Announcements

- Reminder on accommodations
  - Check Piazza/previous lecture
- Project 3-1
  - Official deadline was Tuesday, but due to slip days we expect many students are still working on it
  - TAs are still working to provide OH and Piazza support
- Project 3-2
  - Released yesterday, deadline pushed back to adjust
  - Piazza for details
- Final Project

Cool News!

Edwin E. Catmull

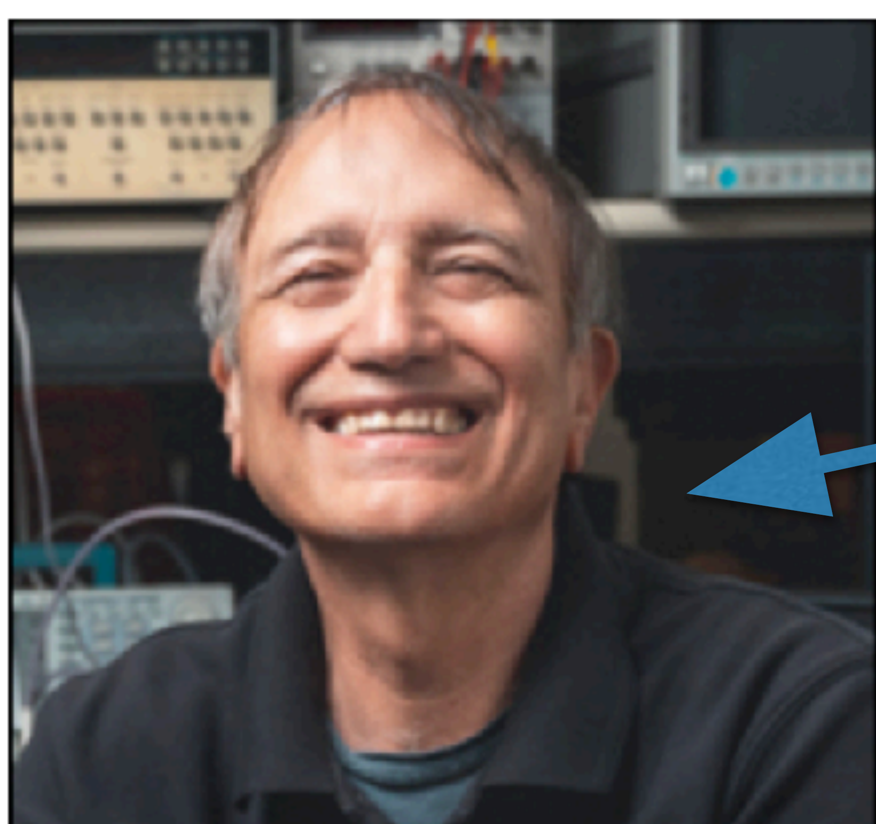
https://awards.acm.org/about/2019-turing

PIONEERS OF MODERN COMPUTER GRAPHICS RECOGNIZED WITH ACM A.M. TURING AWARD

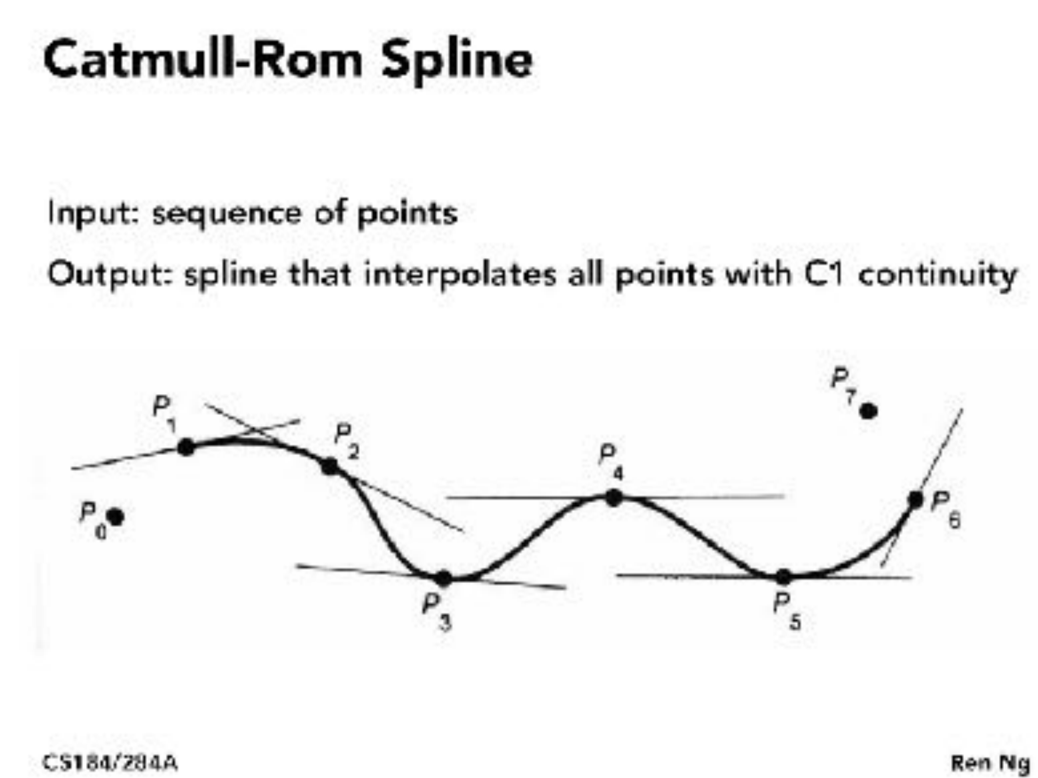
Hanrahan and Catmull's Innovations Paved the Way for Today's 3-D Animated Films

PIXAR
ANIMATION STUDIOS

Patrick M. Hanrahan



Ren's PhD advisor
at Stanford!



Lecture 25:

Intro to Animation

Computer Graphics and Imaging
UC Berkeley CS184/284A

Topics

History, goals and principles

Artist-driven animation: rigging, posing, keyframing

Procedural animation: physical simulation

Cloth simulation

Computer aids: forward & inverse kinematics

Data-driven animation: motion capture

Animation

"Bring things to life"

- Communication tool
- Aesthetic issues often dominate technical issues

An extension of modeling

- Represent scene models as a function of space

Output: sequence of images that when viewed sequentially provide a sense of motion

- Film: 24 frames per second
- Video: 30 fps
- Virtual reality: 90 fps

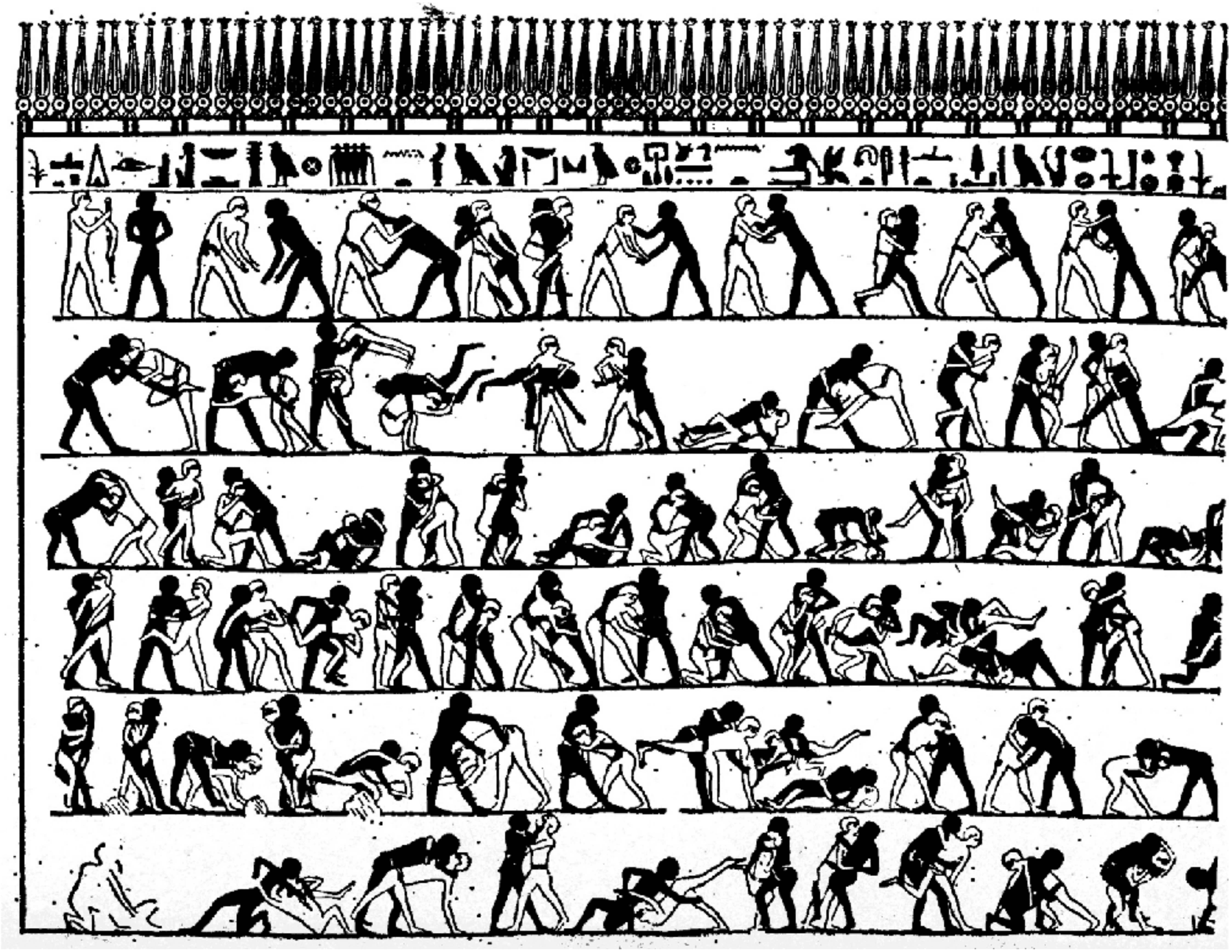
Historical Points in Animation

(slides courtesy Keenan Crane)

First Animation

(Shahr-e Sukhteh, Iran 3200 BCE)

History of Animation



(tomb of Khnumhotep, Egypt 2400 BCE)

History of Animation

Claude Monet, “Woman with a Parasol” (1875)

Marcel Duchamp, "Nude Descending a Staircase, No. 2" (1912)

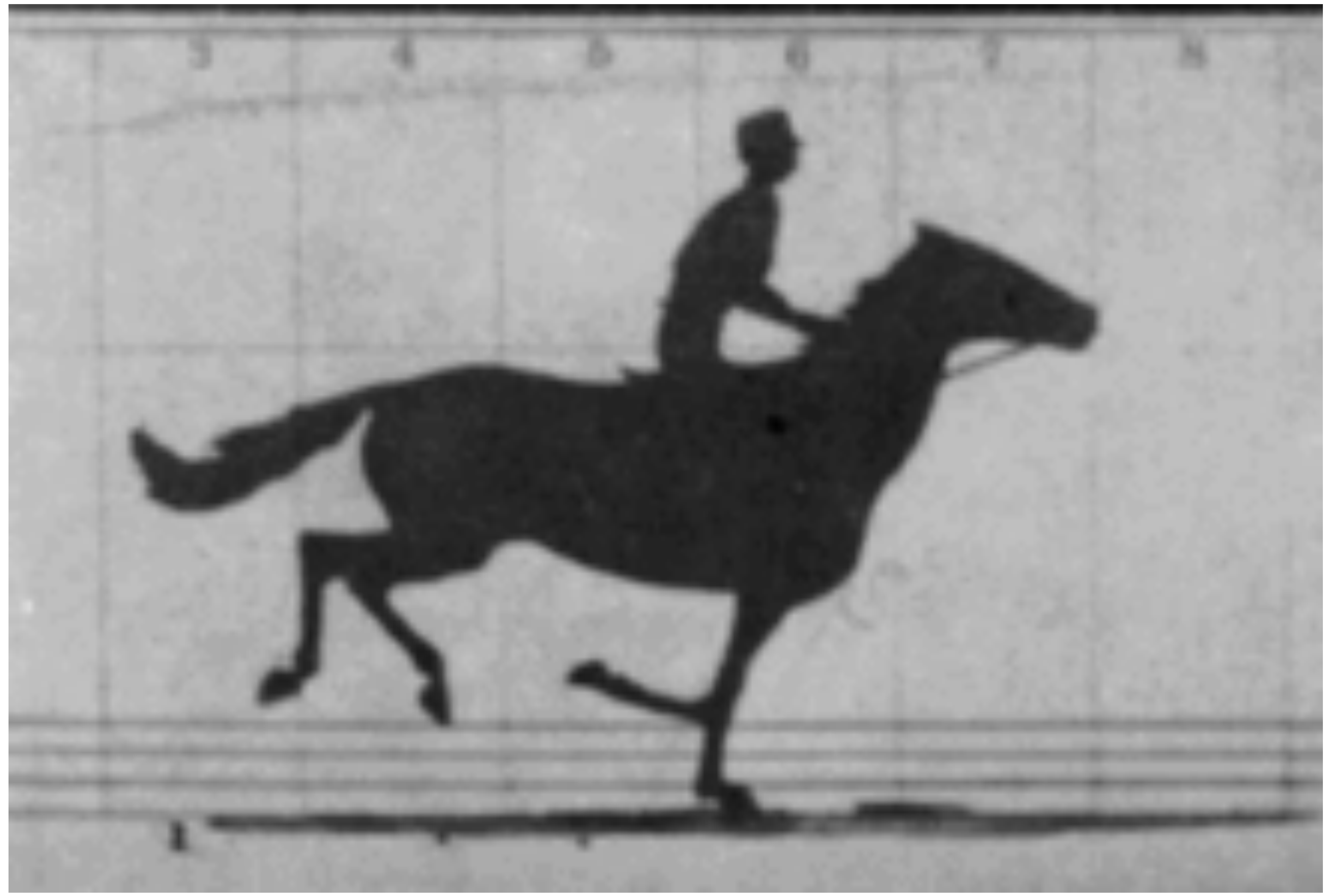
History of Animation

(Phenakistoscope, 1831)

