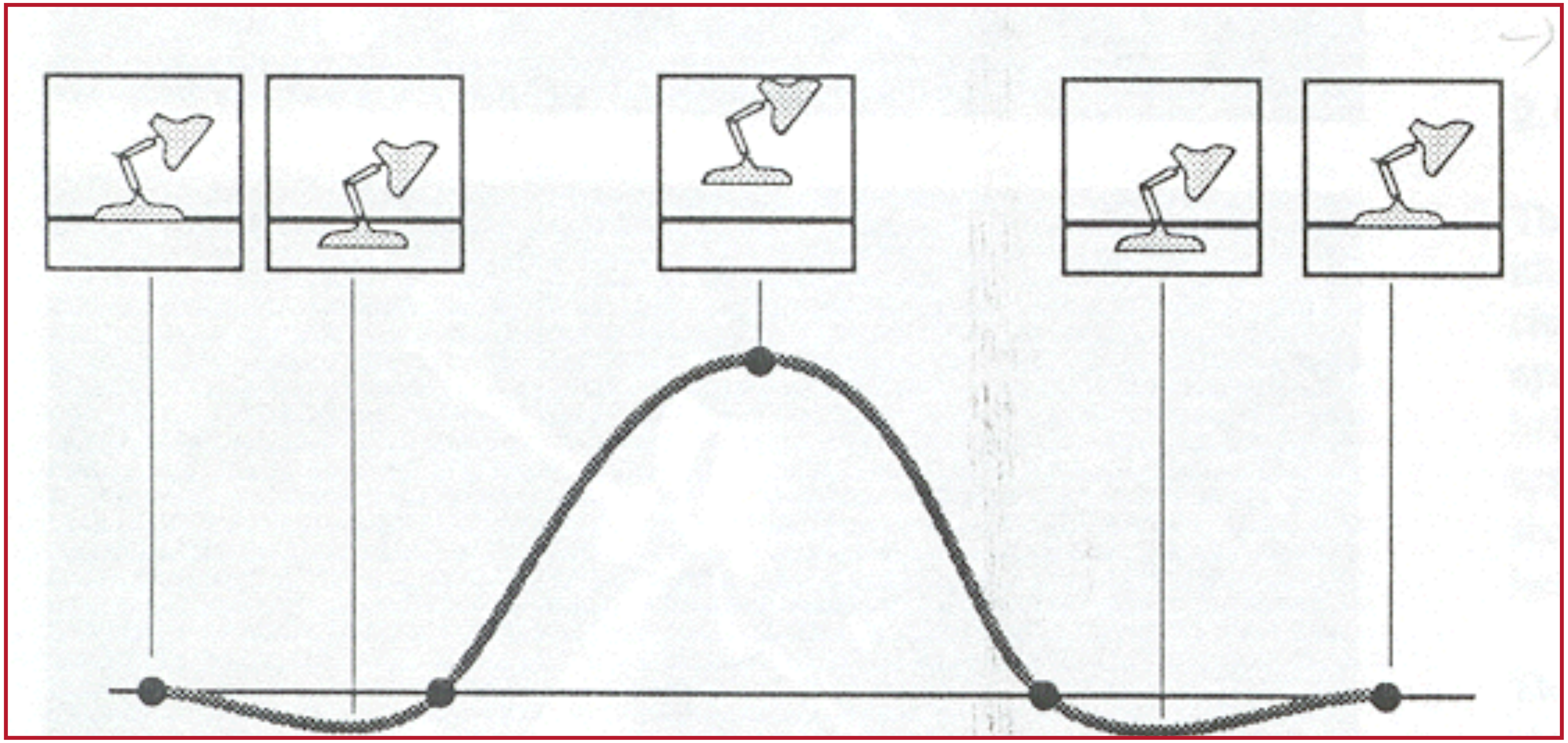
- Inbetweening:
  - Linear interpolation - usually not enough continuity



H&B Figure 16.16

Keyframe Animation

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



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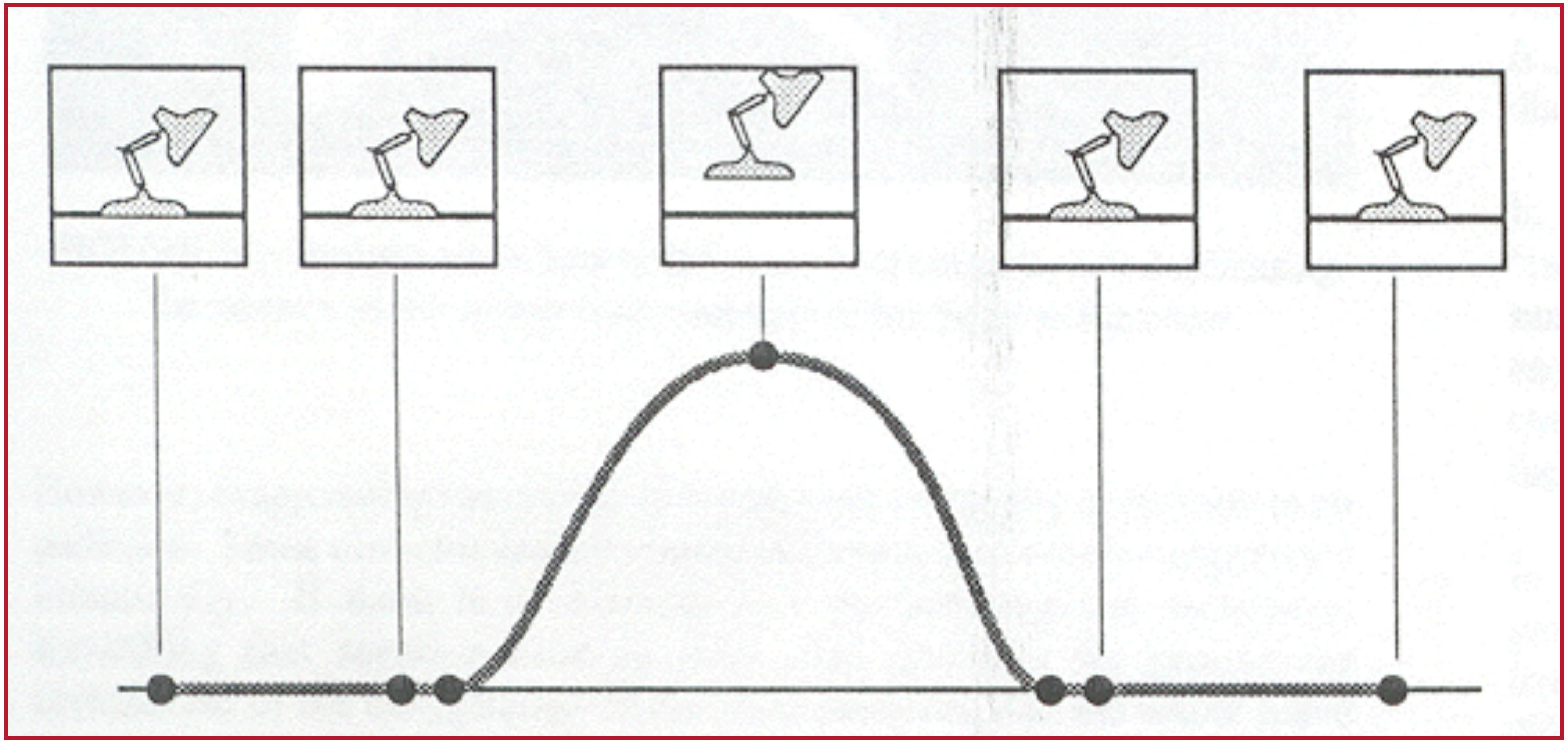

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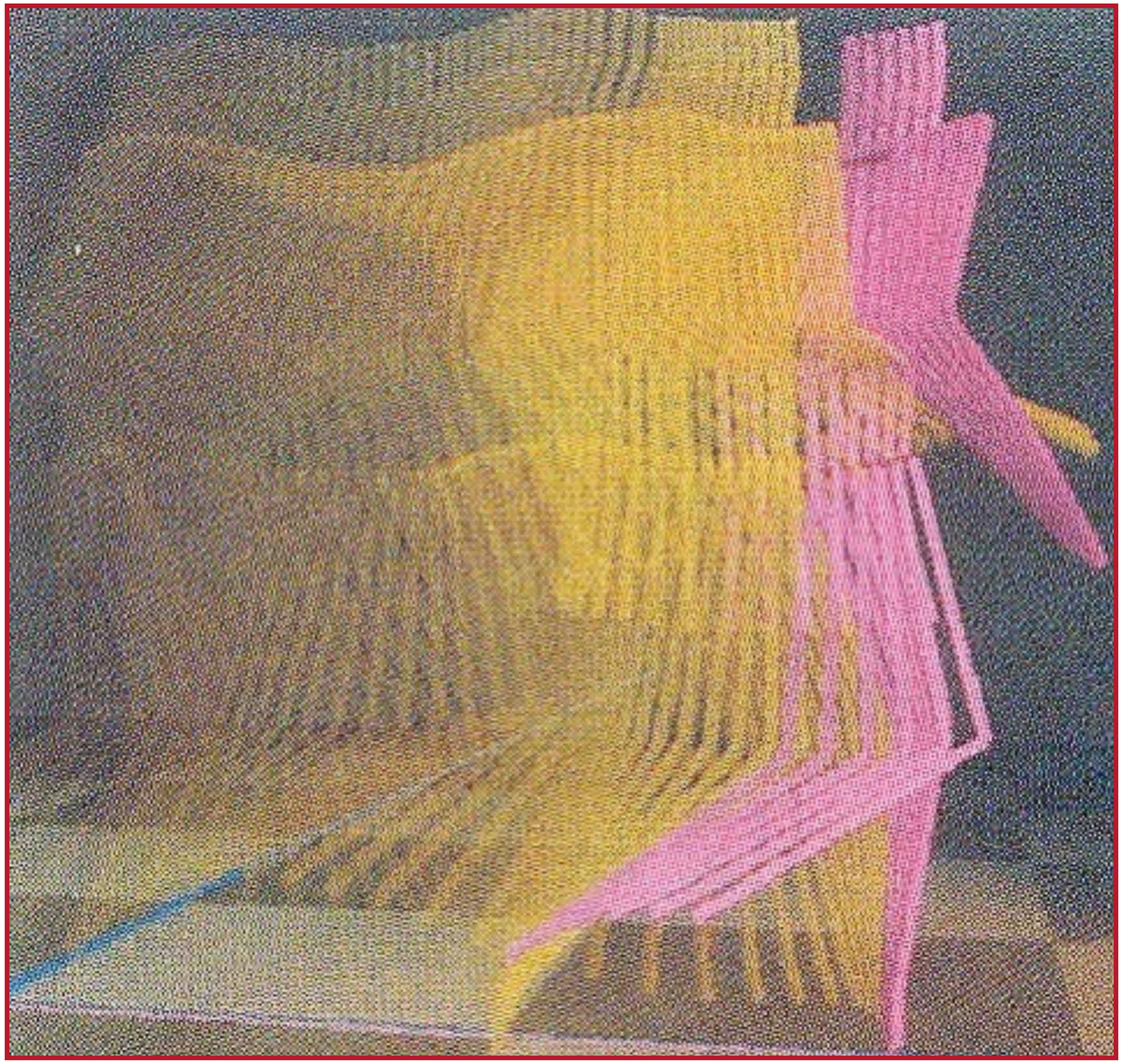
Keyframe Animation

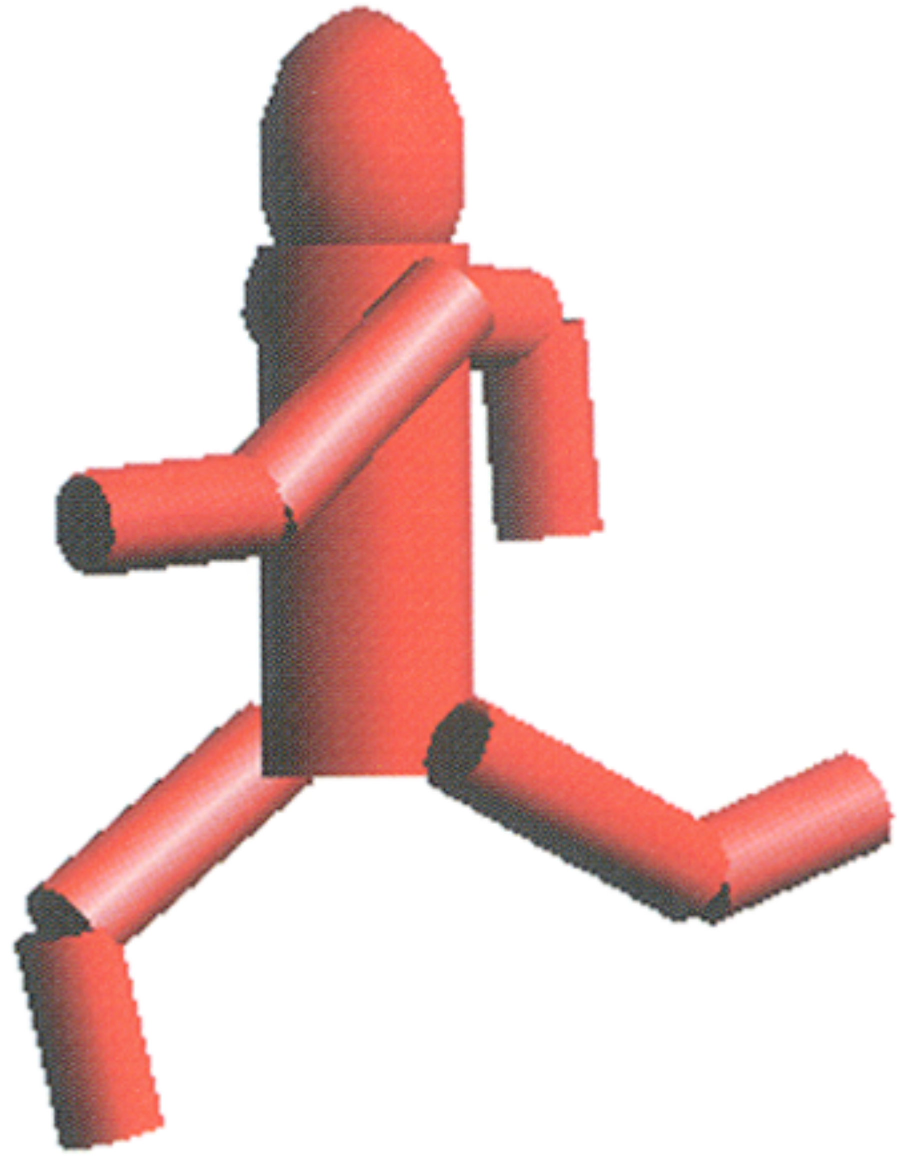
- Inbetweening:
  - Kinematics or dynamics