First Film

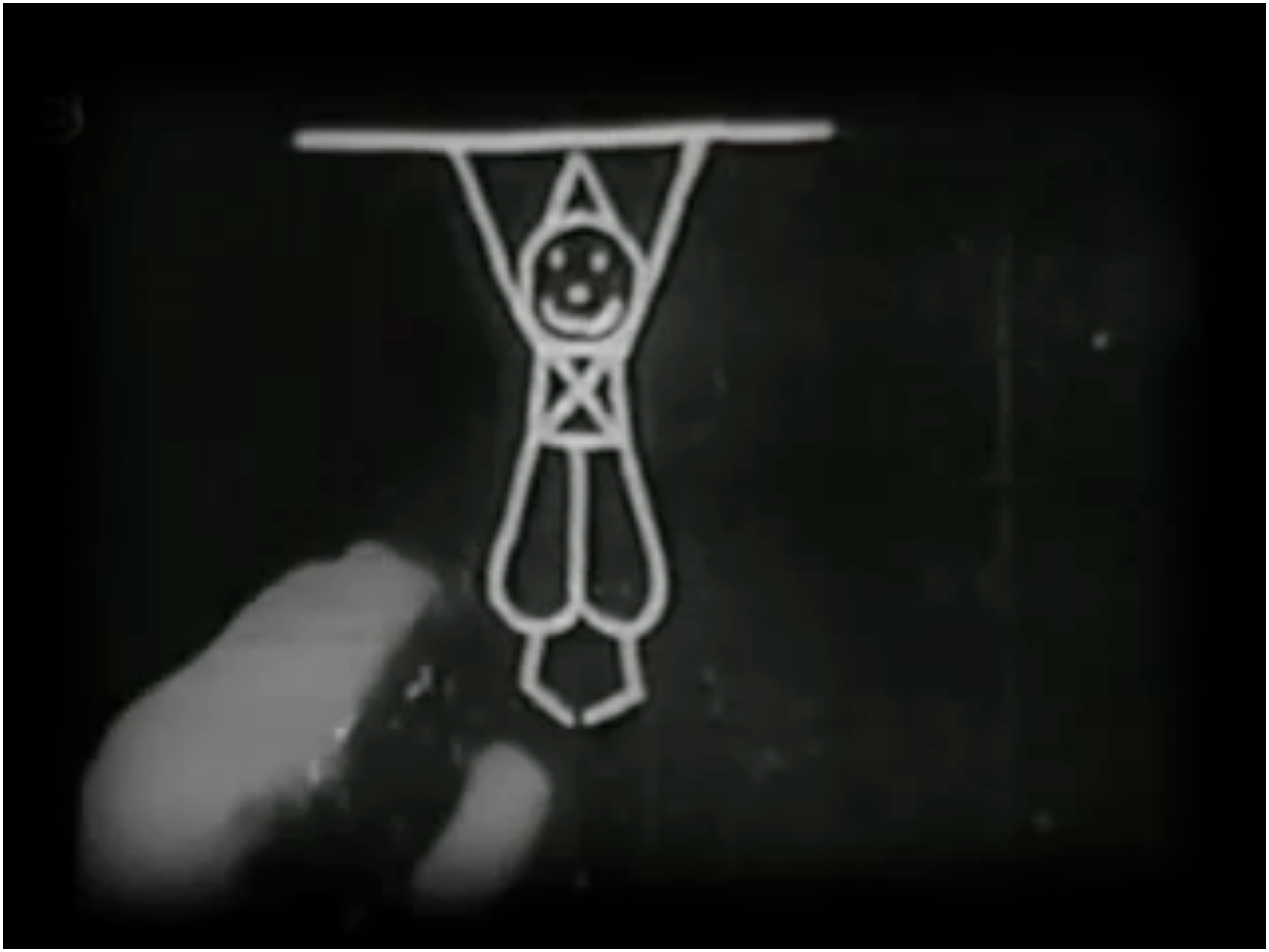
Originally used as scientific tool rather than for entertainment

Critical technology that accelerated development of animation



Edward Muybridge, *"Sallie Gardner"* (1878)

First Animation on Film



Emile Cohl, “Fantasmagorie” (1908)

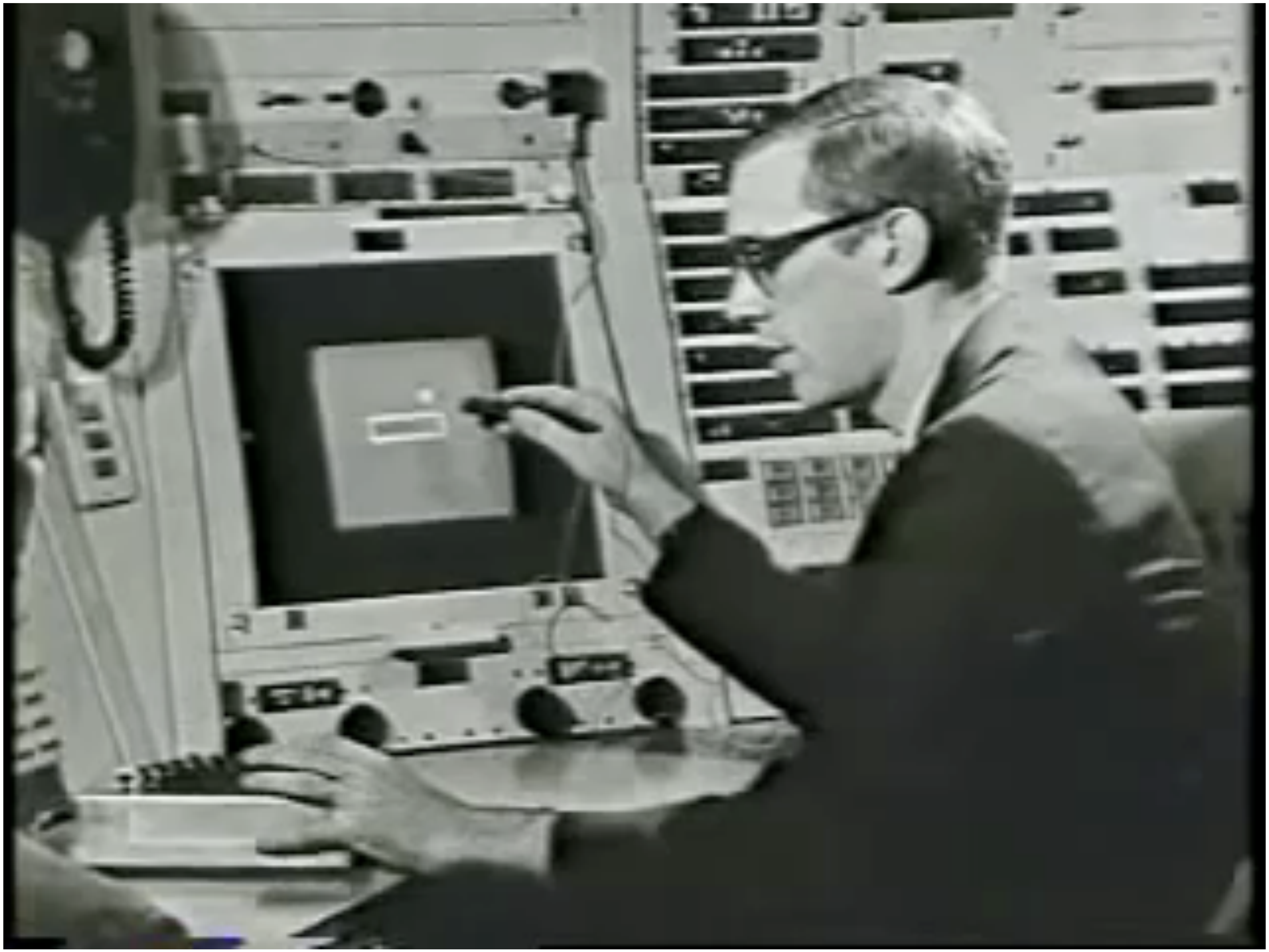
First Feature-Length Animation

Lotte Reiniger, “Die Abenteuer des Prinzen Achmed” (1926)

First Hand-Drawn Feature-Length Animation

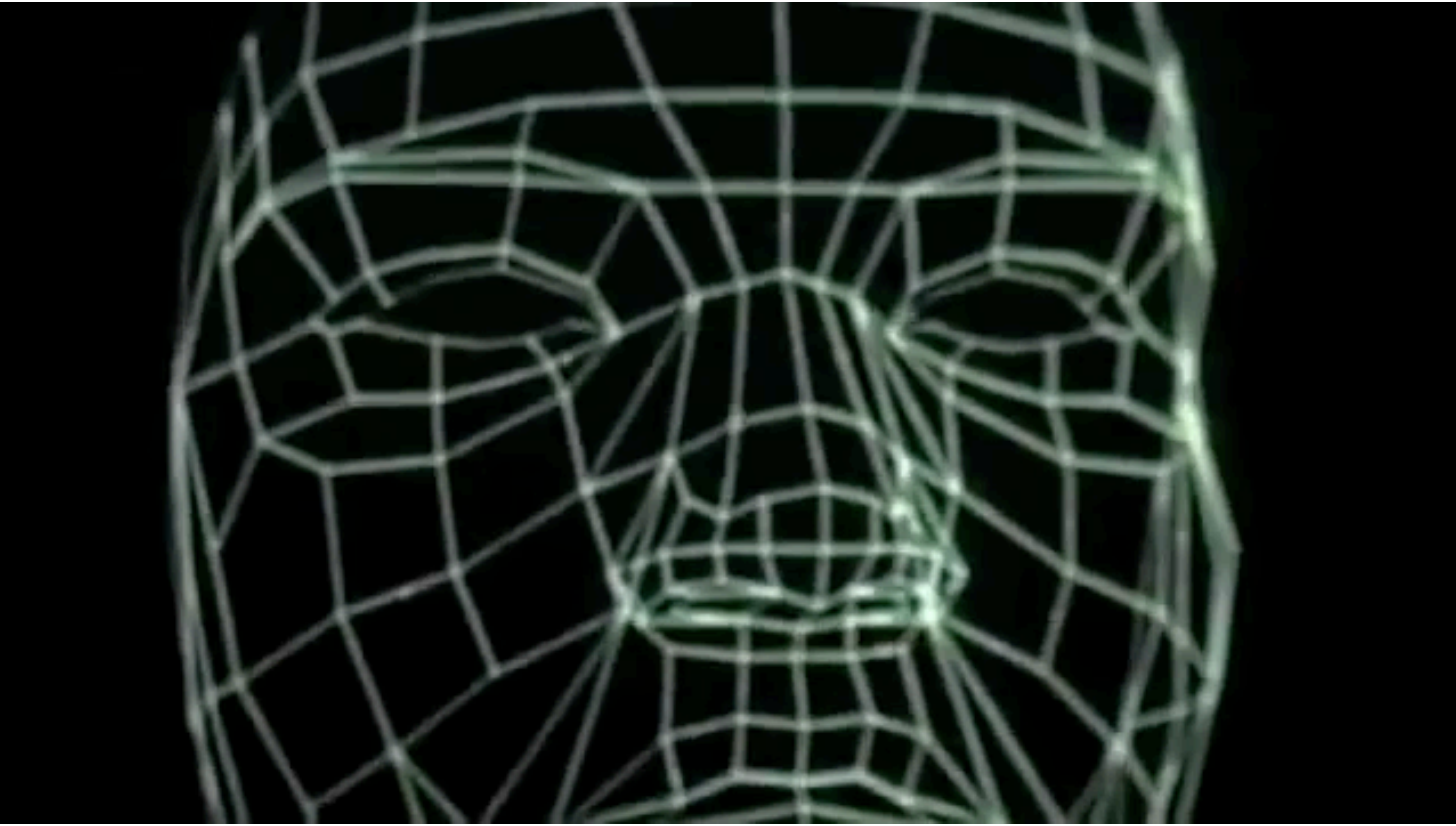
Disney, "Snow White and the Seven Dwarfs" (1937)