Rose et al. `96

Outline

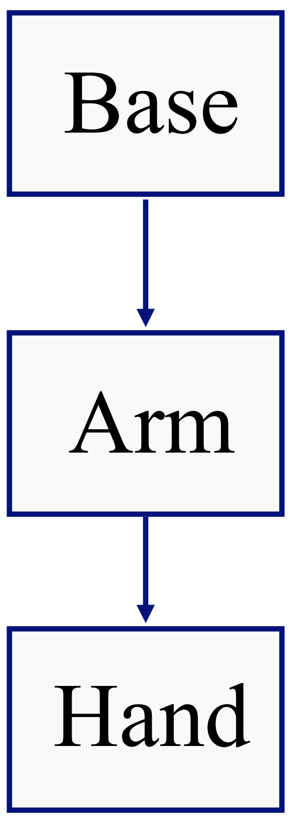
- Principles of animation
- Keyframe animation
- Articulated figures



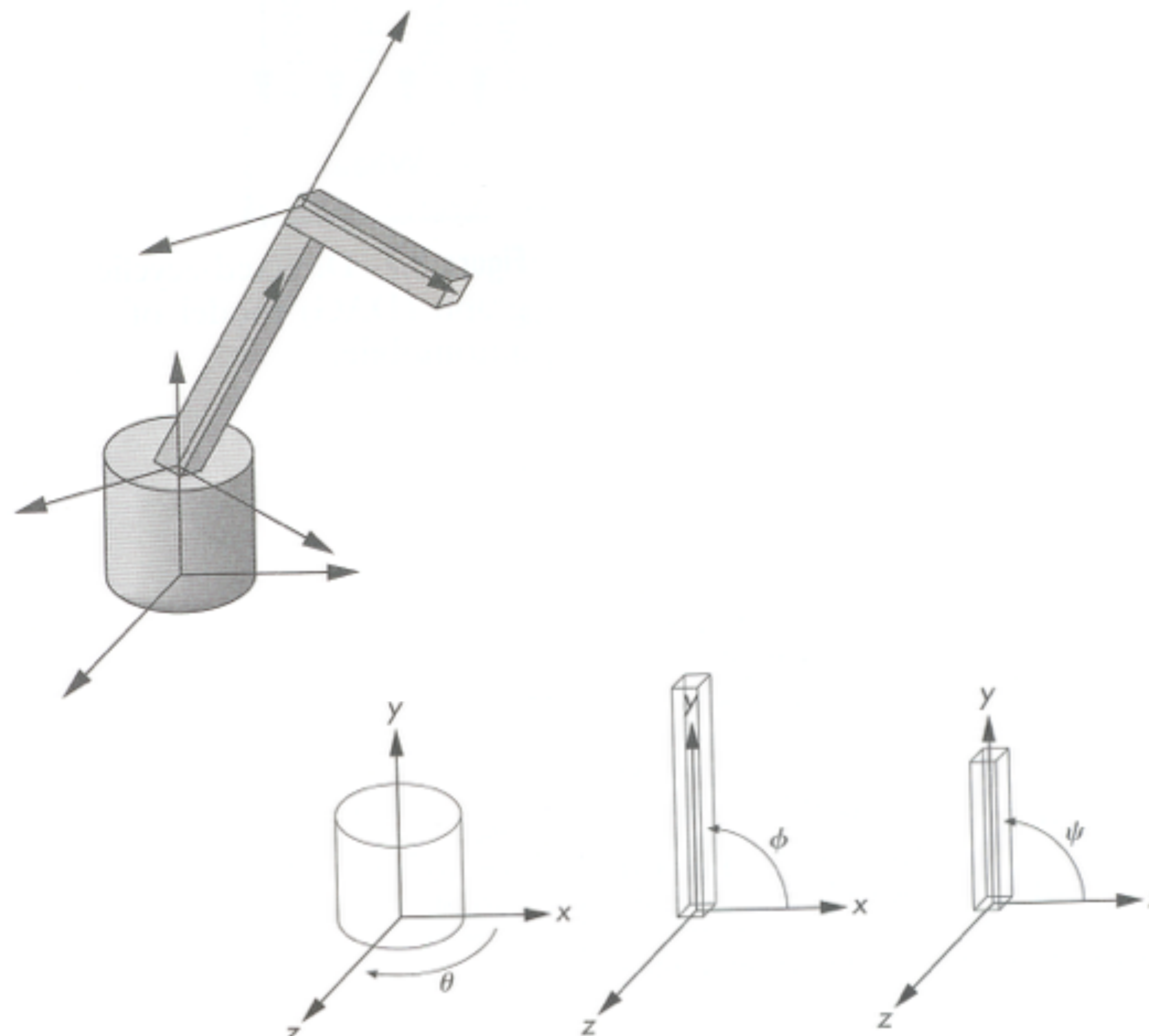
Angel Plate 1

Articulated Figures

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



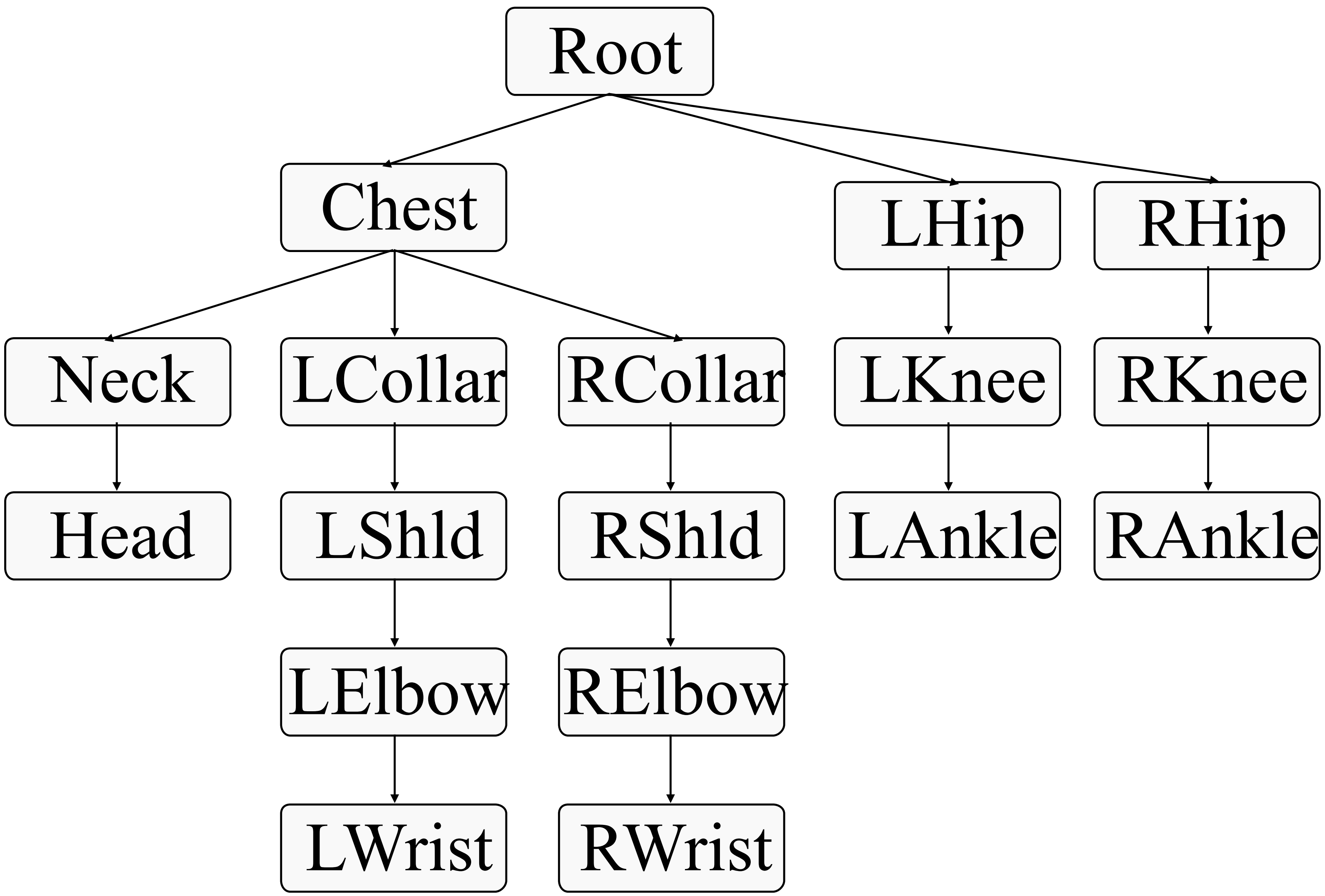
Scene Graph

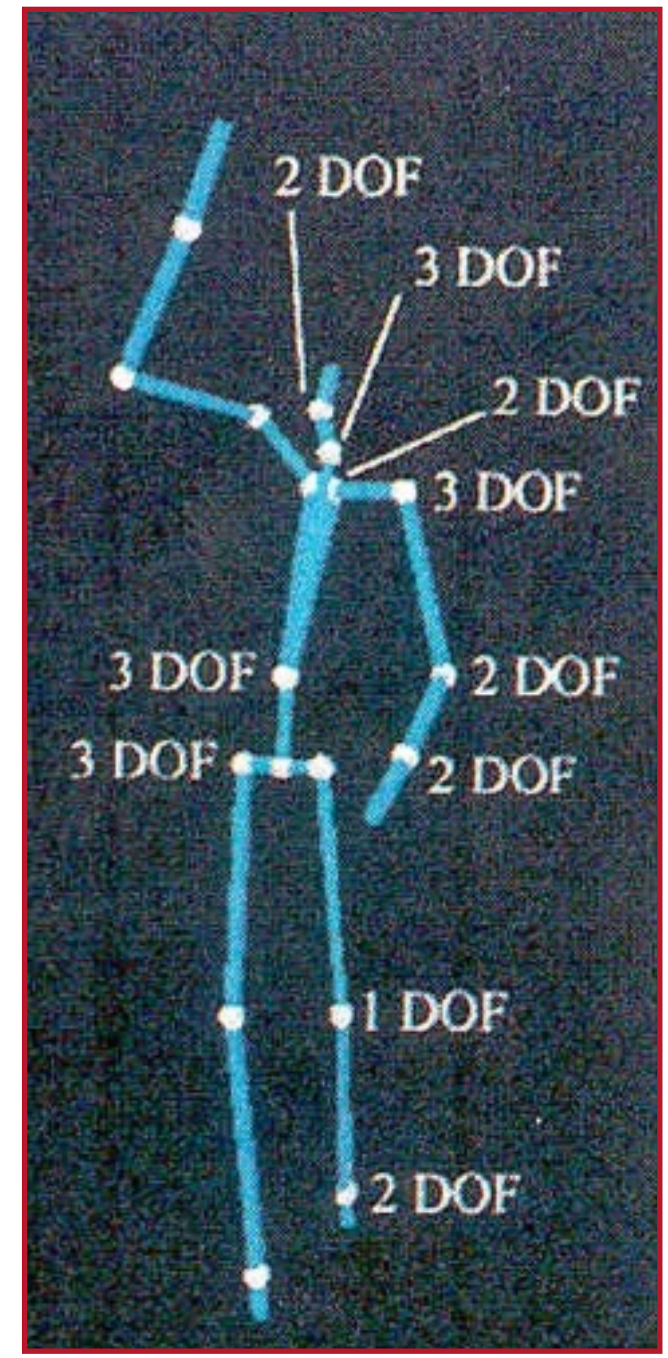


Angel Figures 8.8 & 8.9

Articulated Figures

- Well-suited for humanoid characters