First Digital-Computer-Generated Animation



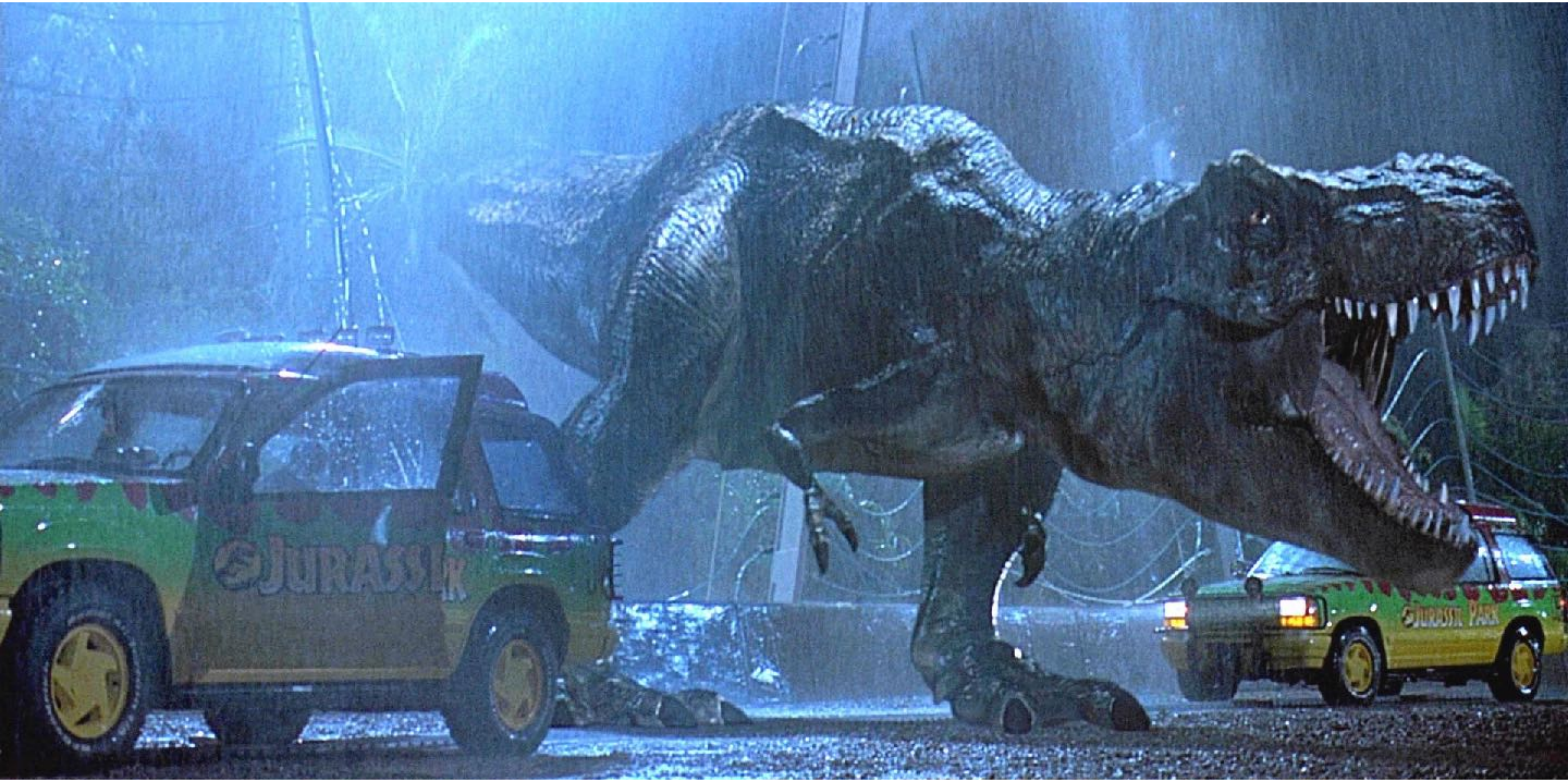
Ivan Sutherland, "Sketchpad" (1963) – Light pen, vector display

Early Computer Animation



Ed Catmull & Frederick Parke, “Computer Animated Faces” (1972)

Digital Dinosaurs!



Jurassic Park (1993)

First CG Feature Film

Pixar, “Toy Story” (1995)

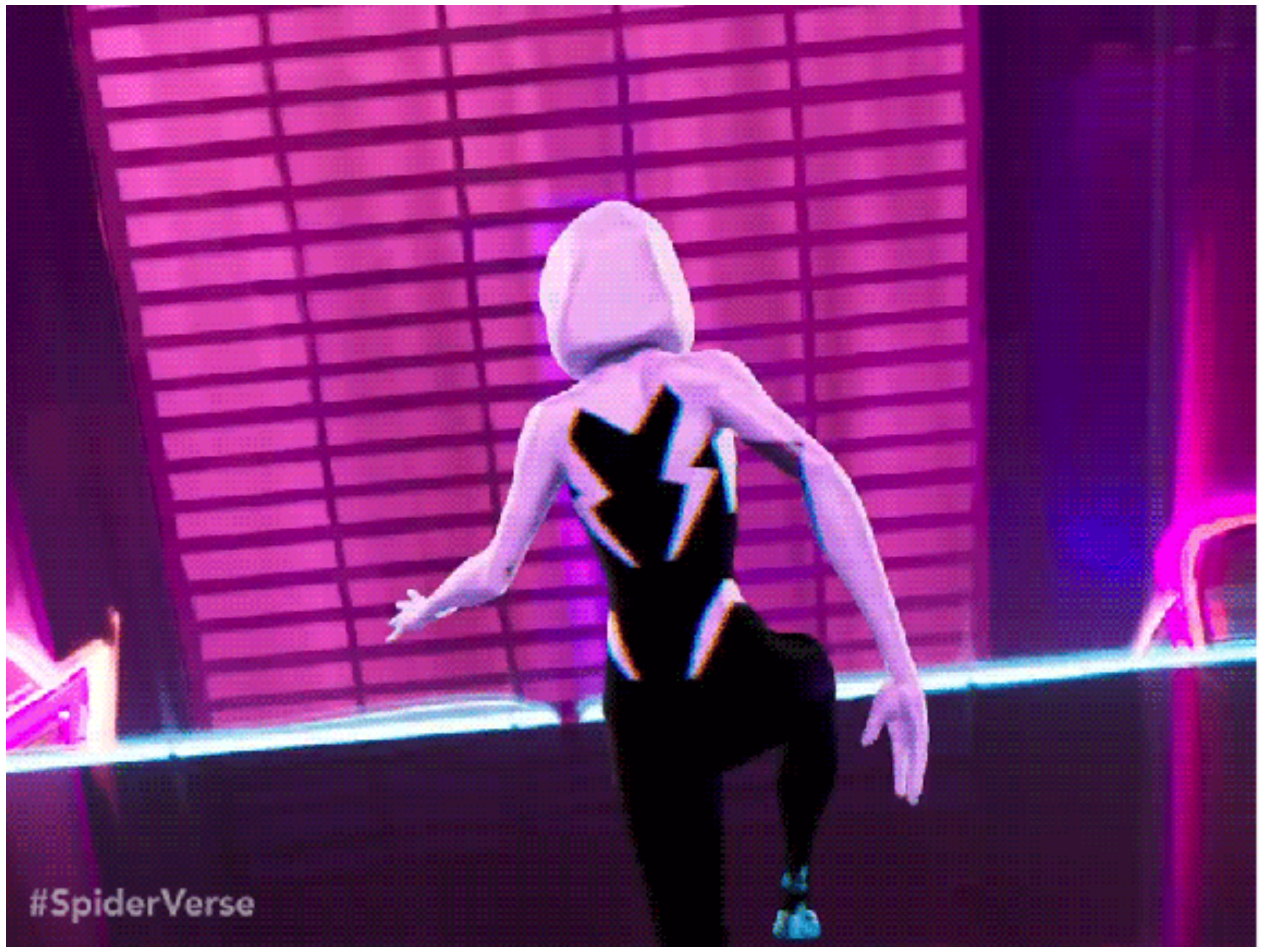
Computer Animation - Present Day

Disney, “Big Hero 6” (2014)

Computer Animation - Present Day

Pixar Animation, "Coco" (2017)

Computer Animation - Present Day



Sony Pictures Animation, “Spider-Man: Into the Spider-Verse” (2018)

Animation Principles

(slides courtesy Mark Pauly)

Animation Principles

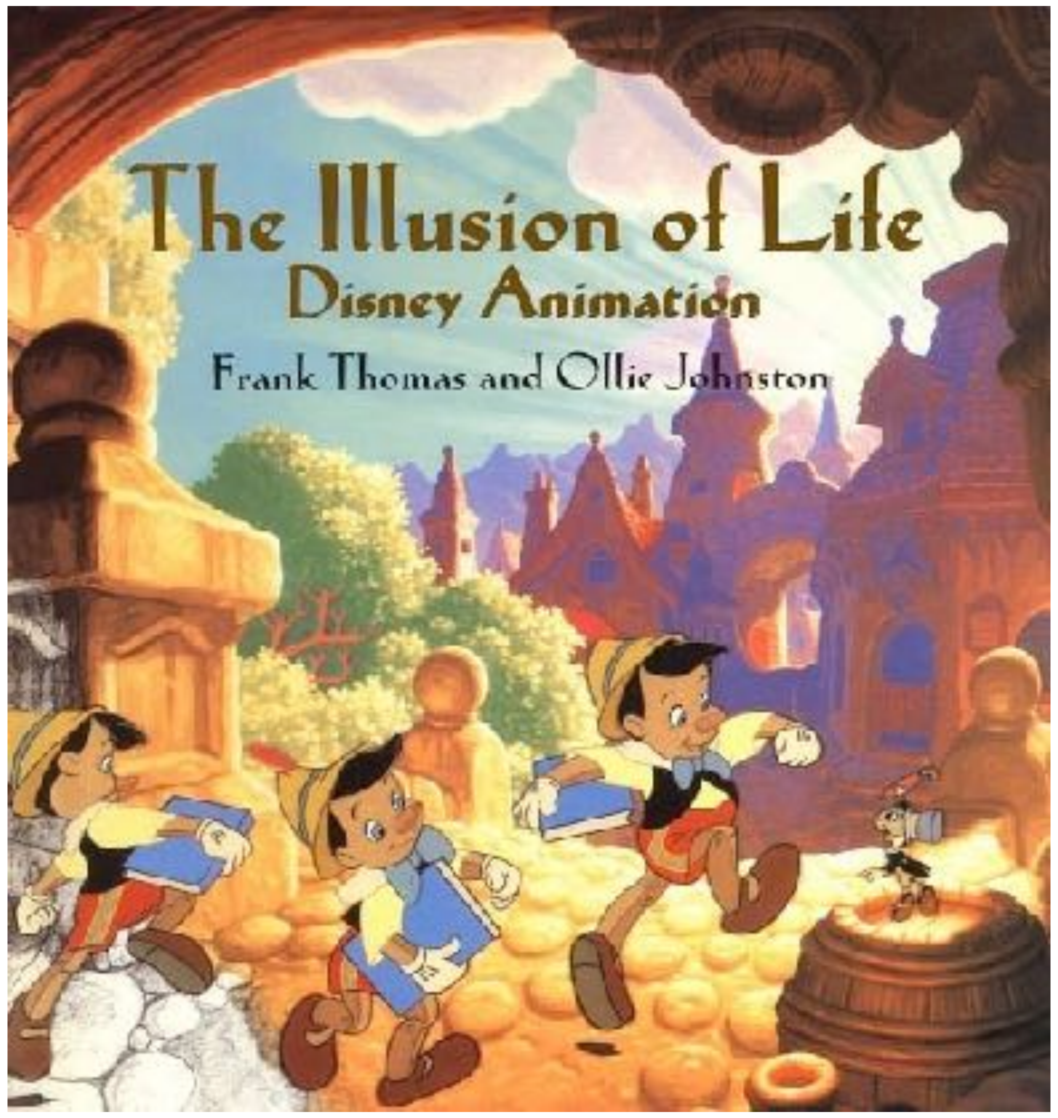
From

- "Principles of Traditional Animation Applied to 3D Computer Animation" - John Lasseter, ACM Computer Graphics, 21(4), 1987

In turn from

- "The Illusion of Life" Frank Thomas and Ollie Johnson

Same for 2D and 3D

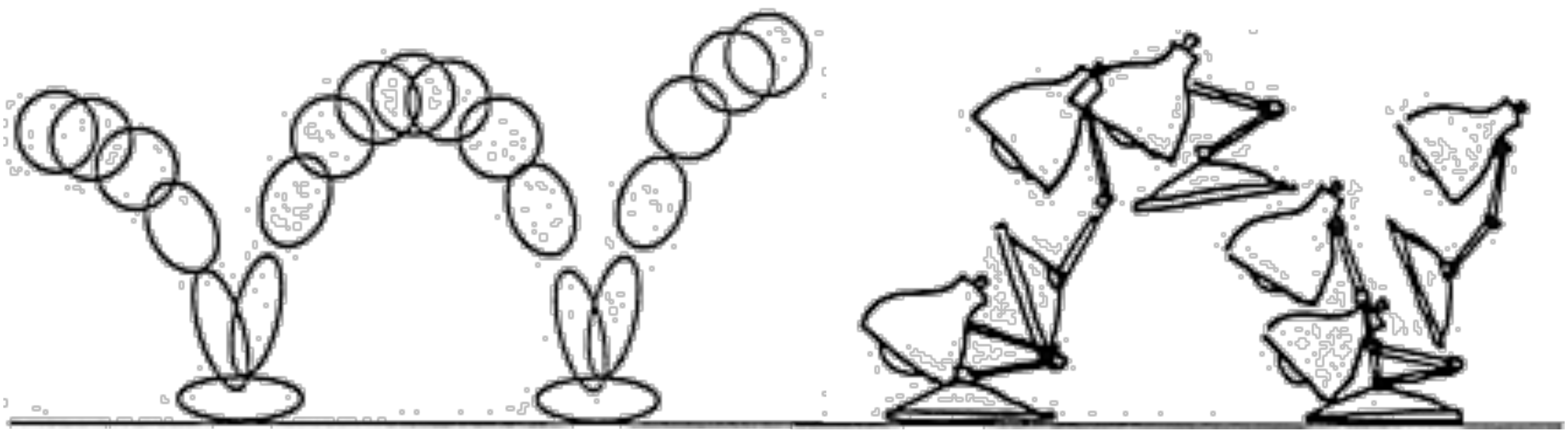


http://www.siggraph.org/education/materials/HyperGraph/animation/character_animation/principles/prin_trad_anim.htm

Squash and Stretch

Refers to defining the rigidity and mass of an object by distorting its shape during an action.

Shape of object changes during movement, but not its volume.

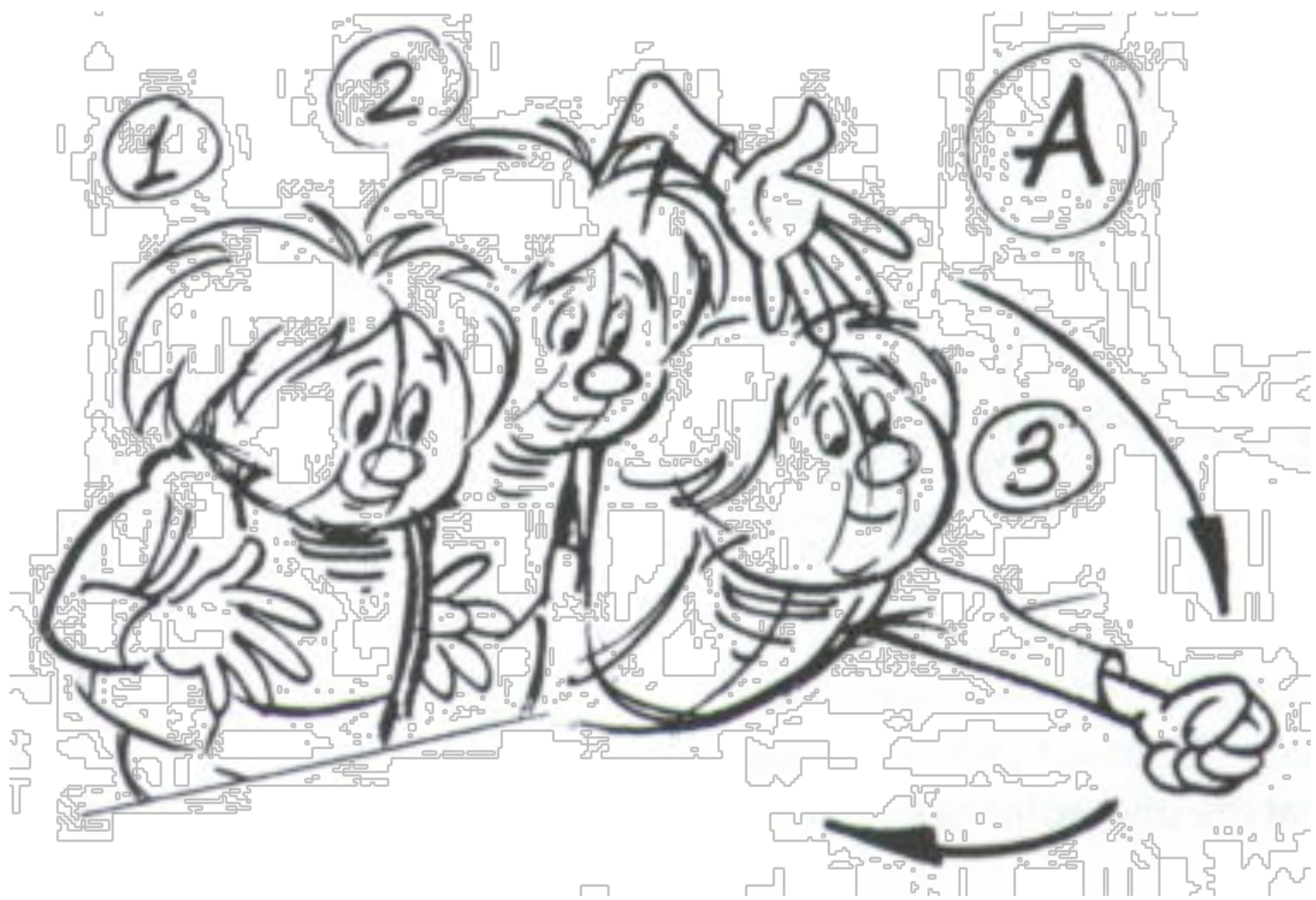


Anticipation

Prepare for each movement

For physical realism

To direct audience's attention



Timing for Animation, Whitaker & Halas

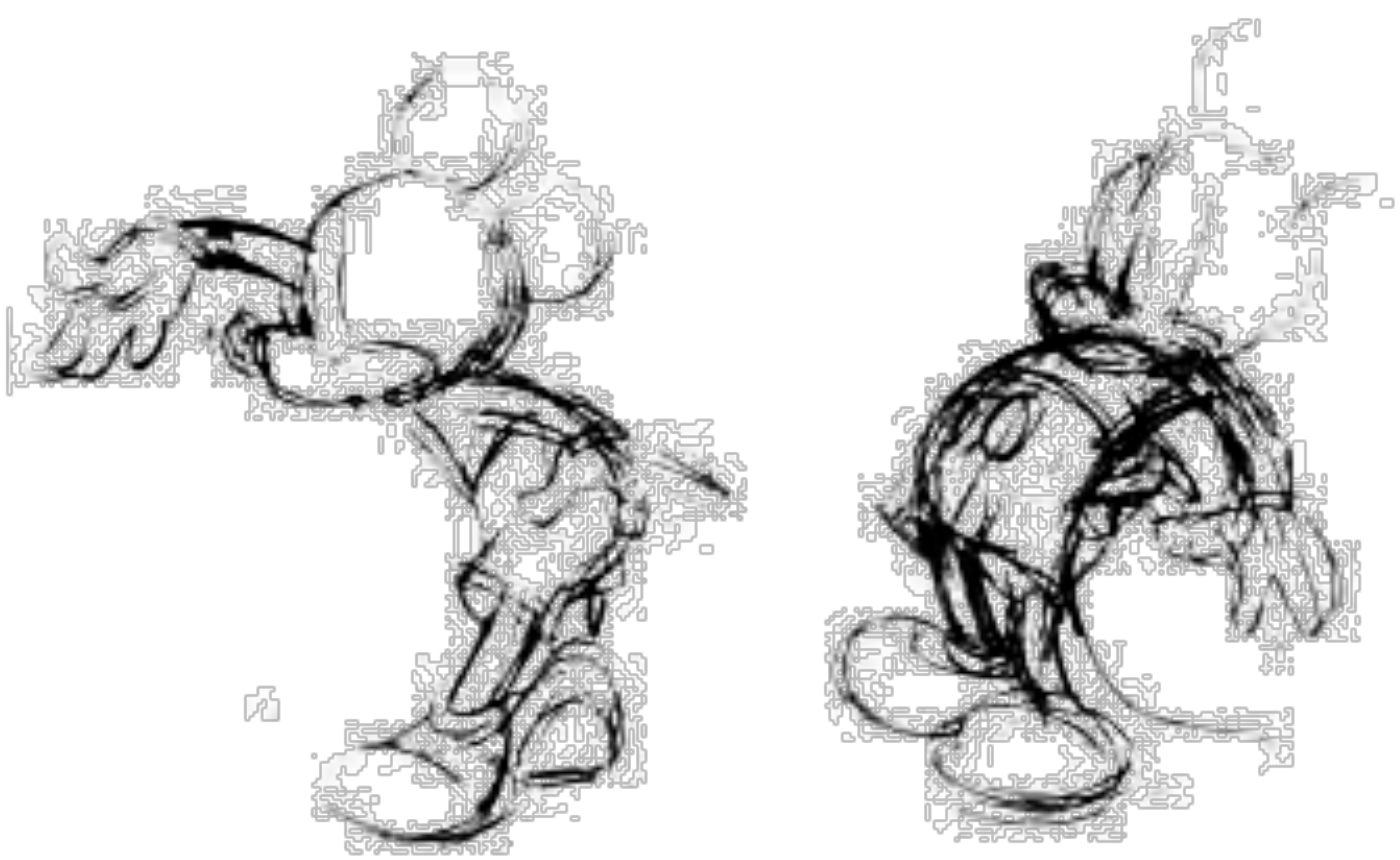
Staging

Picture is 2D

Make situation clear

Audience looking in right place

Action clear in silhouette



Disney Animation: The Illusion of Life

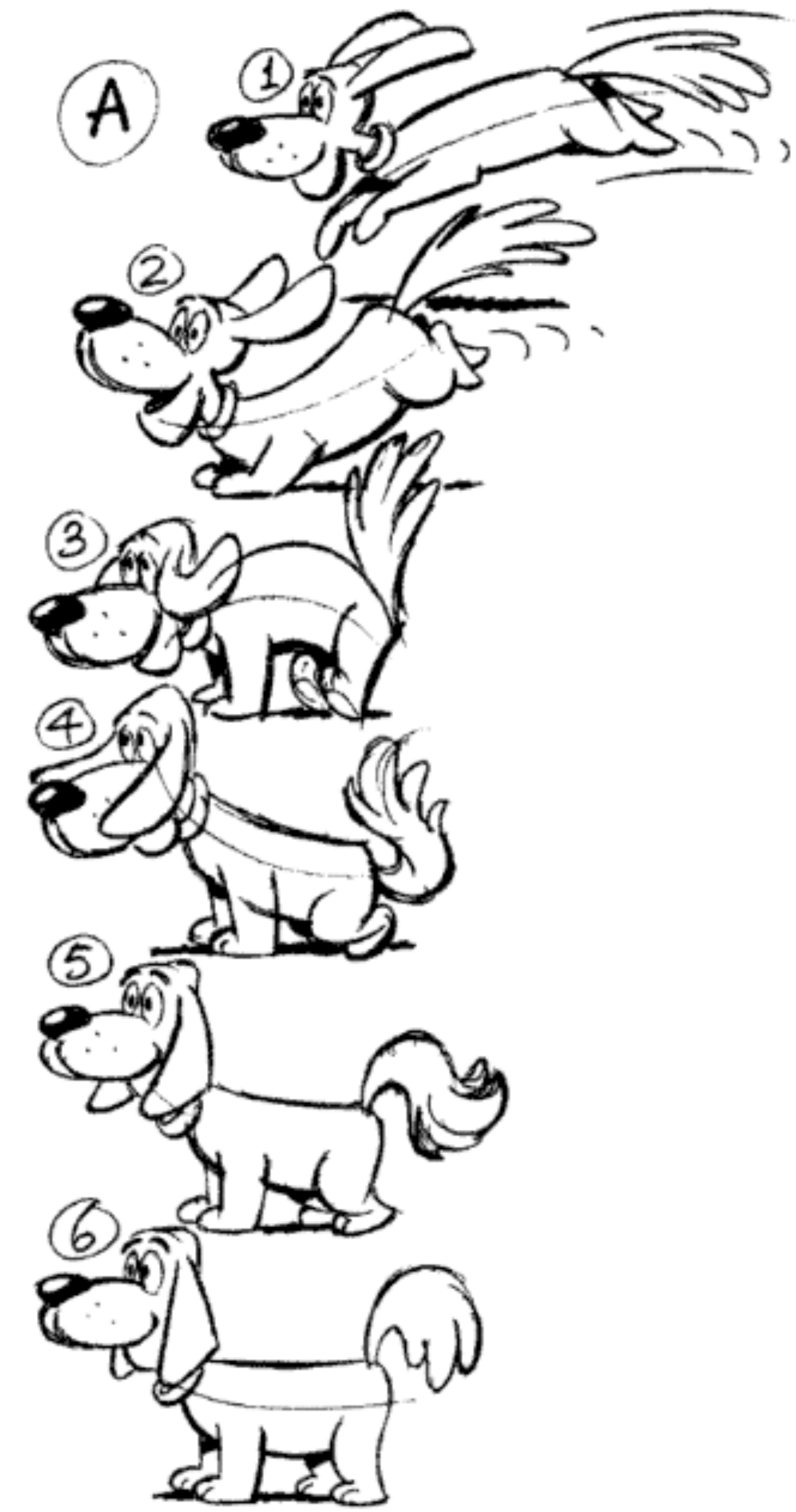
Follow Through

Overlapping motion

Motion doesn't stop suddenly

Pieces continue at different rates

One motion starts while previous is finishing, keeps animation smooth

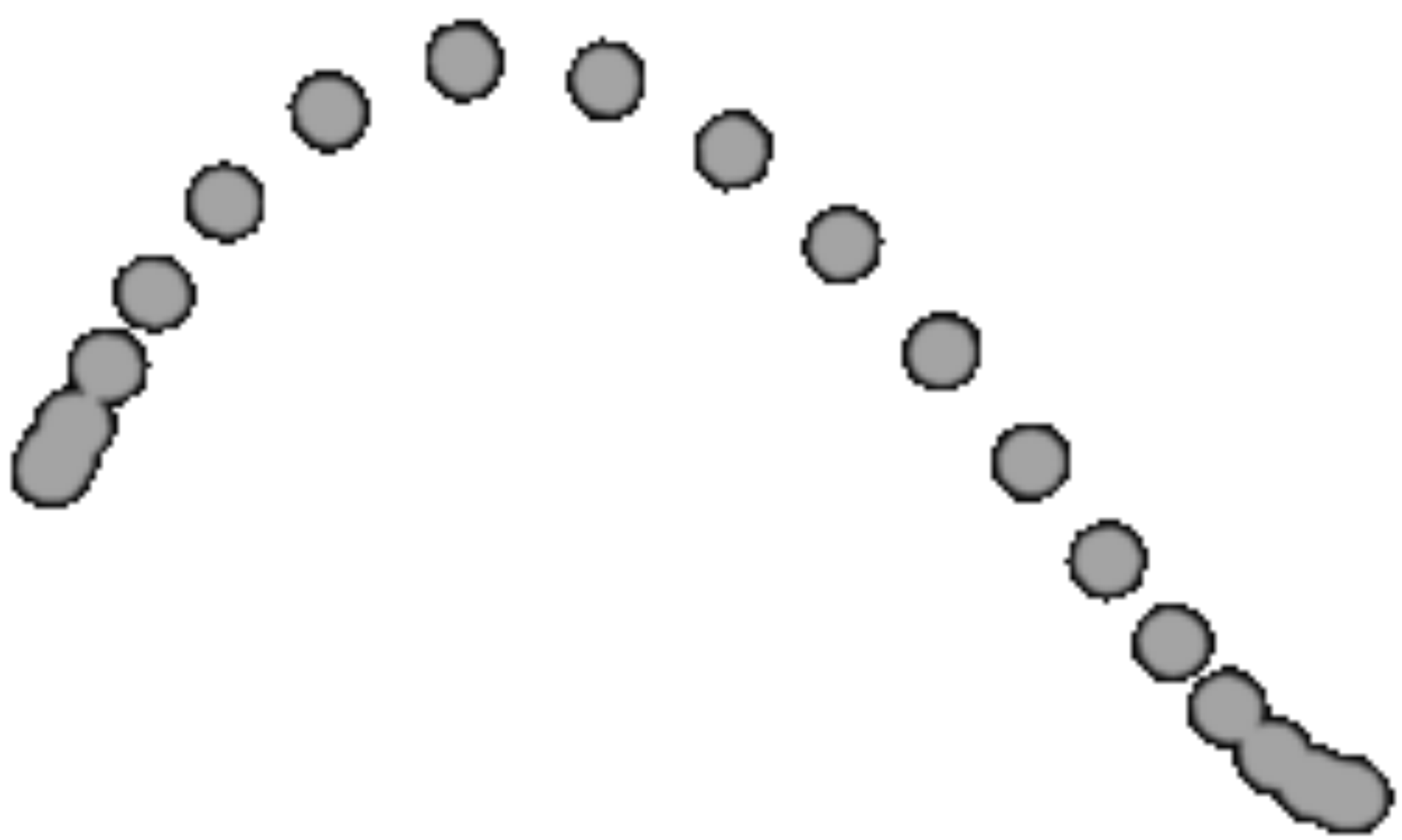


Timing for Animation, Whitaker & Halas

Ease-In and Ease-Out

Movement doesn't start & stop abruptly.