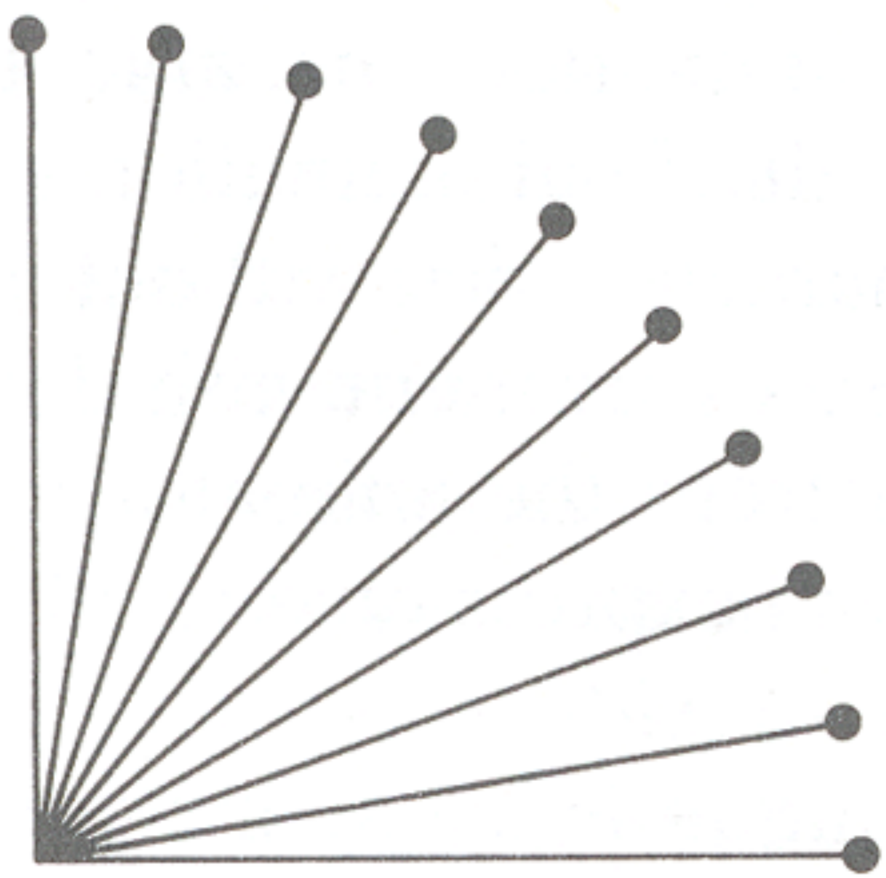




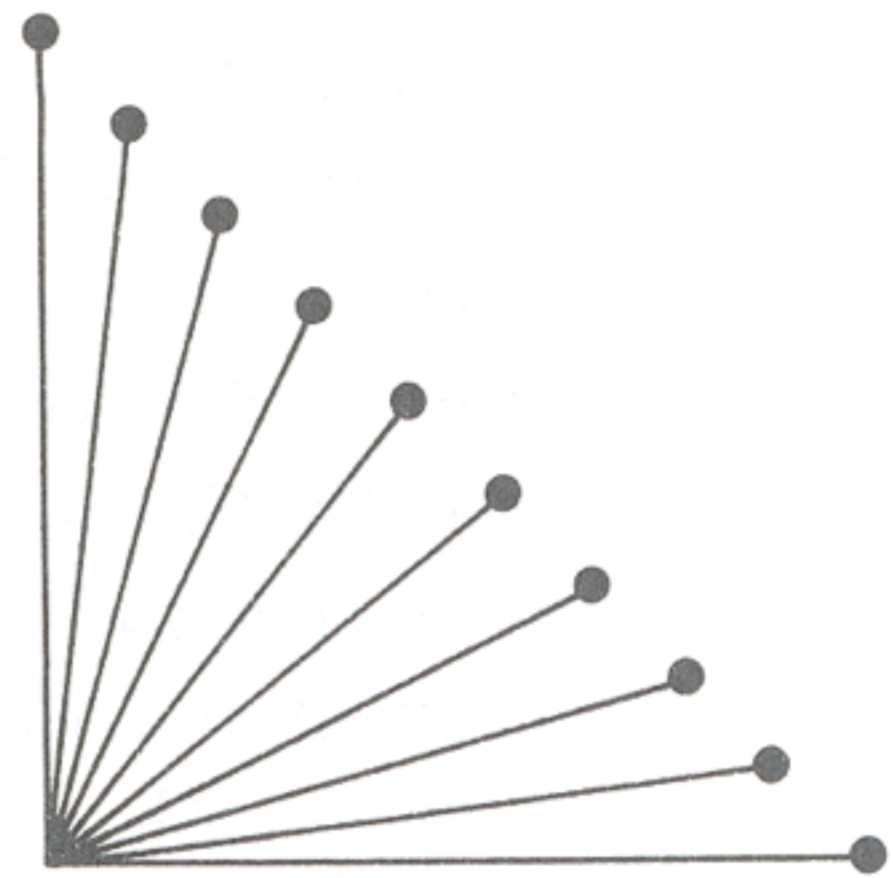
Rose et al. `96

Articulated Figures

- Inbetweening
  - Interpolate angles, not positions, between keyframes



Good arm

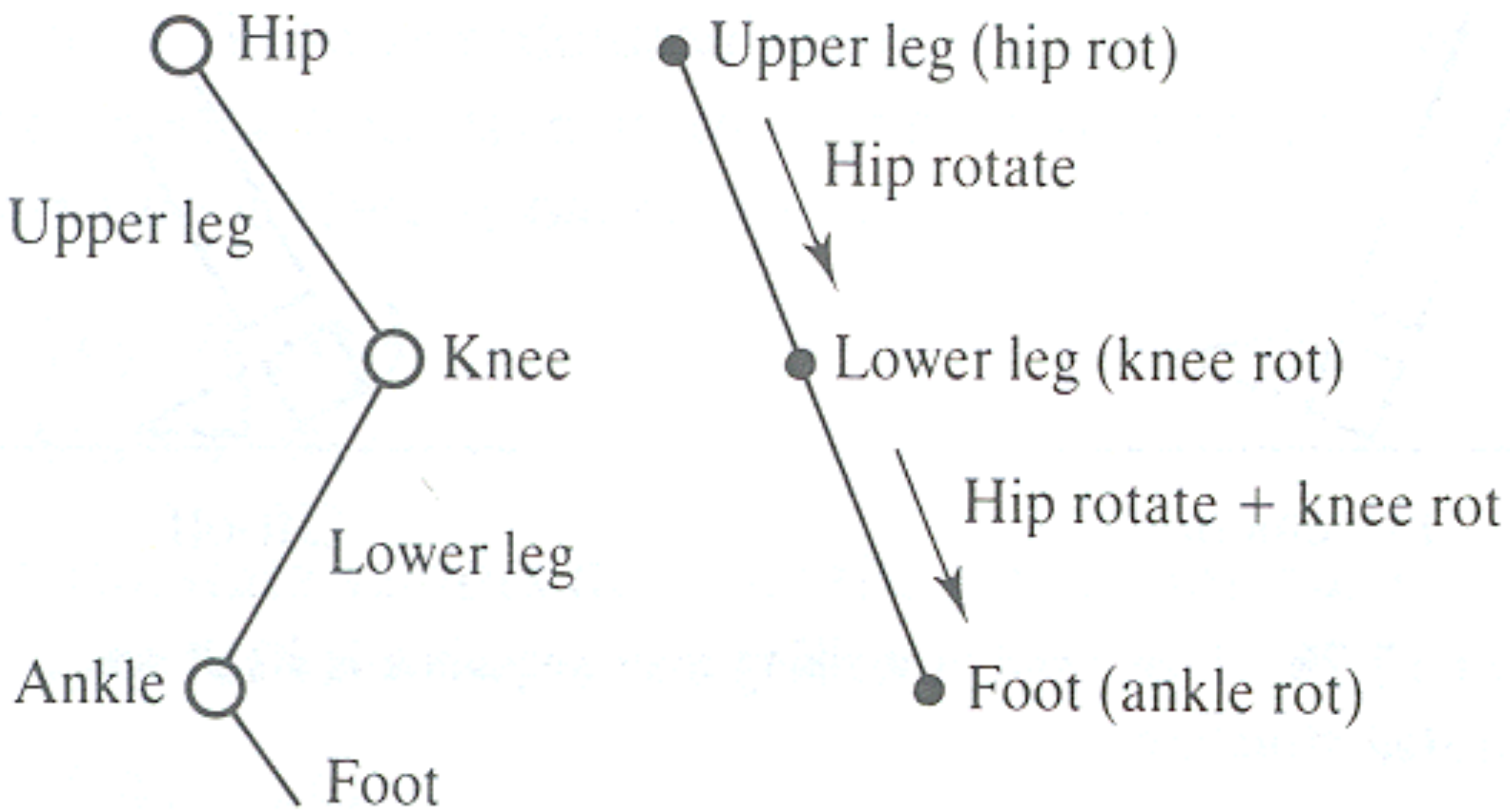


Bad arm

Watt & Watt

Example: Walk Cycle

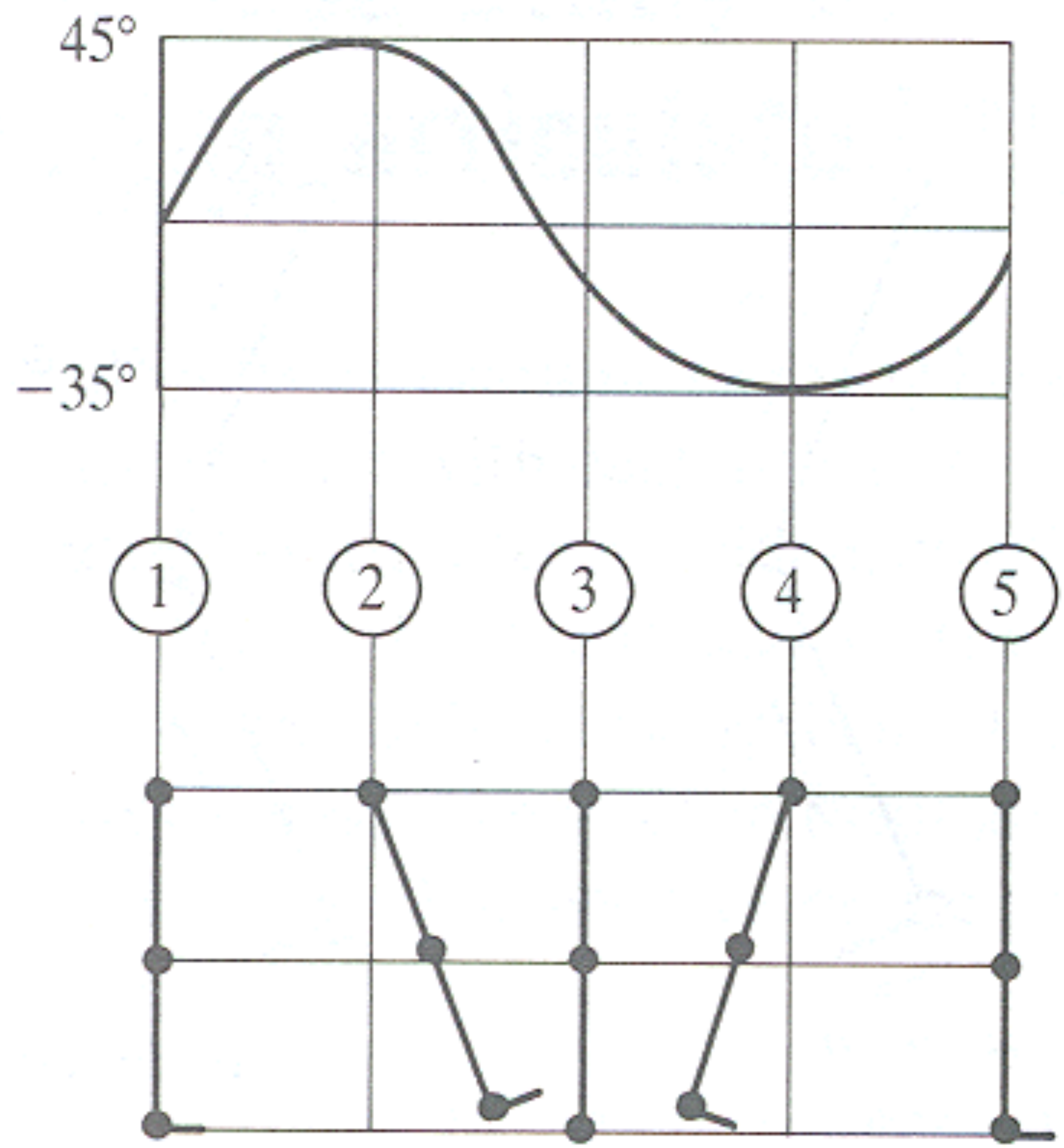
- Articulated figure:



Watt & Watt

Example: Walk Cycle

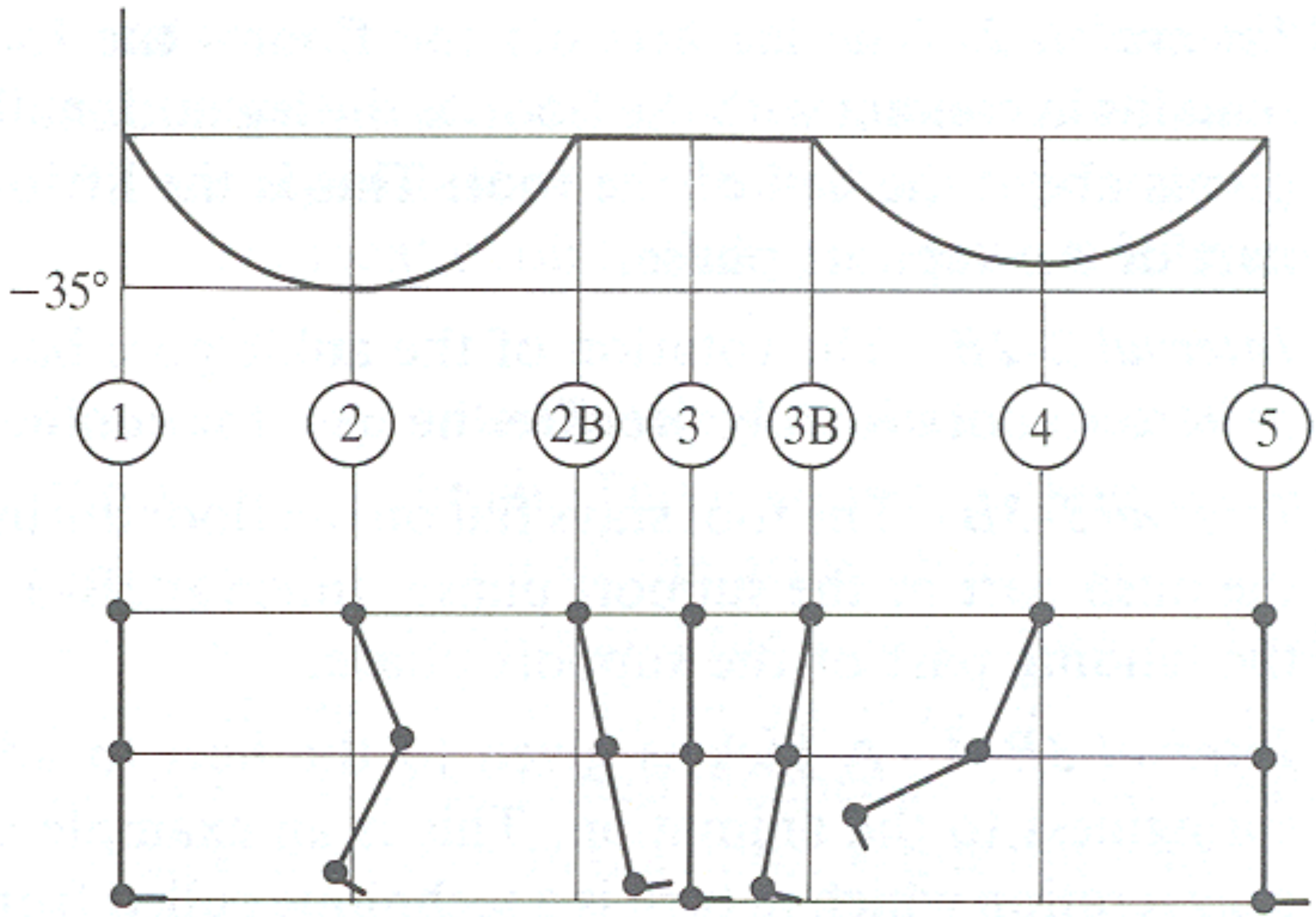
- Hip joint orientation:



Watt & Watt

Example: Walk Cycle

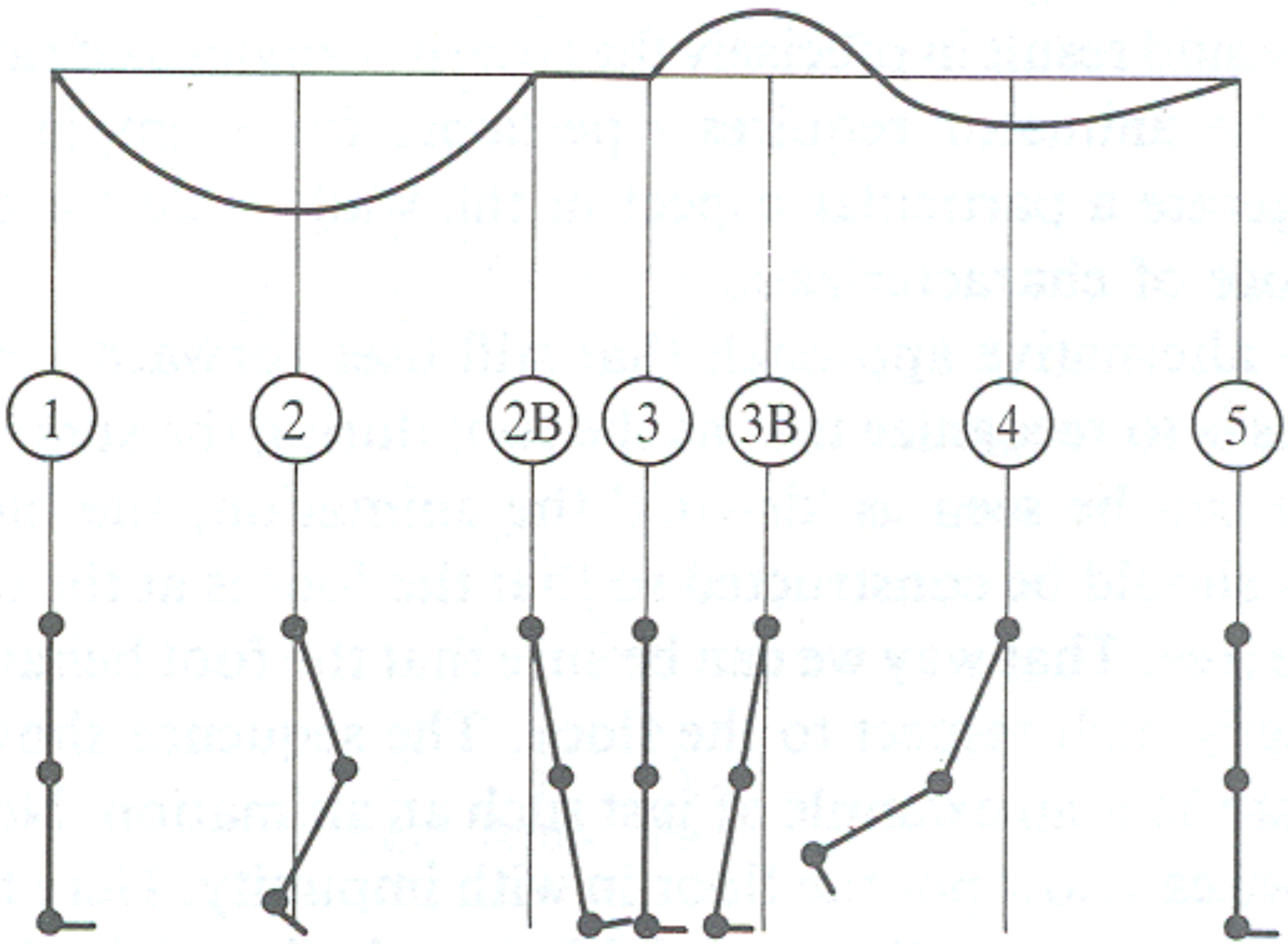
- Knee joint orientation:



Watt & Watt

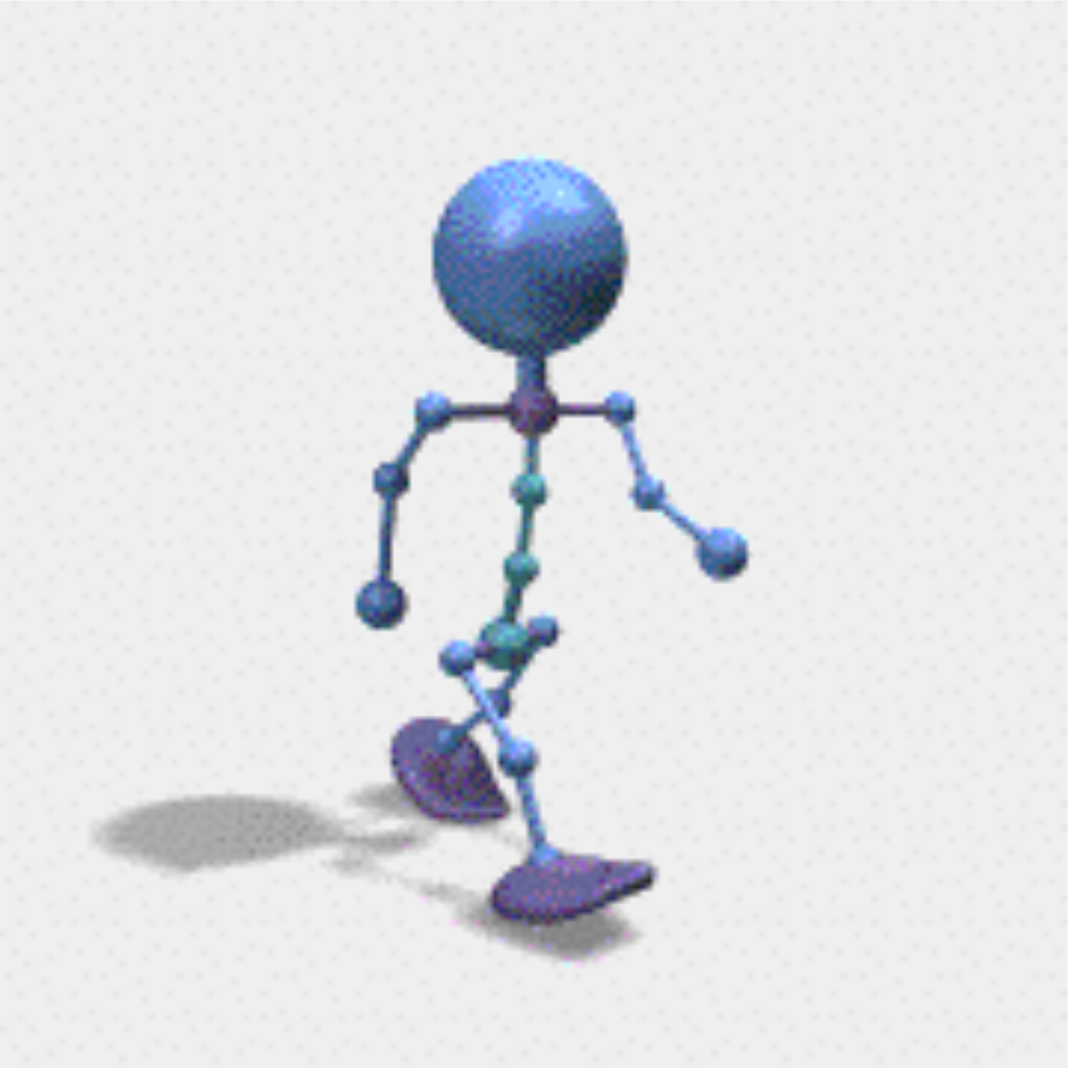
Example: Walk Cycle

- Ankle joint orientation:



Watt & Watt

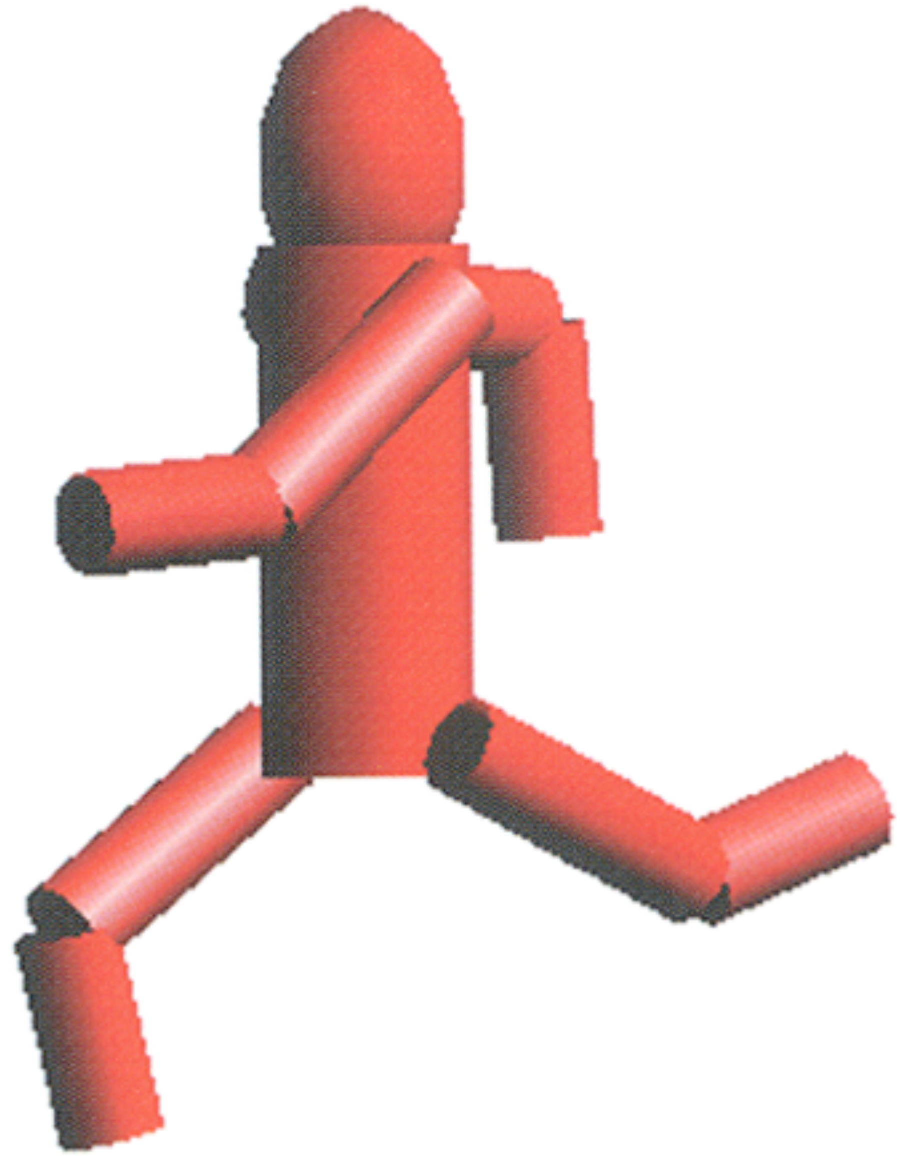
Example: Walk Cycle



https://www.youtube.com/watch?v=k86w0zlzY54

Outline

- Principles of animation
- Keyframe animation
- Articulated figures



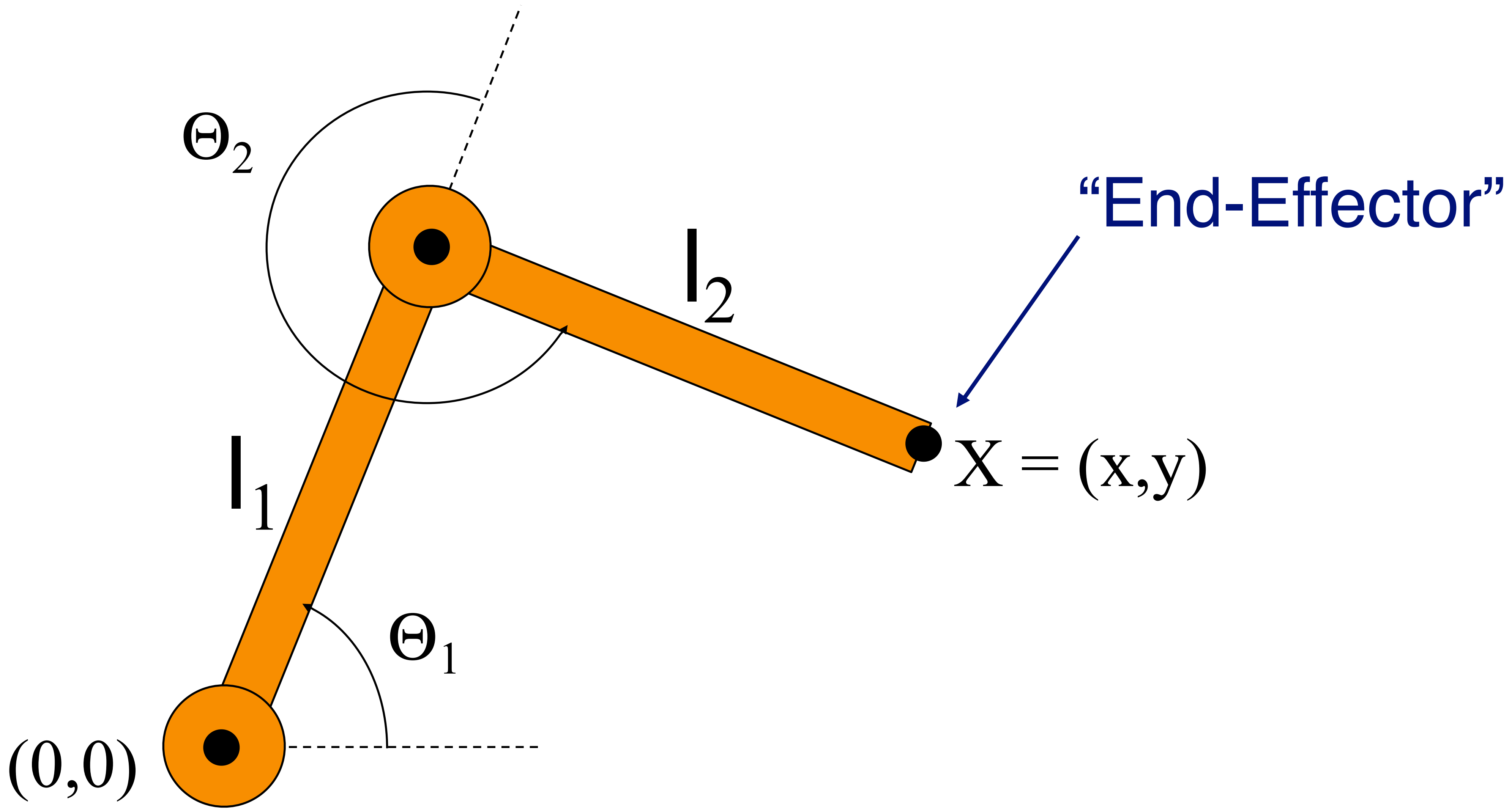
Angel Plate 1

Kinematics and Dynamics

- Kinematics
  - Considers only motion
  - Determined by positions, velocities, accelerations
- Dynamics
  - Considers underlying forces
  - Compute motion from initial conditions and physics