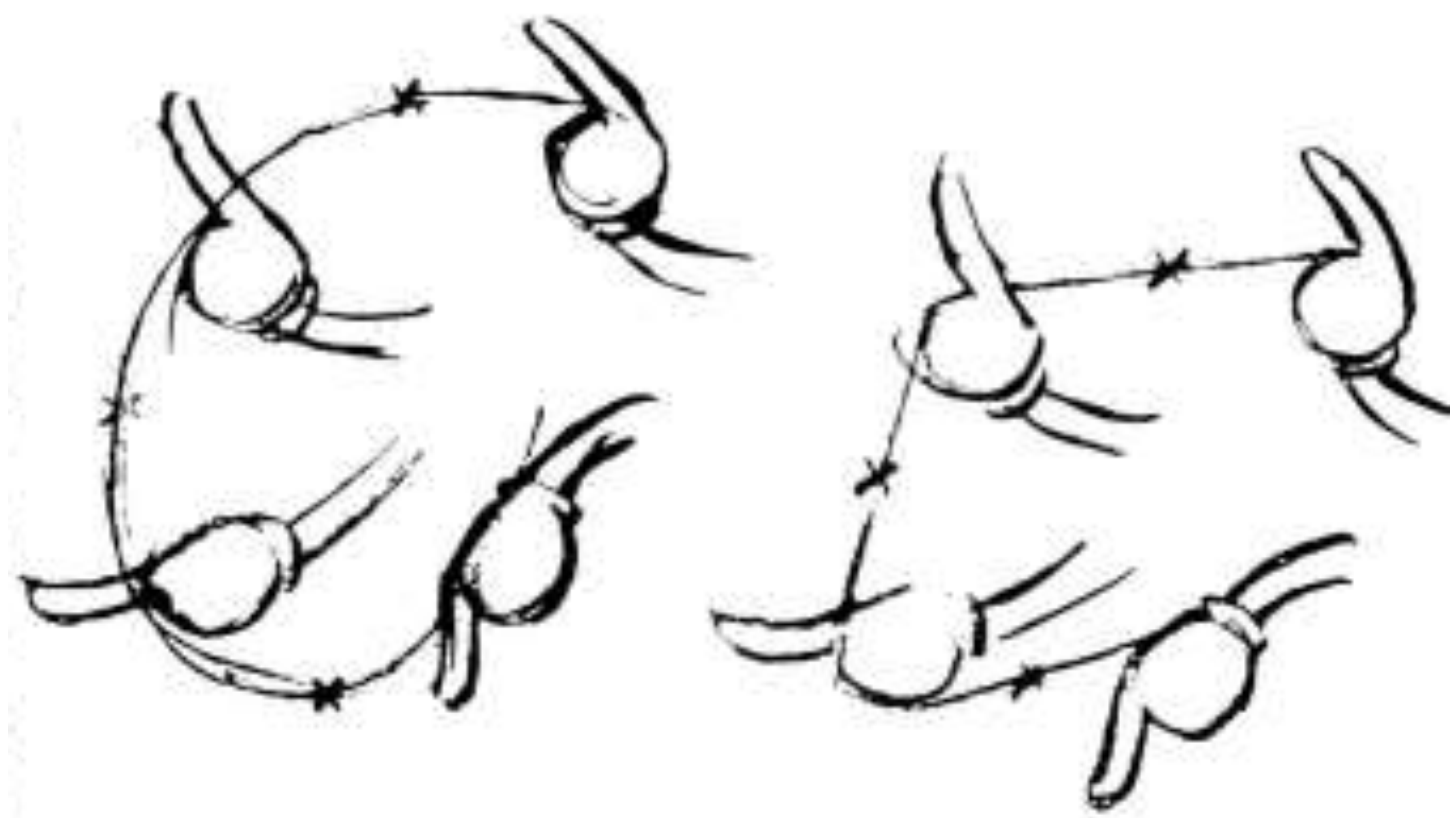
Also contributes to weight and emotion



Arcs

Move in curves, not in straight lines

This is how living creatures move



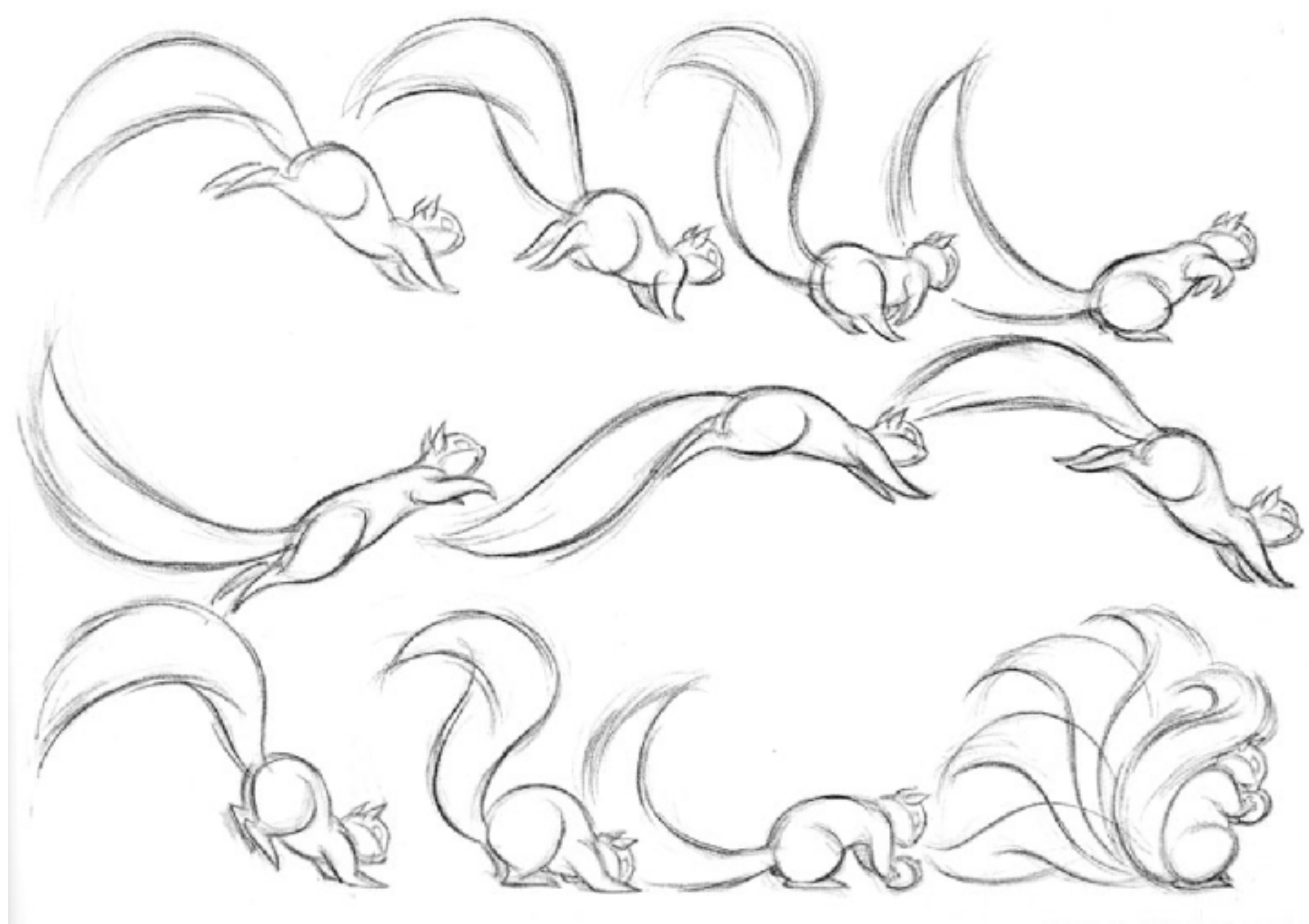
Disney Animation: The Illusion of Life

Secondary Action

Motion that results from some other action

Needed for interest and realism

Shouldn't distract from primary motion

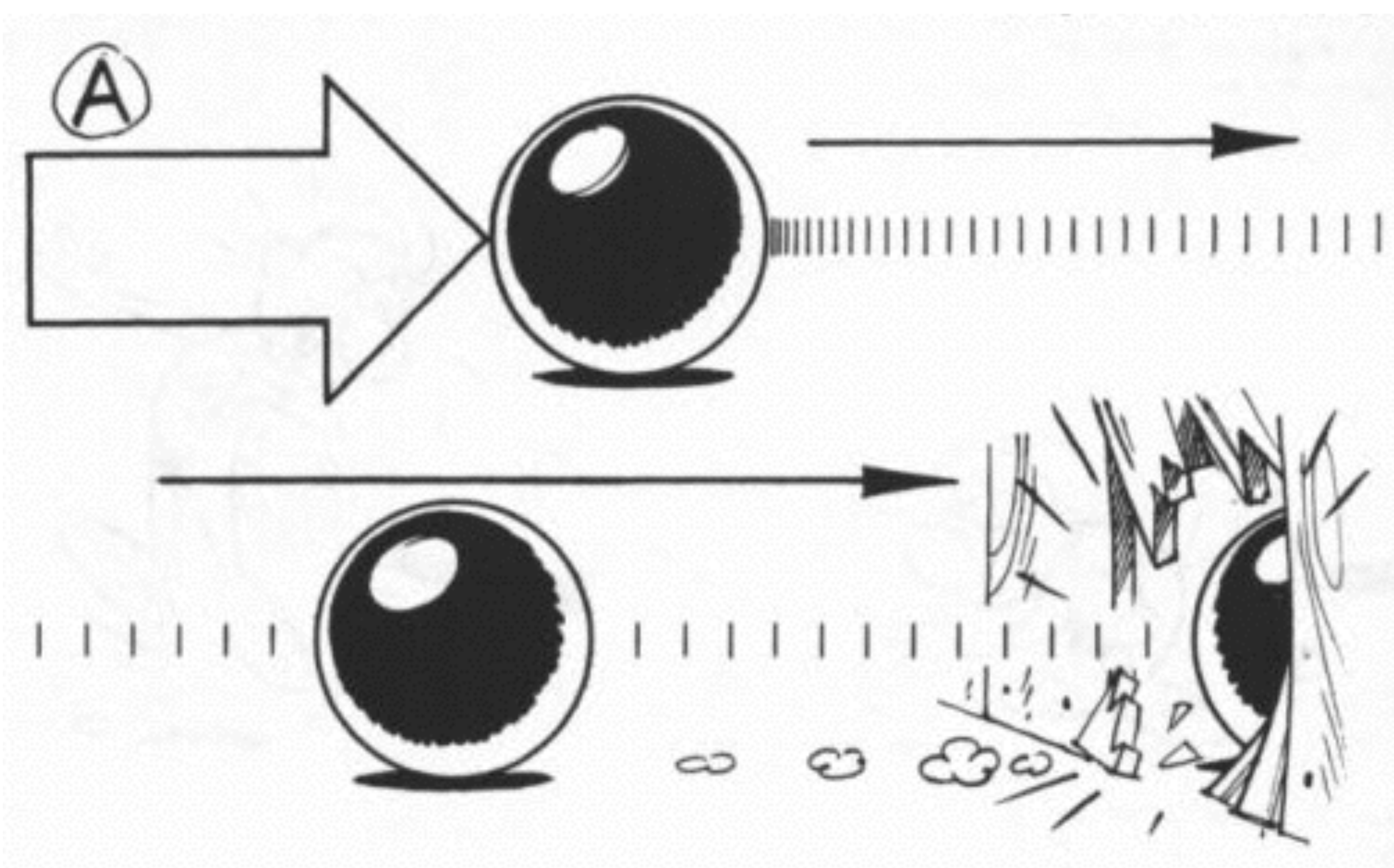


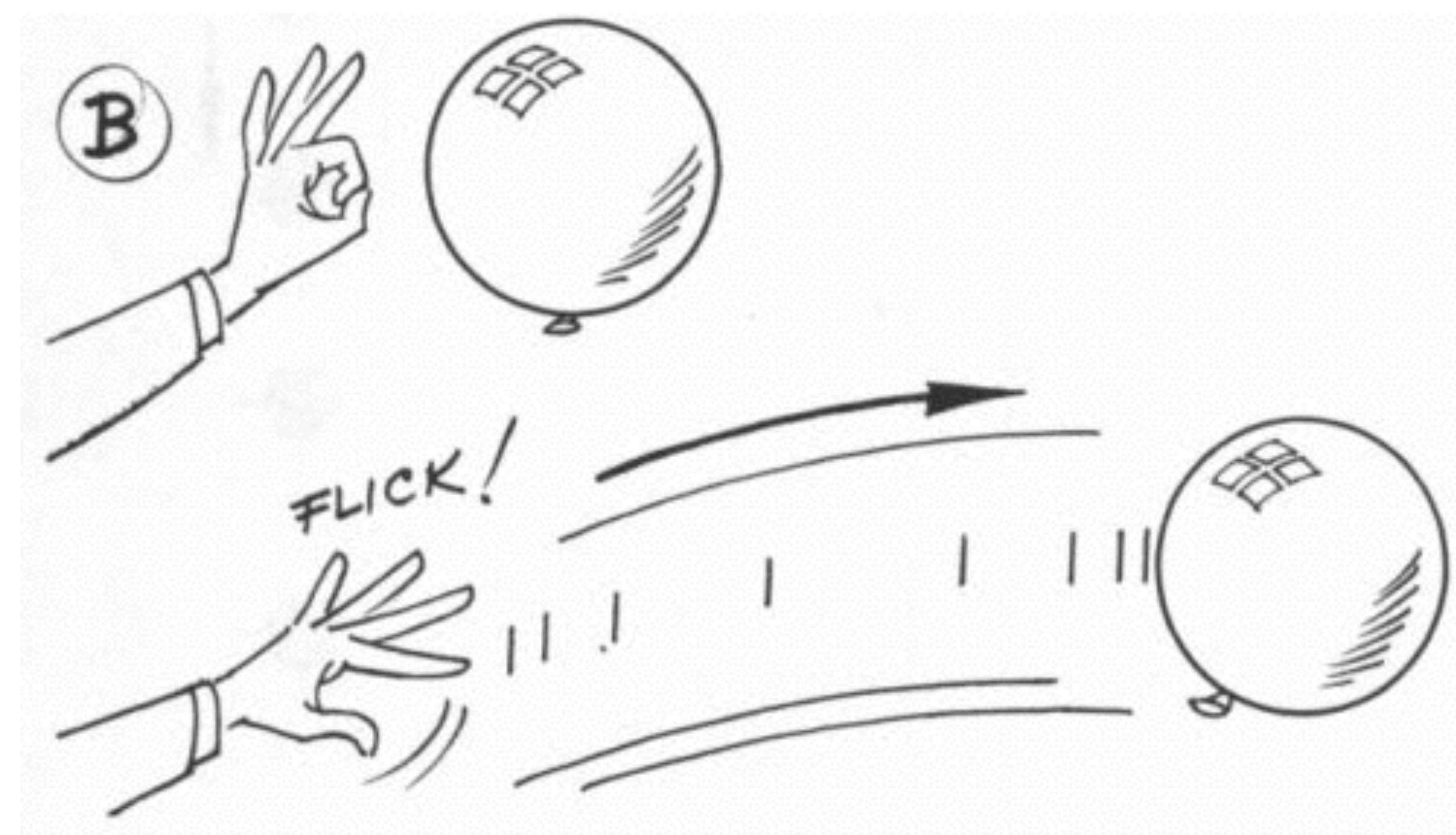
Cartoon Animation, Preston Blair

Timing

Rate of acceleration conveys weight

Speed and acceleration of character's movements convey emotion





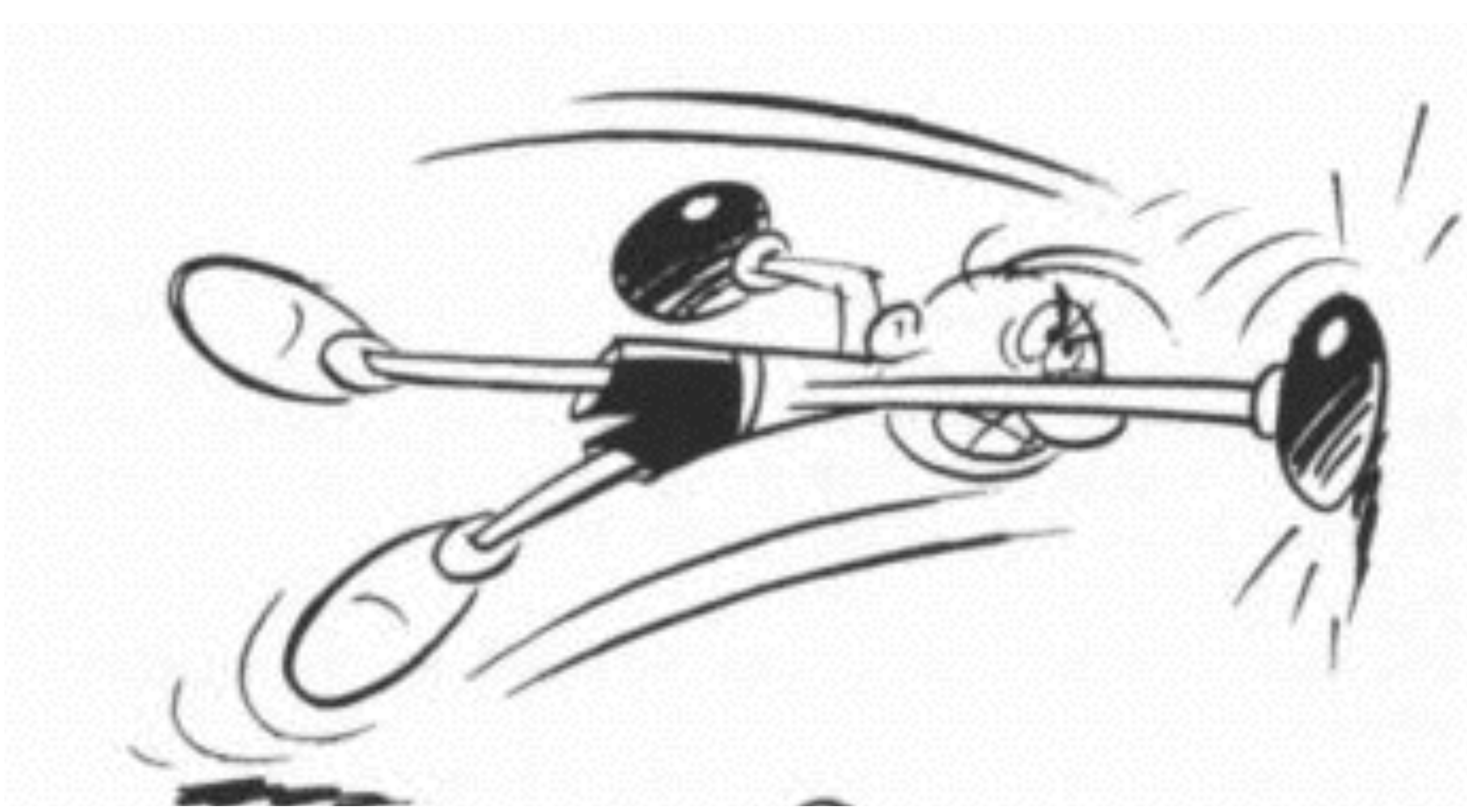