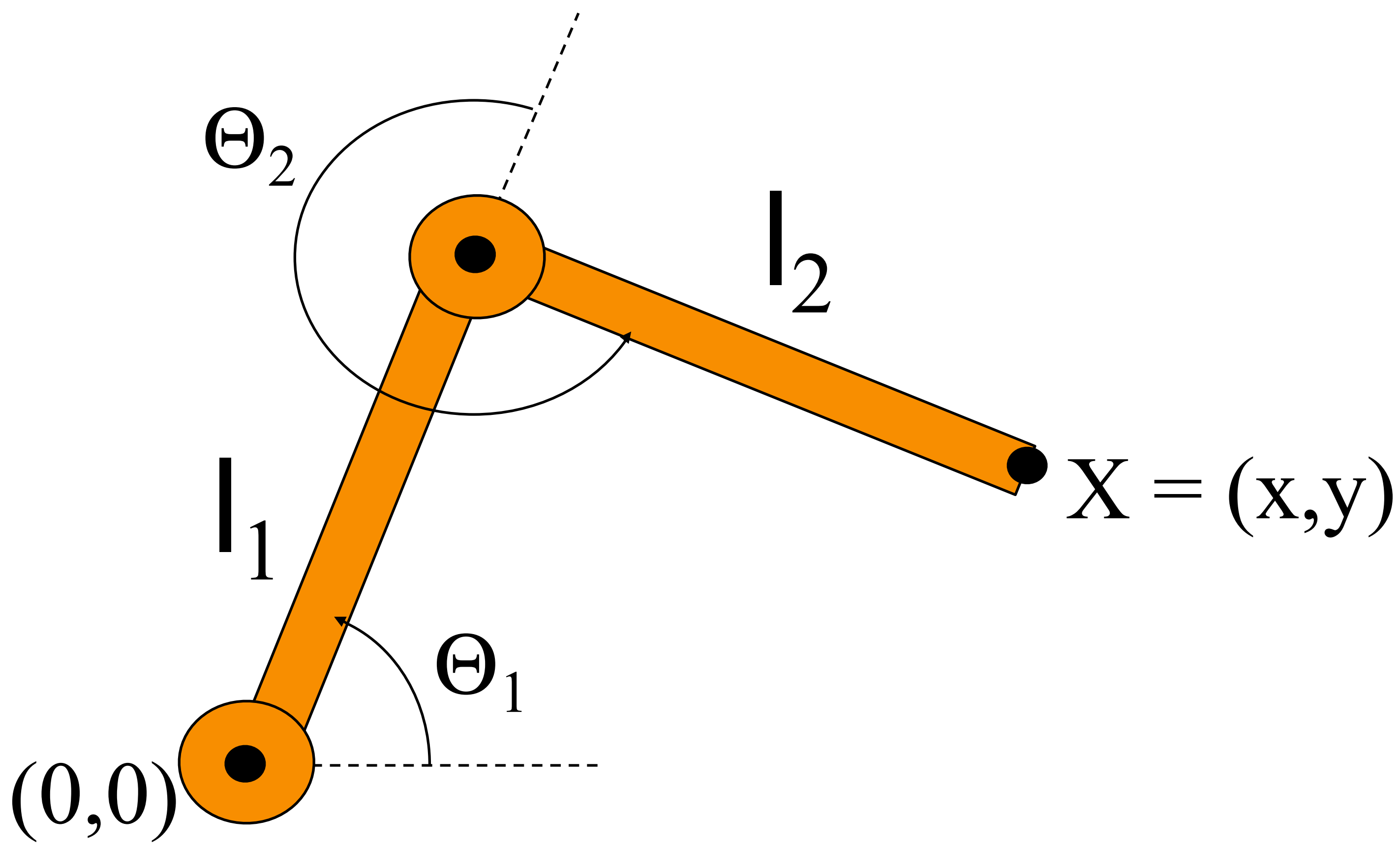
Example: 2-Link Structure

- Two links connected by rotational joints



Forward Kinematics

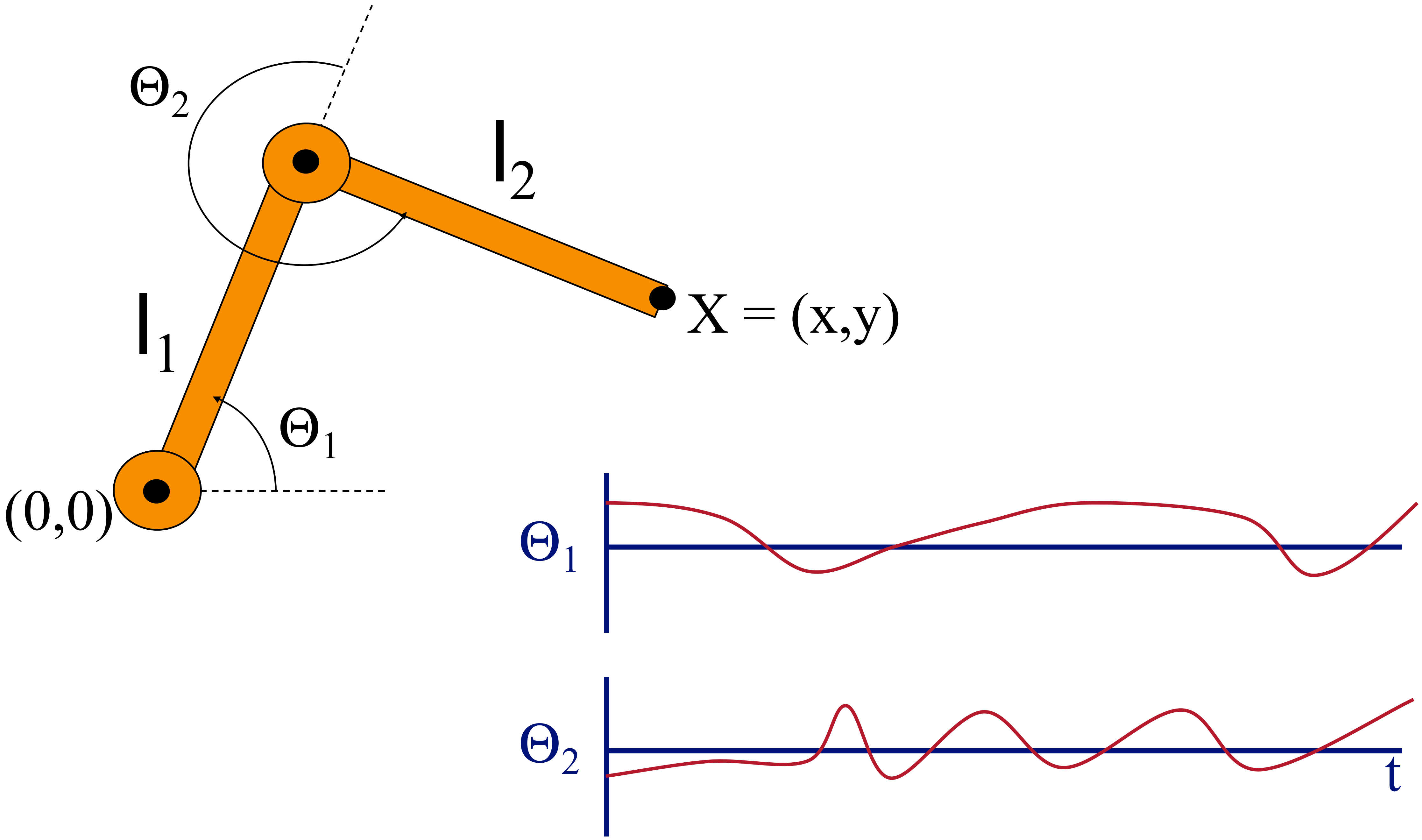
- Animator specifies joint angles: Θ_1 and Θ_2
- Computer finds positions of end-effector: X



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

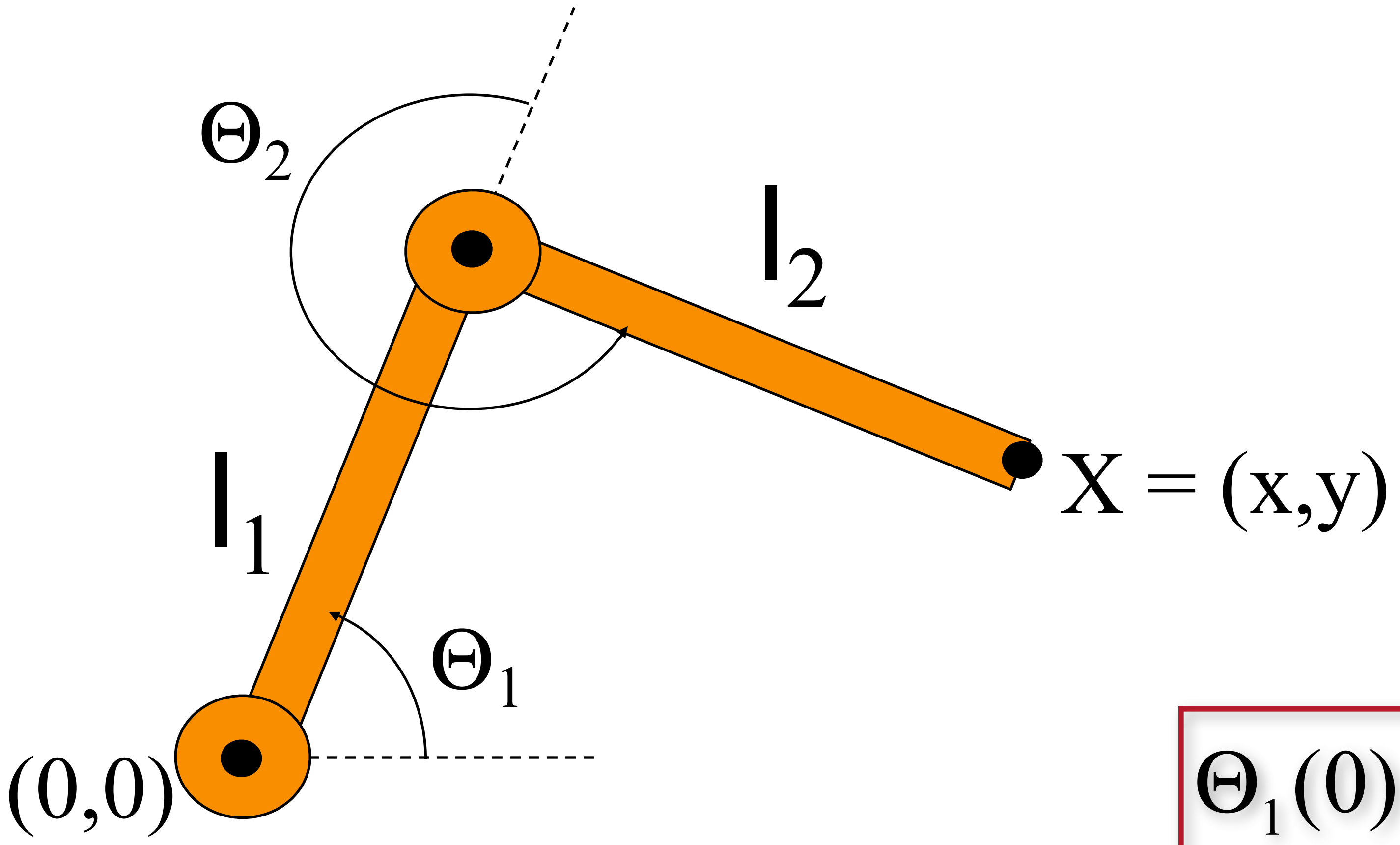
Forward Kinematics

- Joint motions can be specified by spline curves



Forward Kinematics

- Joint motions can be specified by initial conditions and velocities

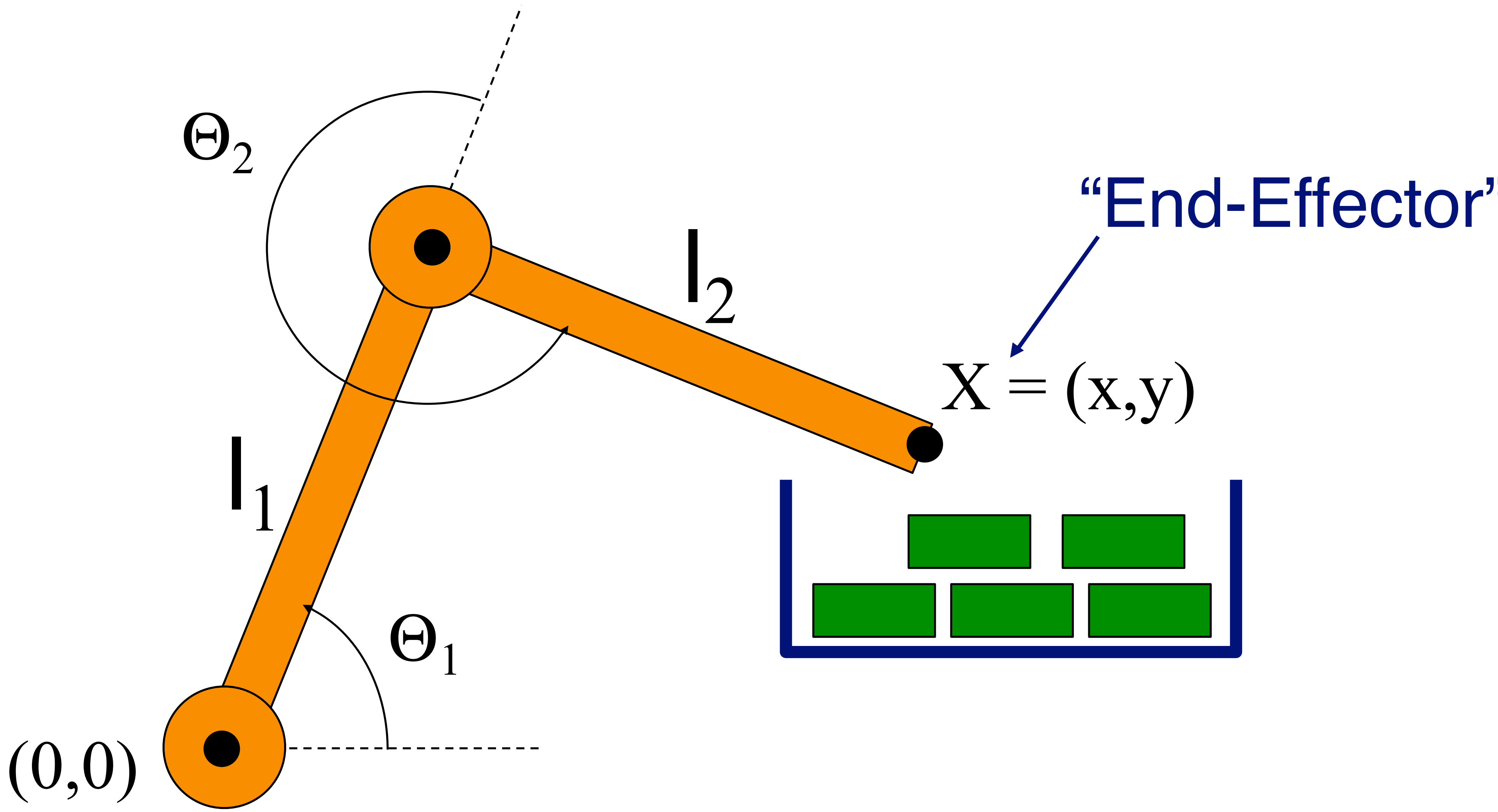


$$\Theta_1(0) = 60^\circ \qquad \Theta_2(0) = 250^\circ$$

$$\frac{d\Theta_1}{dt} = 1.2 \qquad \frac{d\Theta_2}{dt} = -0.1$$

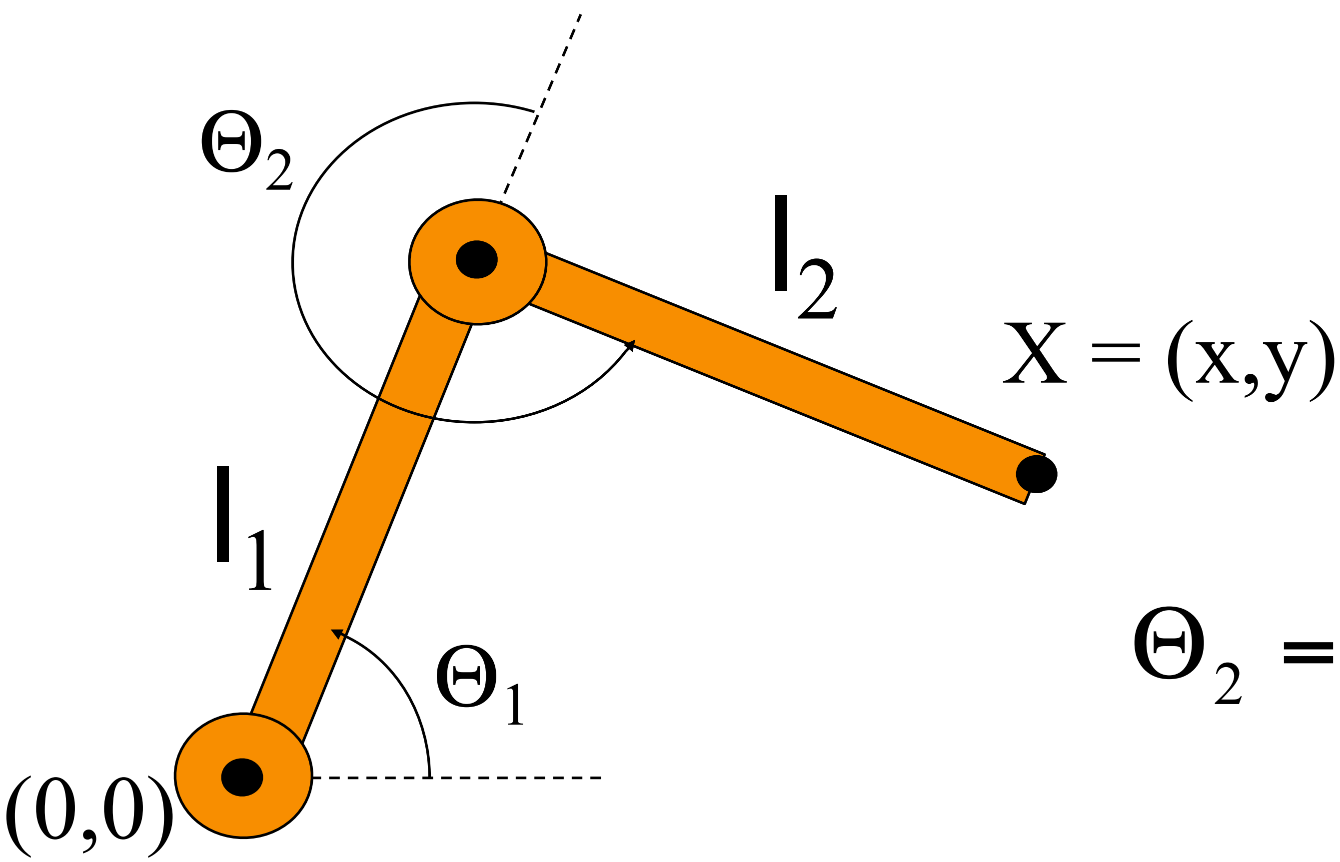
Example: 2-Link Structure

- 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:

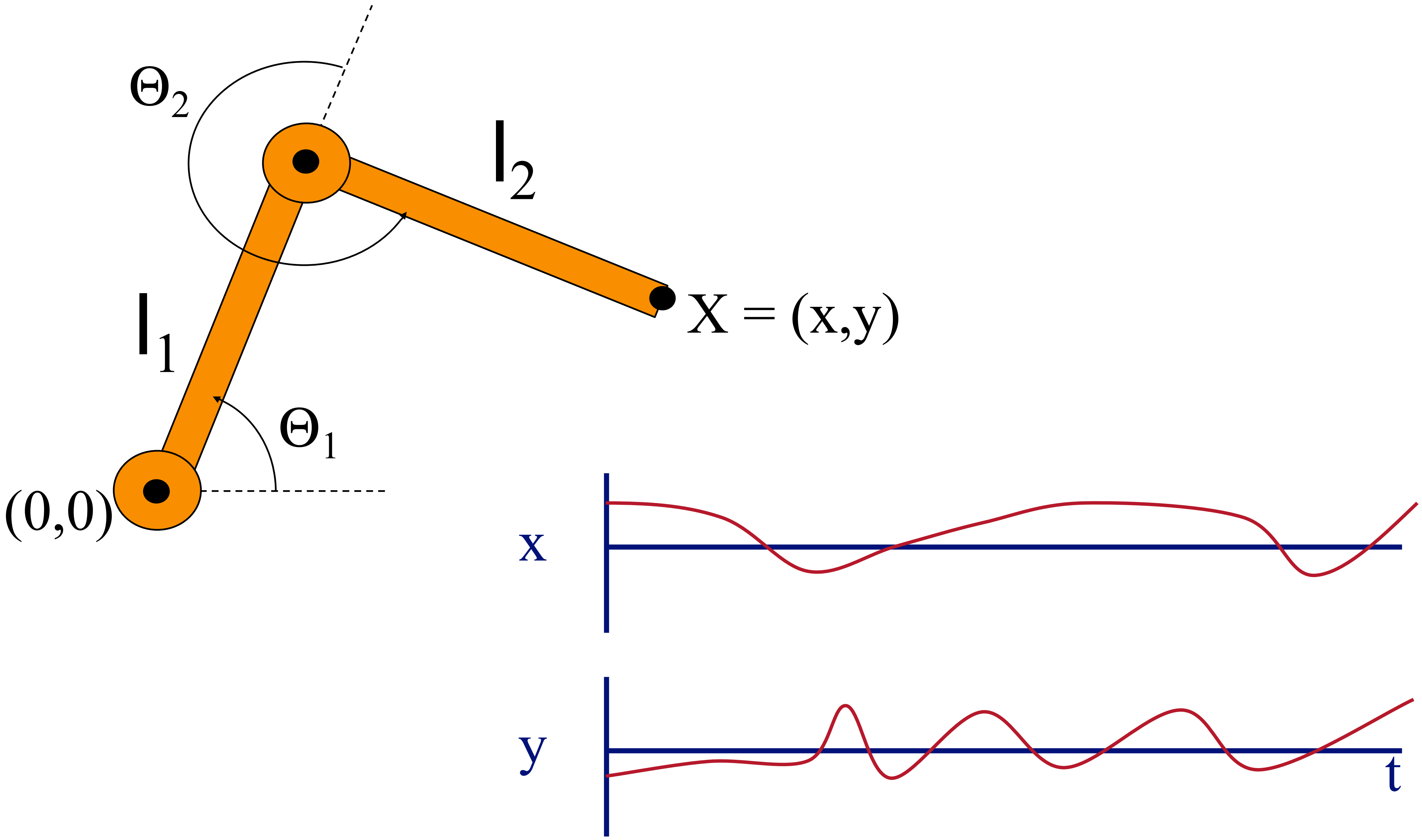


$$\Theta_2 = \cos^{-1}\left(\frac{x^2 + x^2 - l_1^{\,2} - l_2^{\,2}}{2 l_1 l_2}\right)$$