Timing for Animation, Whitaker & Halas

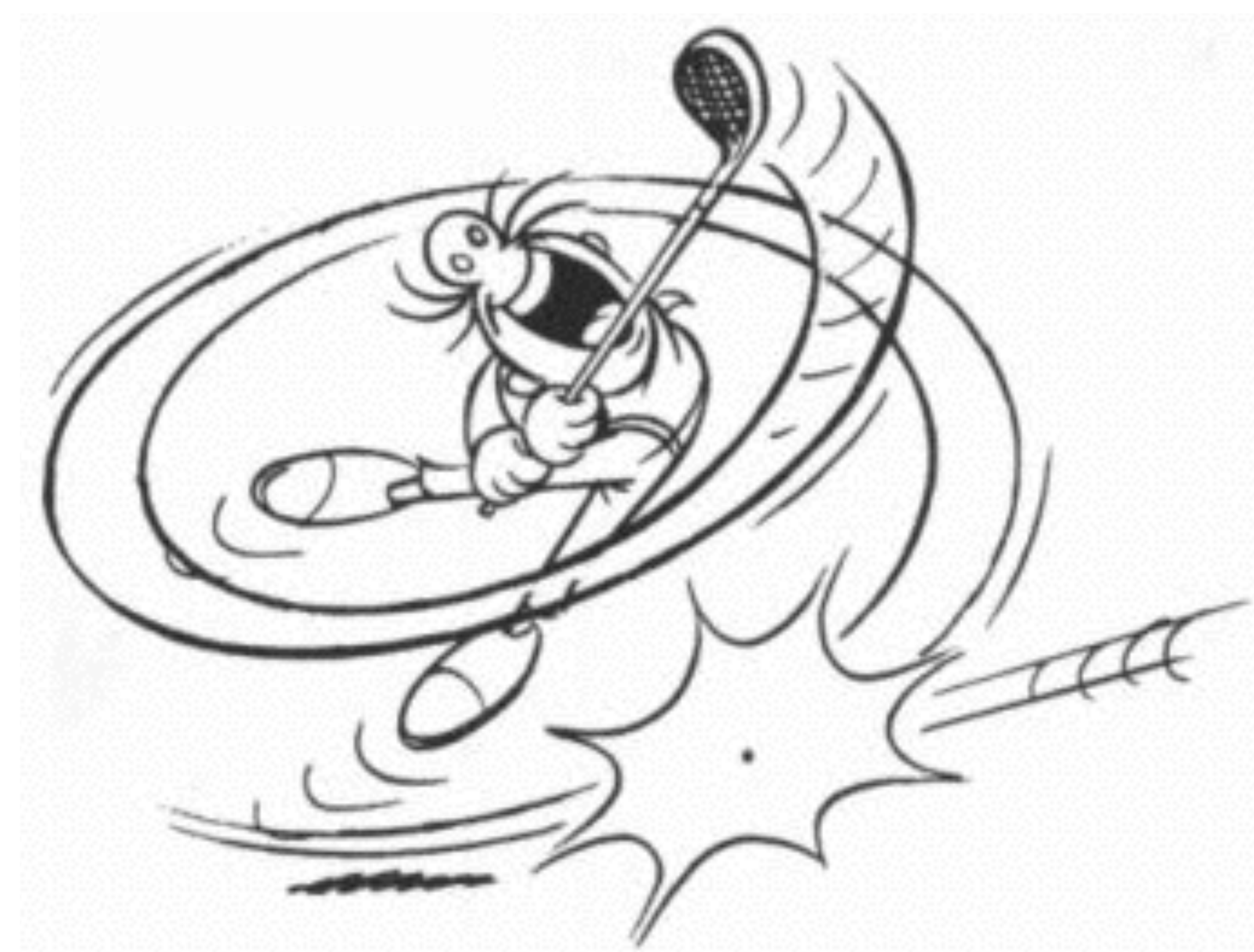
Exaggeration

Helps make actions clear

Helps emphasize story points and emotion

Must balance with non-exaggerated parts





Timing for Animation, Whitaker & Halas

Appeal

Attractive to the eye, strong design

Avoid symmetries

Disney Animation: The Illusion of Life

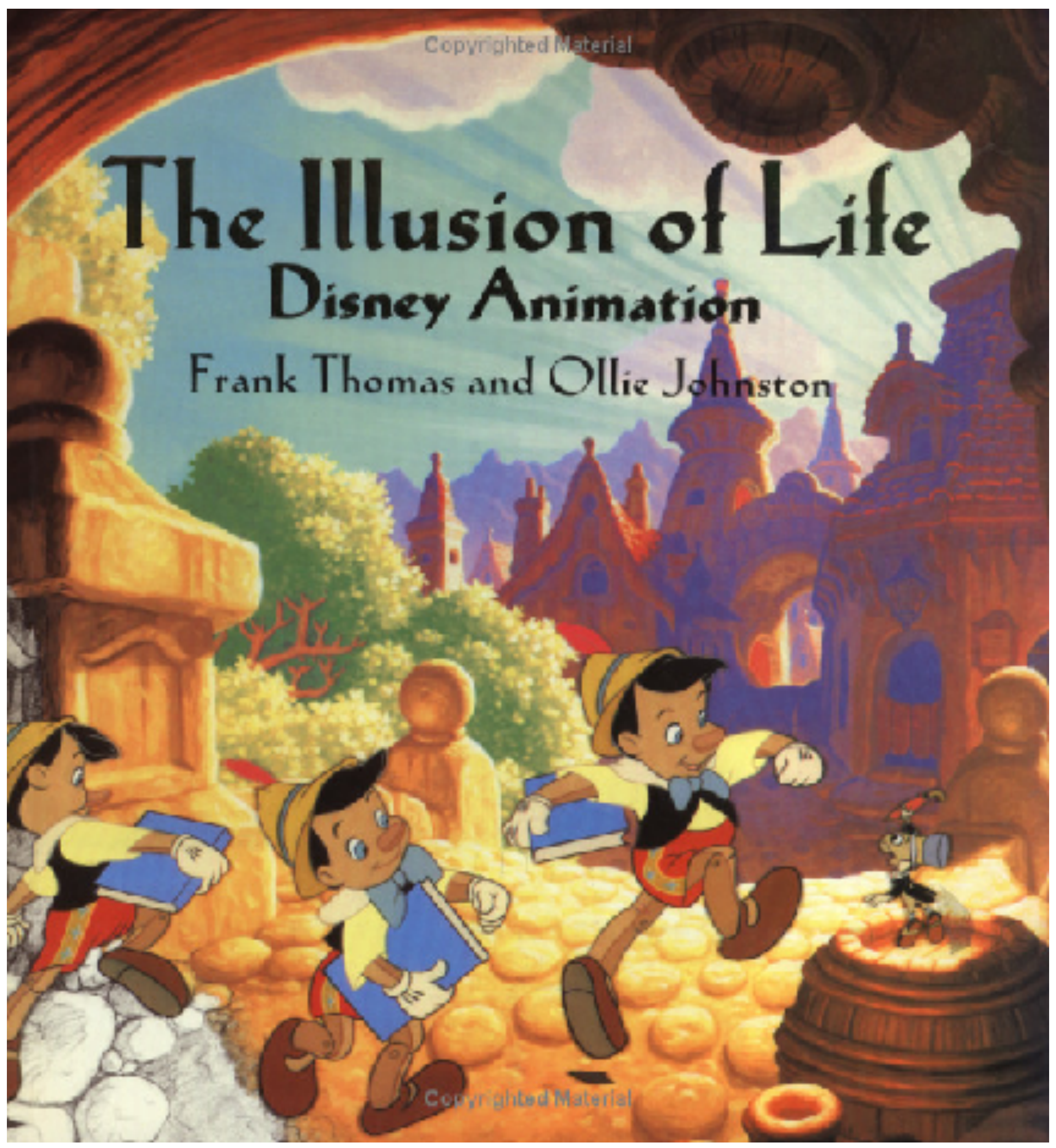
Personality

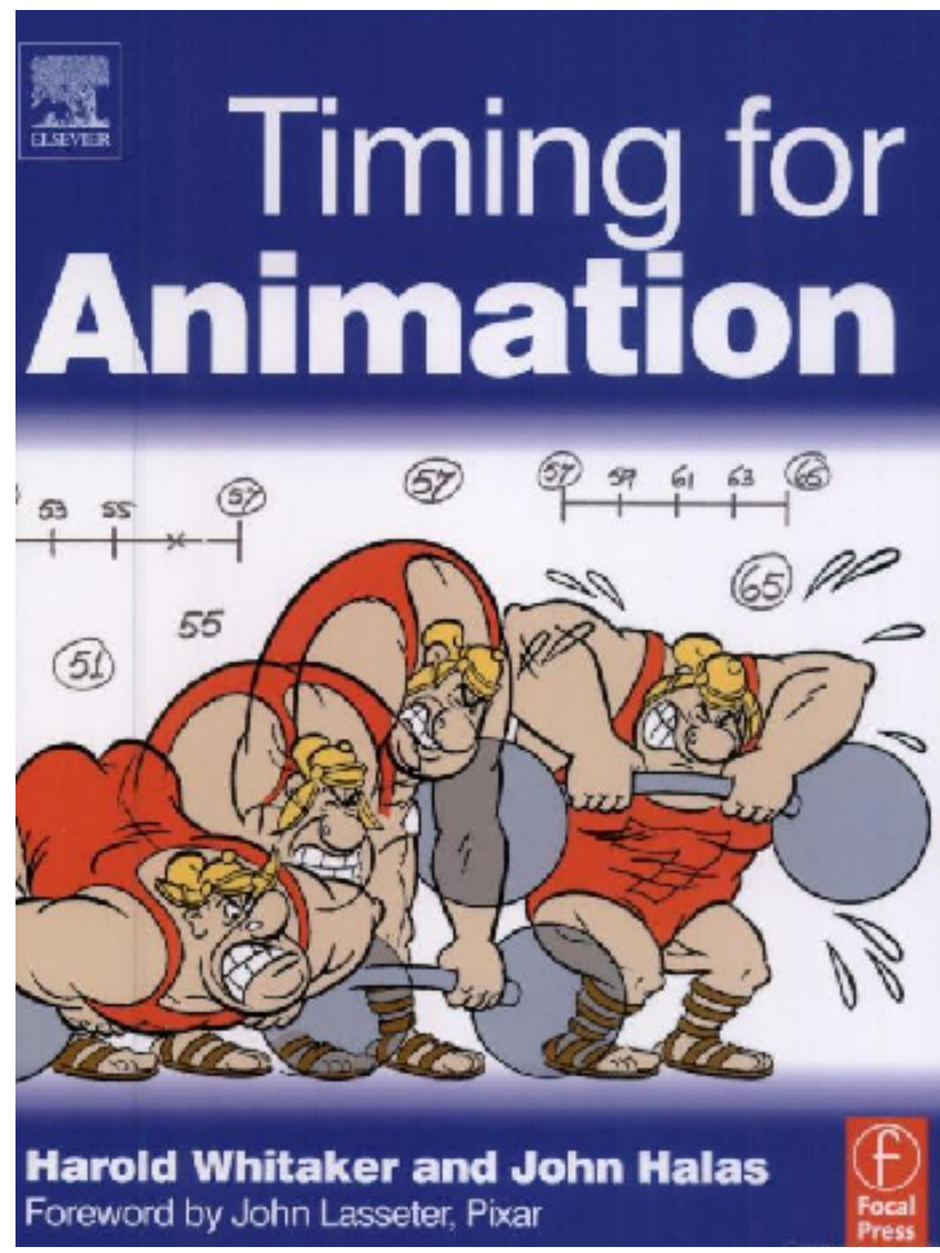
Action of character is result of its thoughts

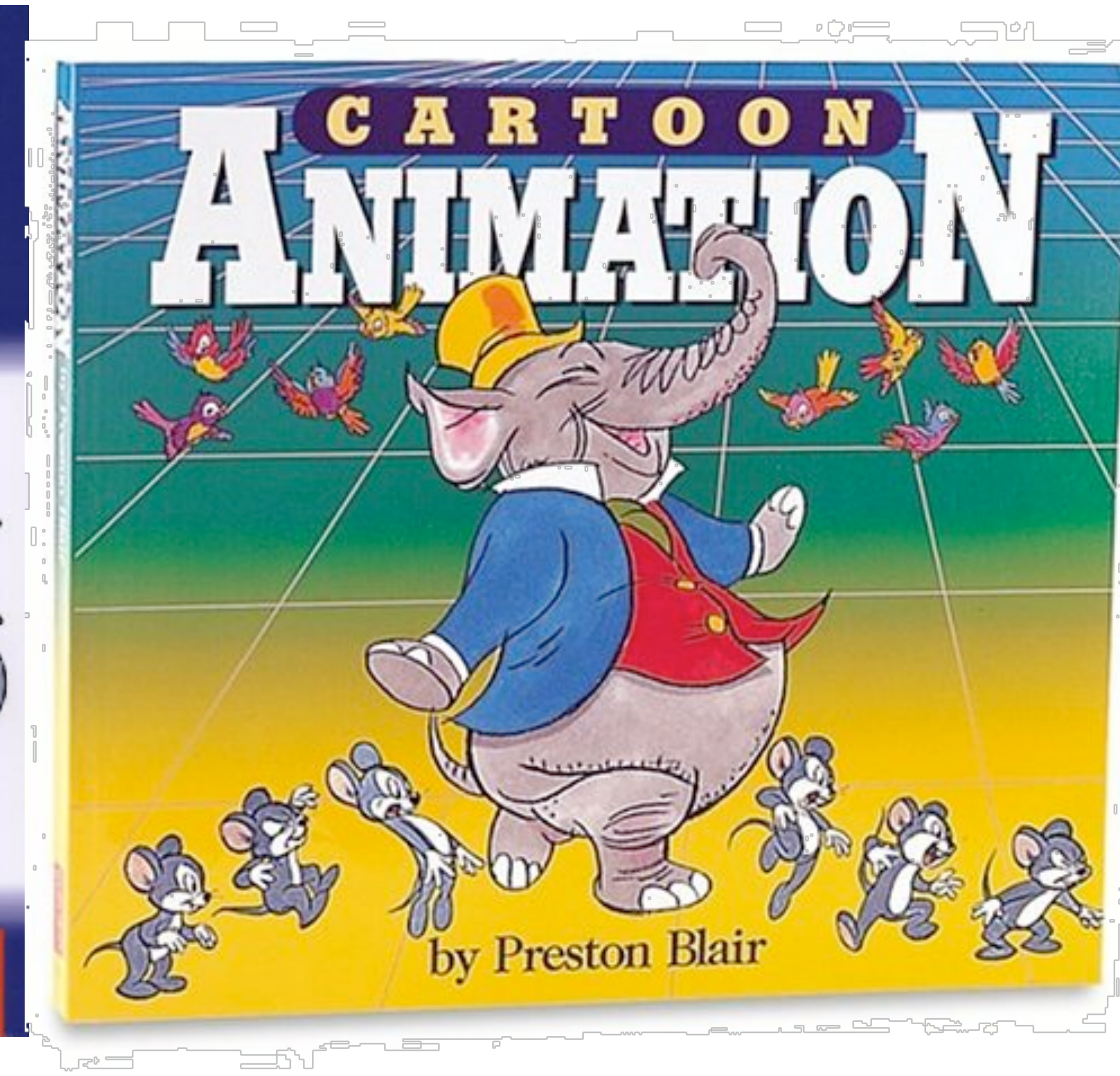
Know purpose & mood before animating each action

No two characters move the same way