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

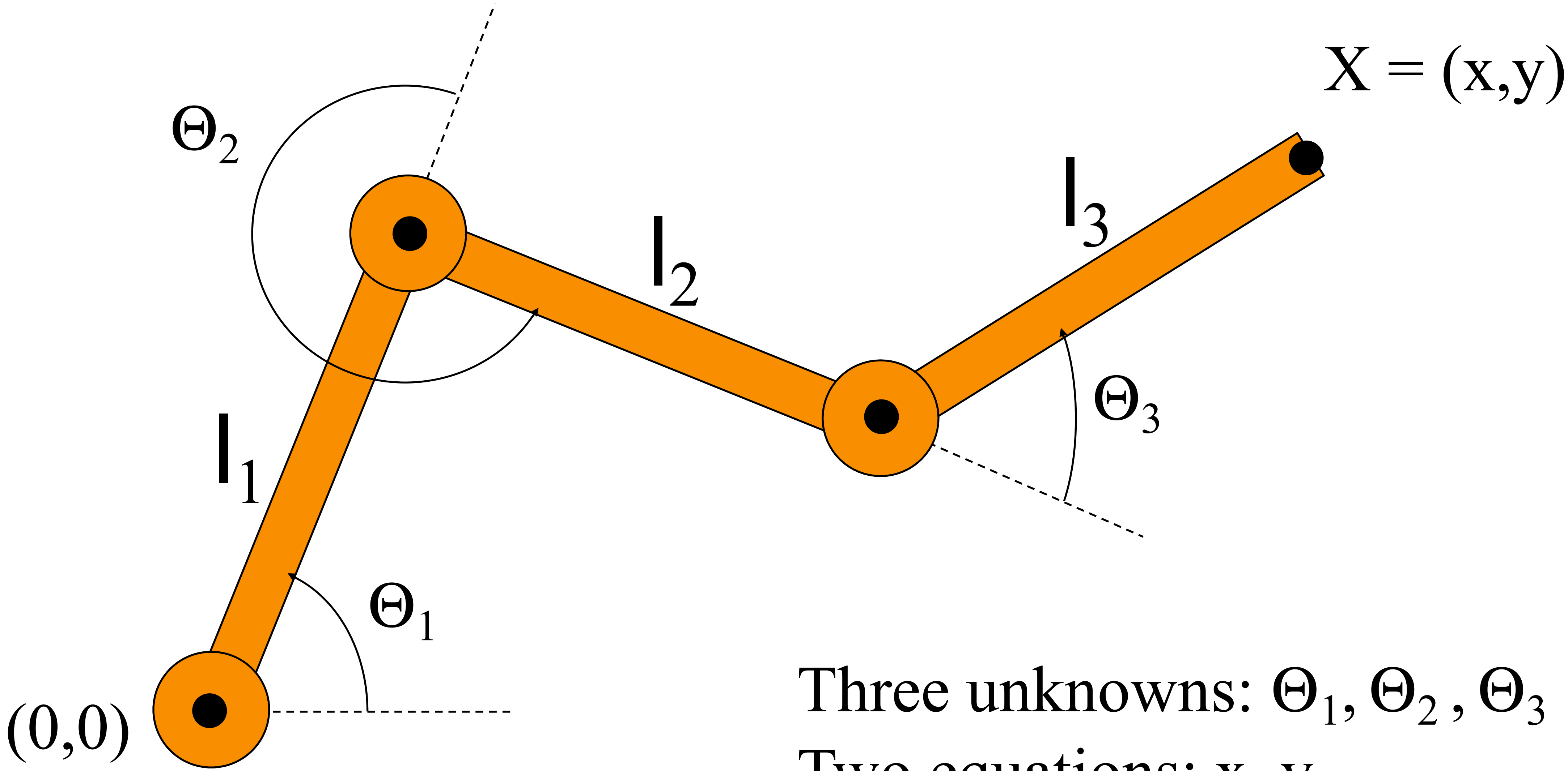
Inverse Kinematics

- End-effector postions can be specified by splines



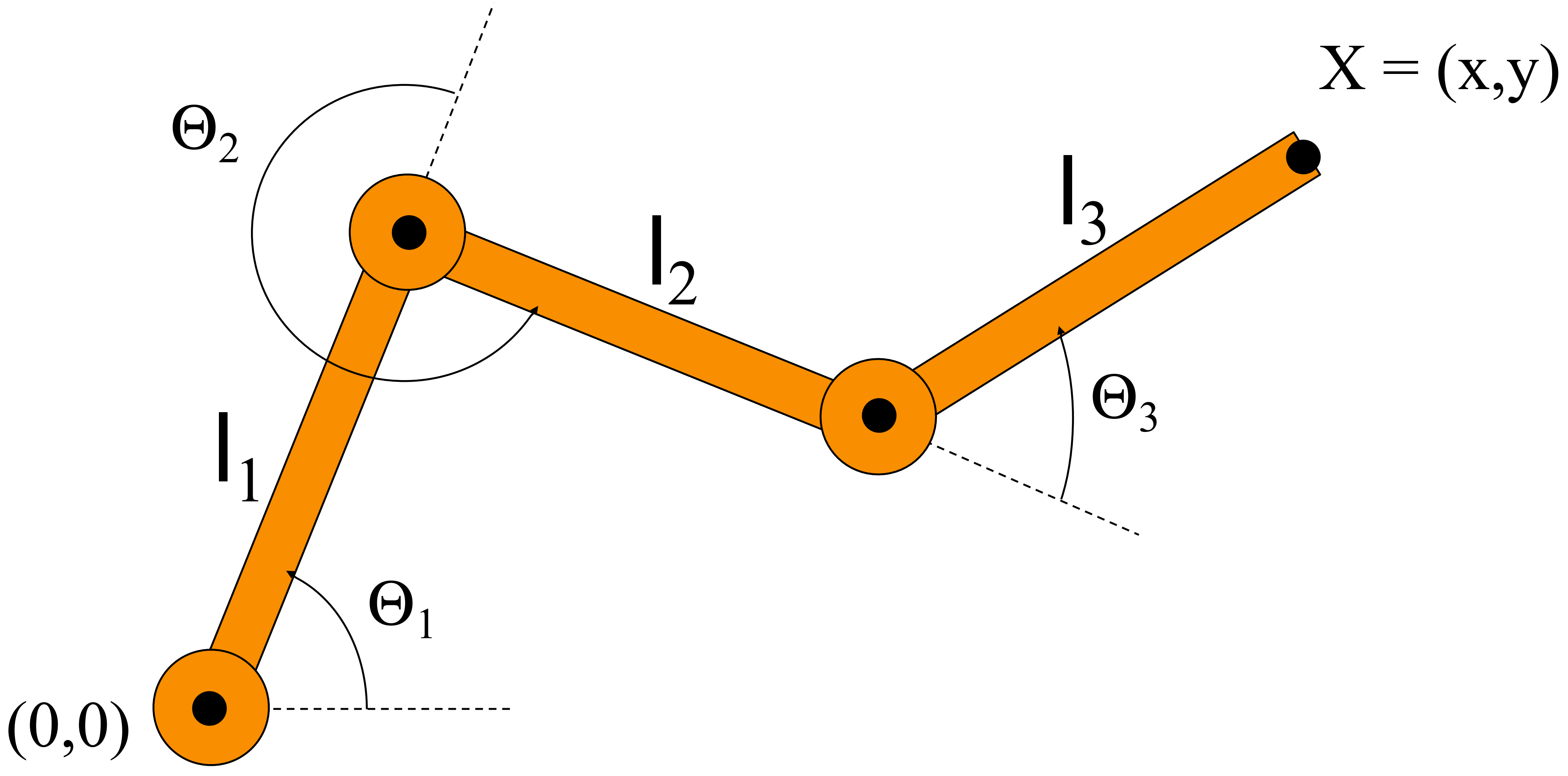
Inverse Kinematics

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



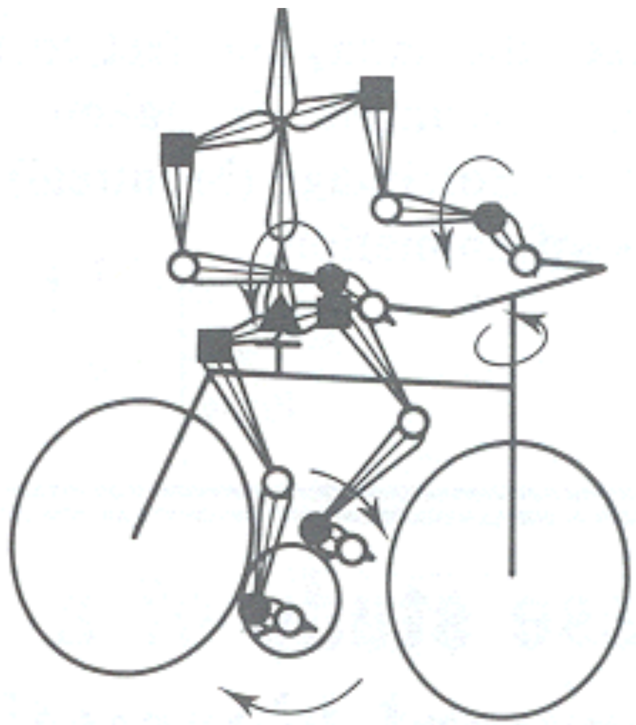
Inverse Kinematics

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



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



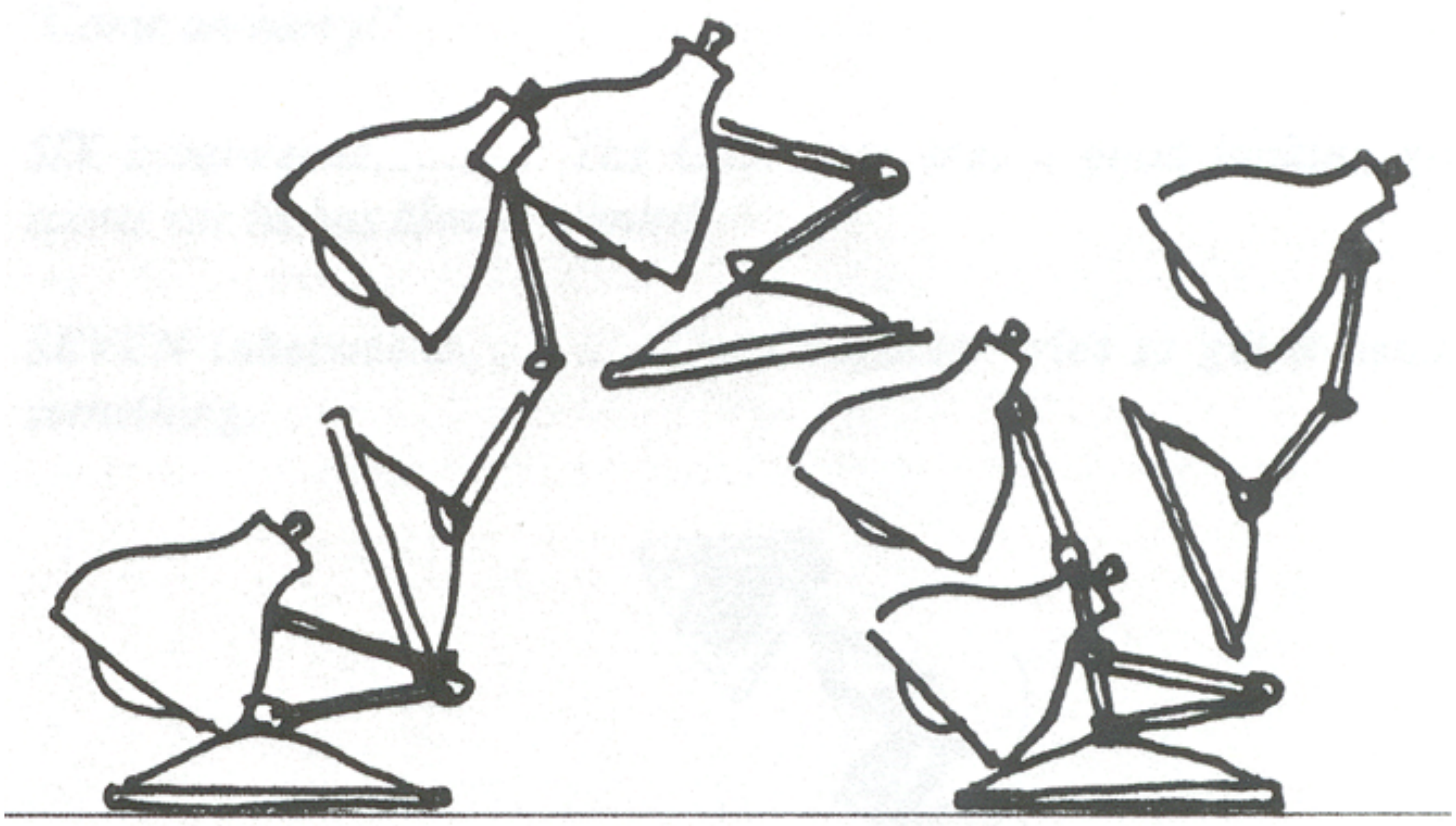
Inverse kinematics provides easier specification for many animation tasks, but it is computationally more difficult

Overview

- Kinematics
  - Considers only motion
  - Determined by positions, velocities, accelerations
- Dynamics
  - Considers underlying forces
  - Compute motion from initial conditions and physics

Dynamics

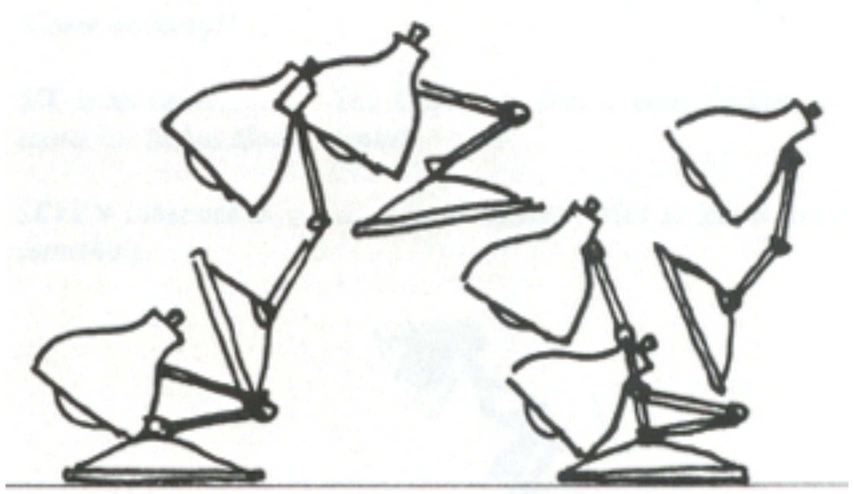
- Simulation of physics insures realism of motion



Lasseter `87

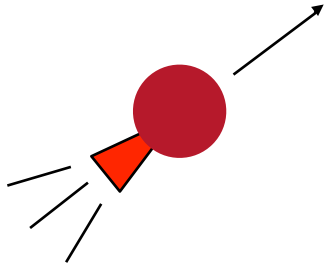
Spacetime Constraints

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

- Discretize time steps:

$$x'_i = \frac{x_i - x_{i-1}}{h}$$

$$x''_i = \frac{x_{i+1} - 2x_i + x_{i-1}}{h^2}$$

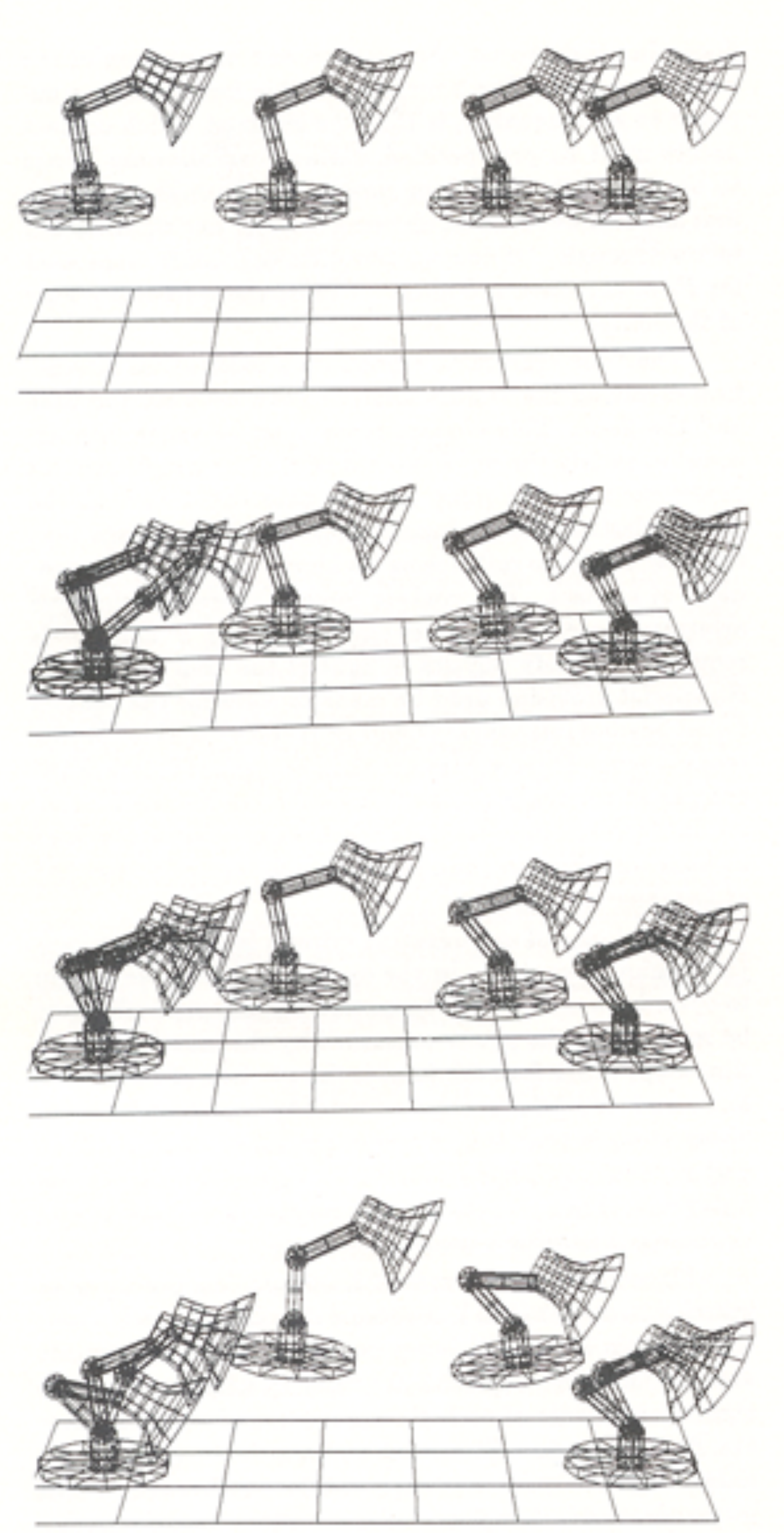
$$m\left(x''_i = \frac{x_{i+1} - 2x_i + x_{i-1}}{h^2}\right) - f_i - mg = 0$$