Further Reading







12 Animation Principles

1. Squash and stretch
2. Anticipation
3. Staging
4. Straight ahead and pose-to-pose
5. Follow through
6. Ease-in and ease-out
7. Arcs
8. Secondary action
9. Timing
10. Exaggeration
11. Solid drawings
12. Appeal

12 Animation Principles

Cento Lodgiani, https://vimeo.com/93206523

12 Animation Principles

Applications:

- Movies
- Games
- User interfaces
- …

Computer Animation

Keyframe Animation

Keyframes

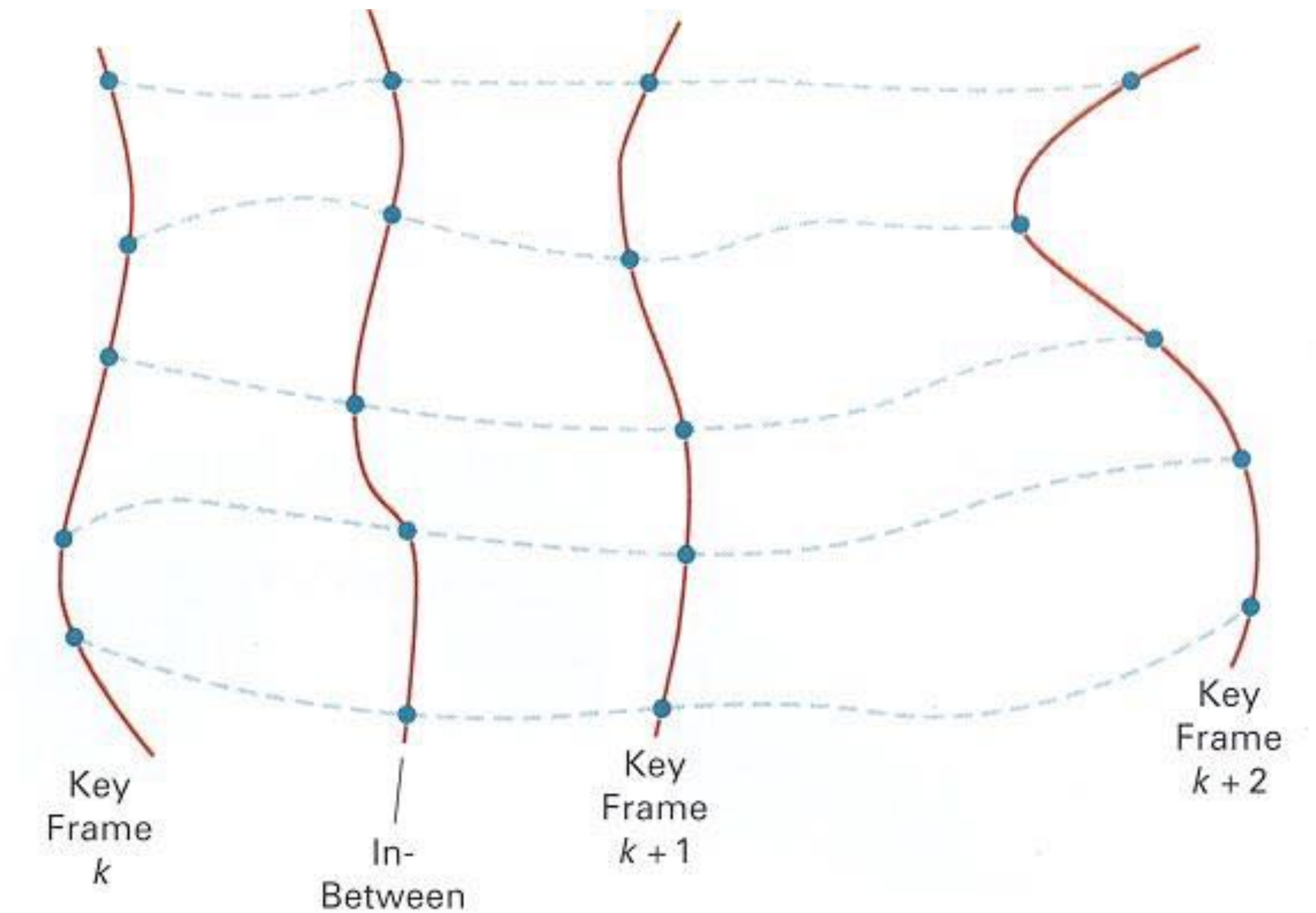
“Tweens”

Animator (e.g. lead animator) creates keyframes

Assistant (person or computer) creates in-between frames (“tweening”)