Minimize $h\sum_i |f_i|^2$ subject to $x_0 = a$ and $x_1 = b$

Witkin & Kass `88

Spacetime Constraints

- Solve with iterative optimization methods



Witkin & Kass `88

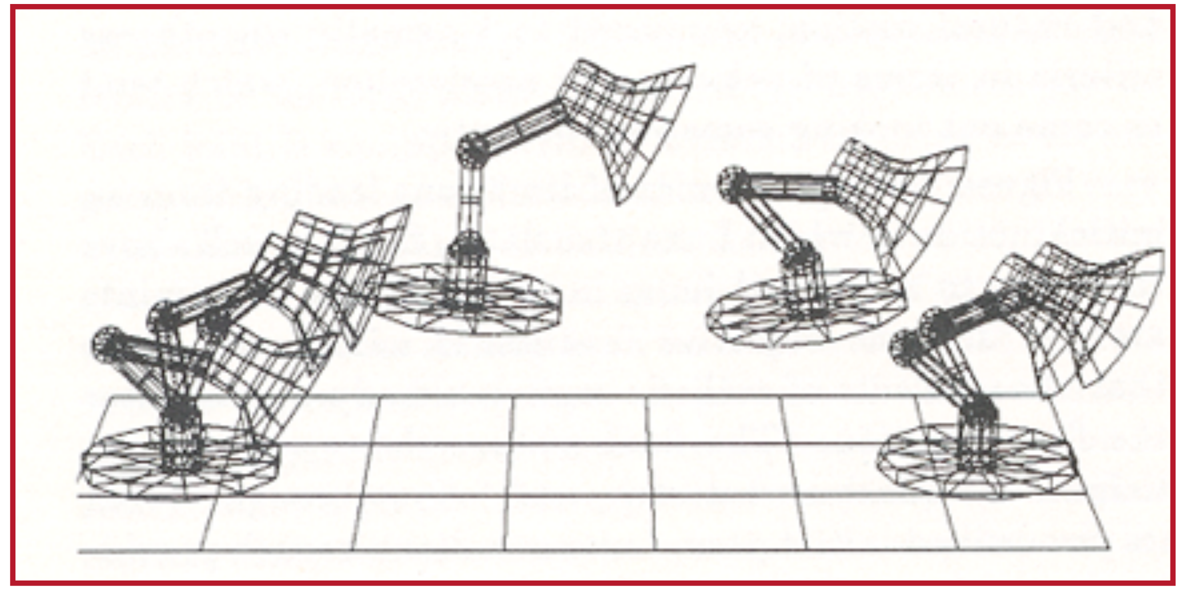
Spacetime Constraints

- 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

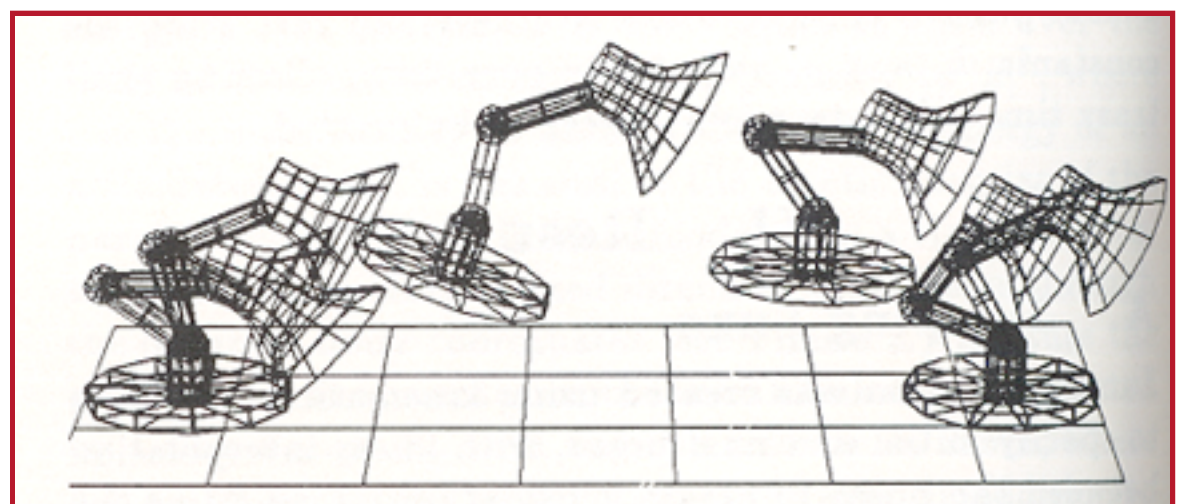
- Challenges:
  - Specifying constraints and objective functions
  - Avoiding local minima during optimization

Spacetime Constraints

- Adapting motion:



Original Jump

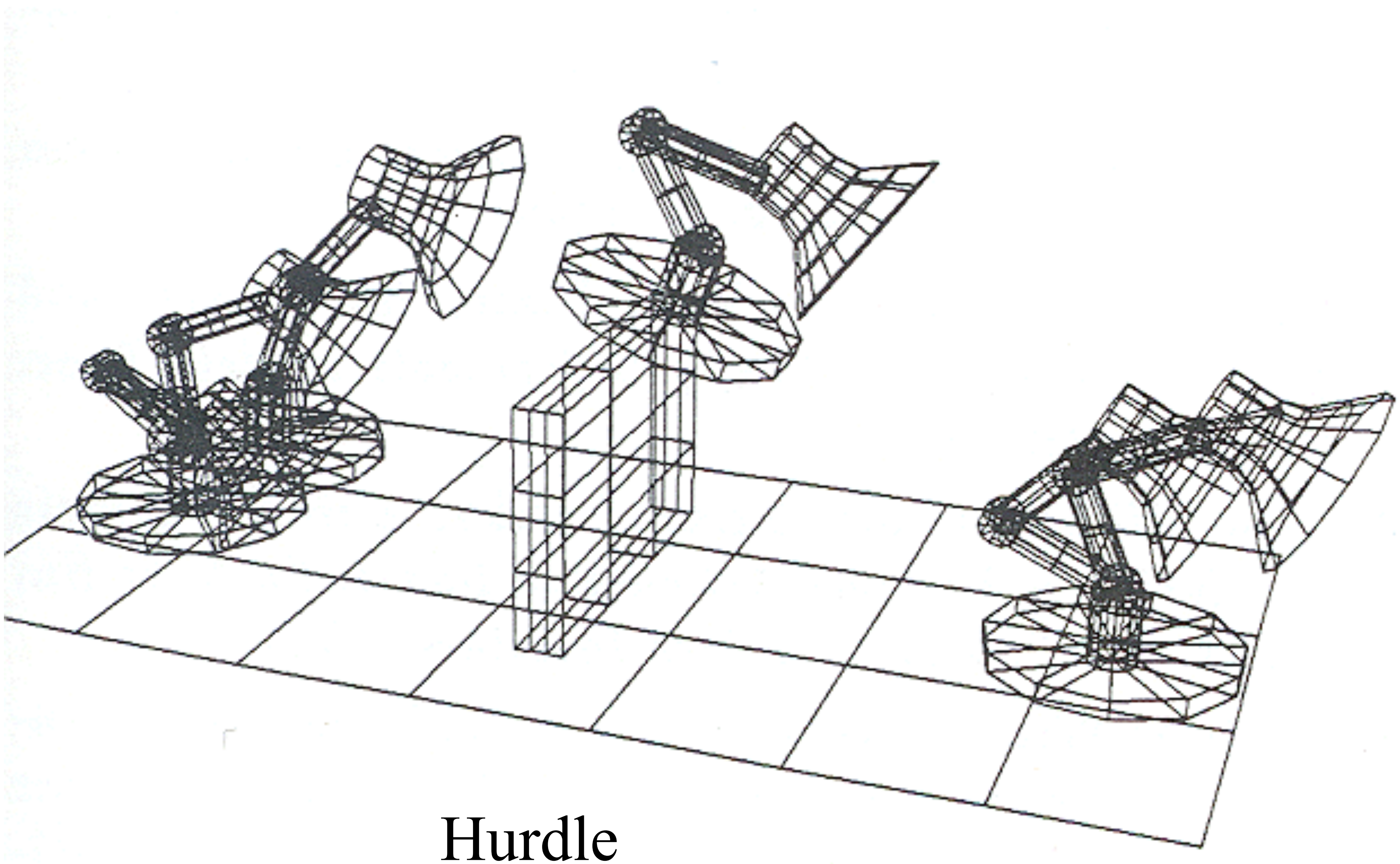


Heavier Base

Witkin & Kass `88

Spacetime Constraints

- Adapting motion:



Hurdle

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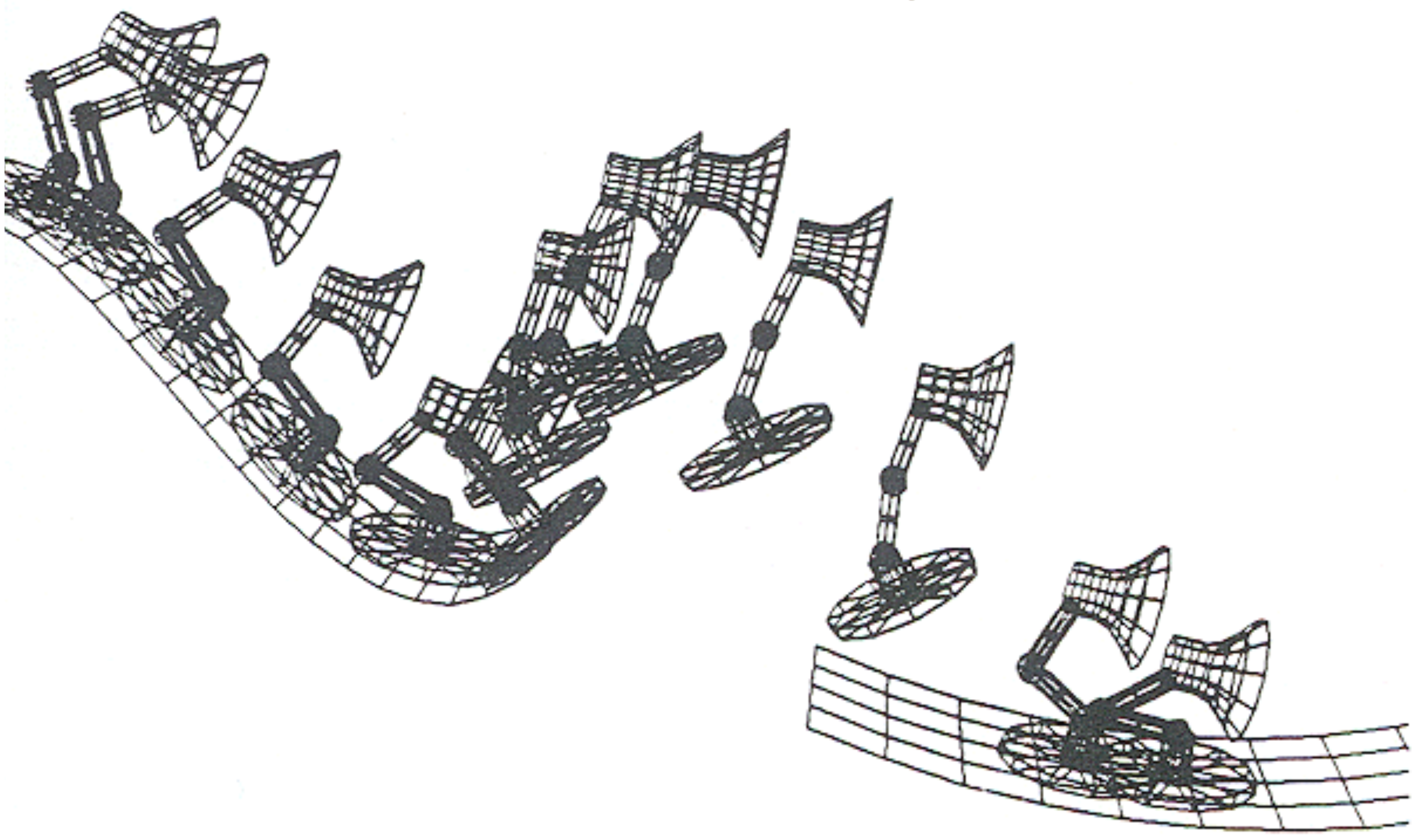
Spacetime Constraints

- Adapting motion:



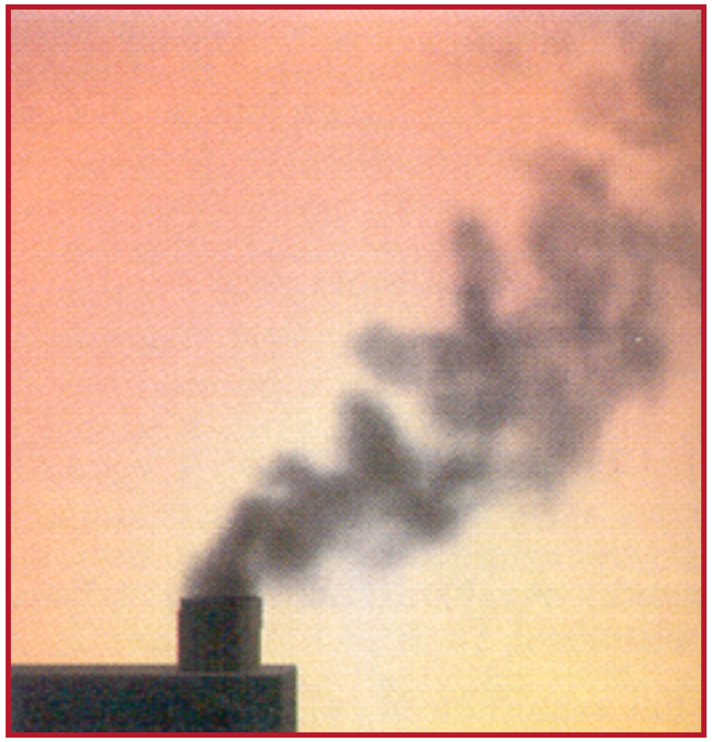
Ski Jump

Witkin & Kass `88

Dynamics

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

Cloth
(Baraff & Witkin `98)



Hot Gases
(Foster & Metaxas `97)

Summary

- Principles of animation
- Keyframe animation
- Articulated figures