Keyframe Interpolation

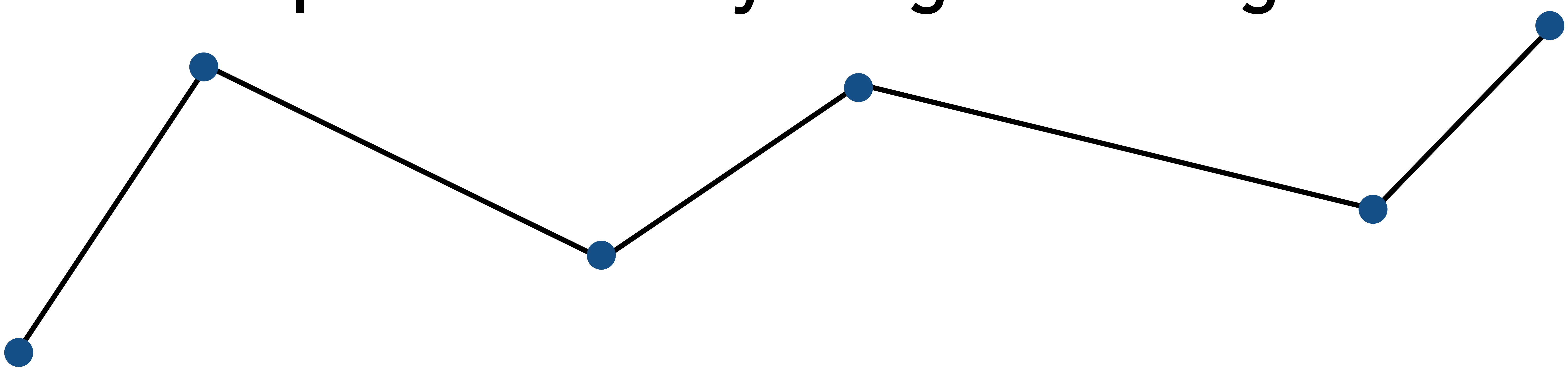
Think of each frame as a vector of parameter values



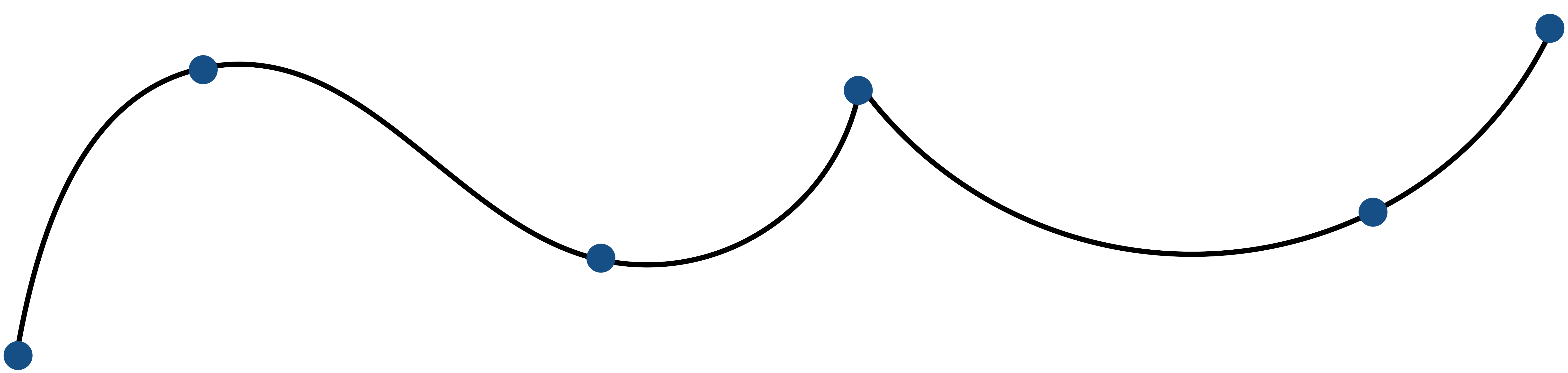
Hearn, Baker and Carithers, Figure 16.11

Keyframe Interpolation of Each Parameter

Linear interpolation usually not good enough



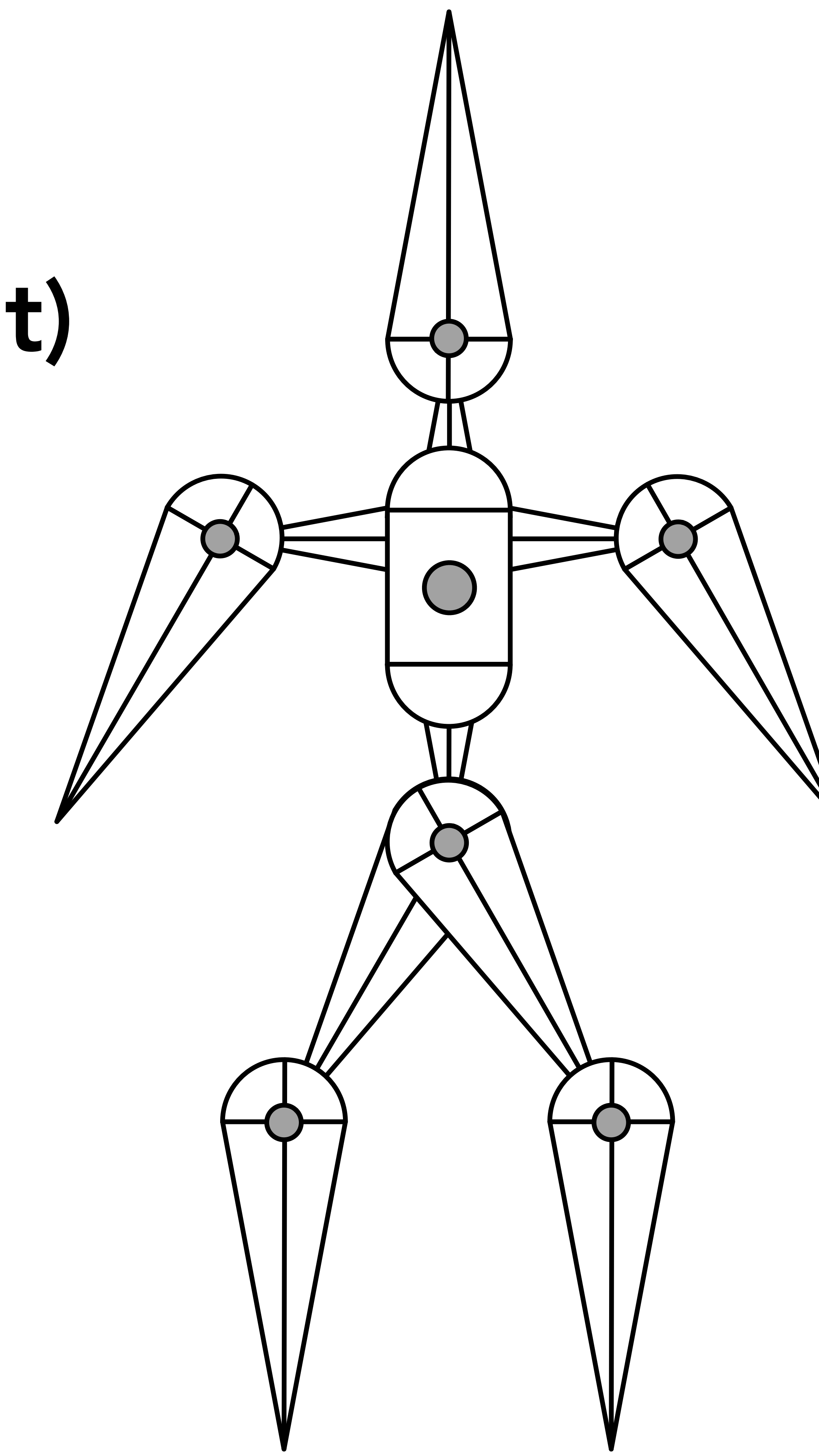
Recall splines for smooth / controllable interpolation



Forward Kinematics

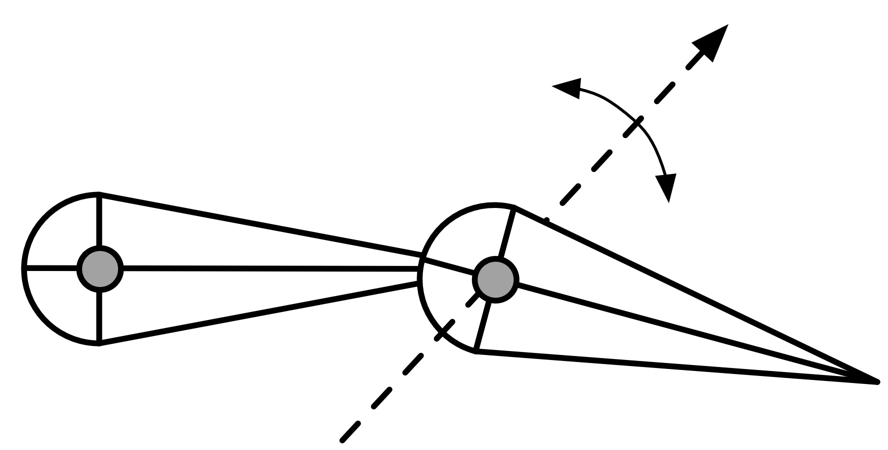
Articulated skeleton

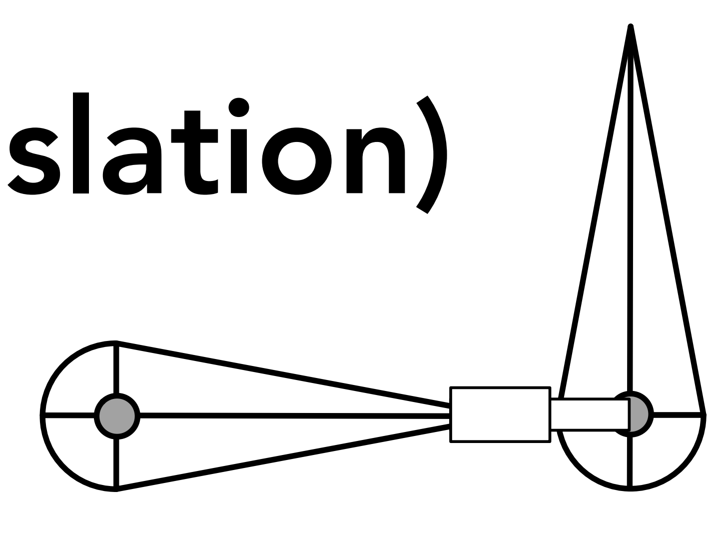
- Topology (what's connected to what)
- Geometric relations from joints
- Tree structure (in absence of loops)



Joint types

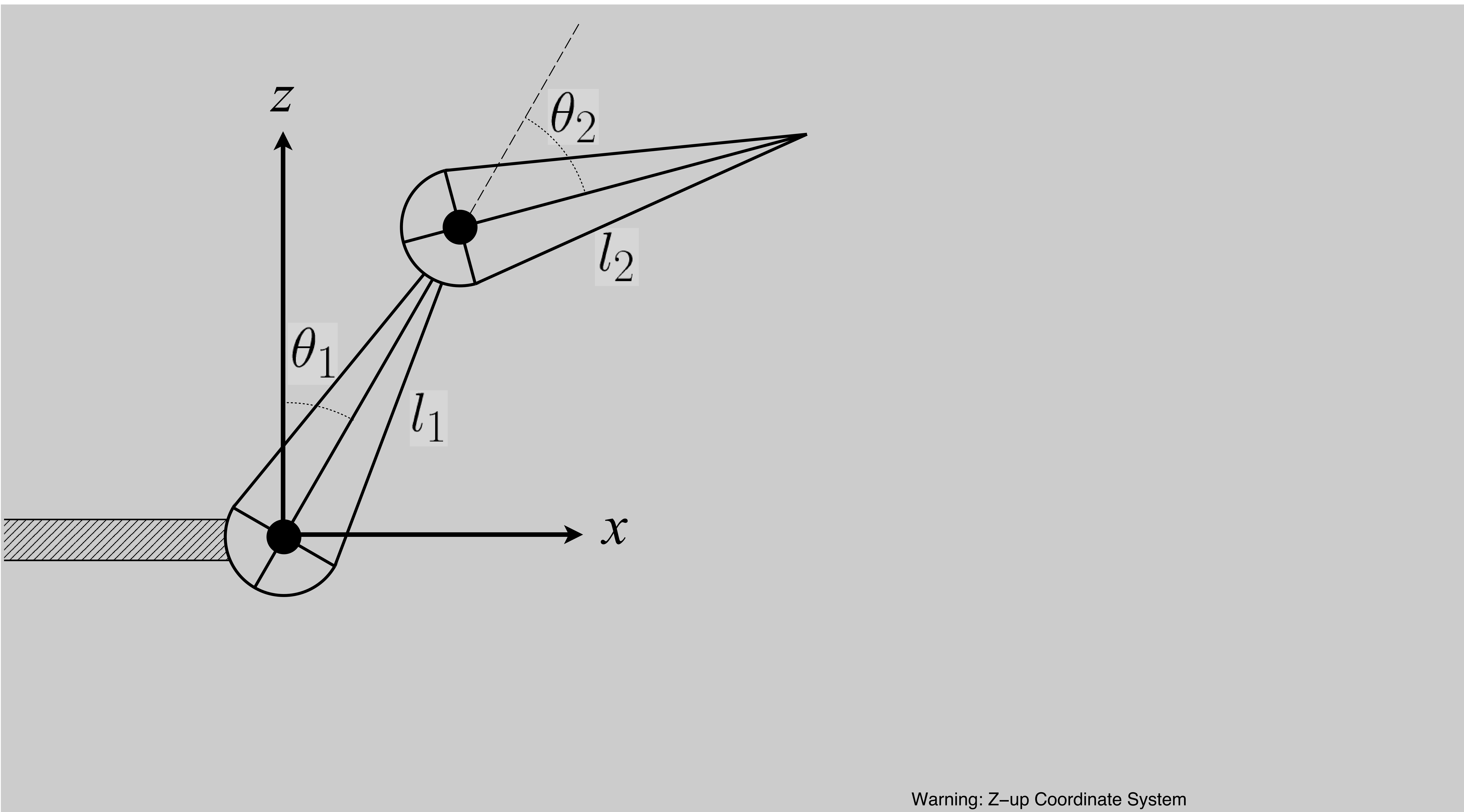
- Pin (1D rotation)
- Ball (2D rotation)
- Prismatic joint (translation)





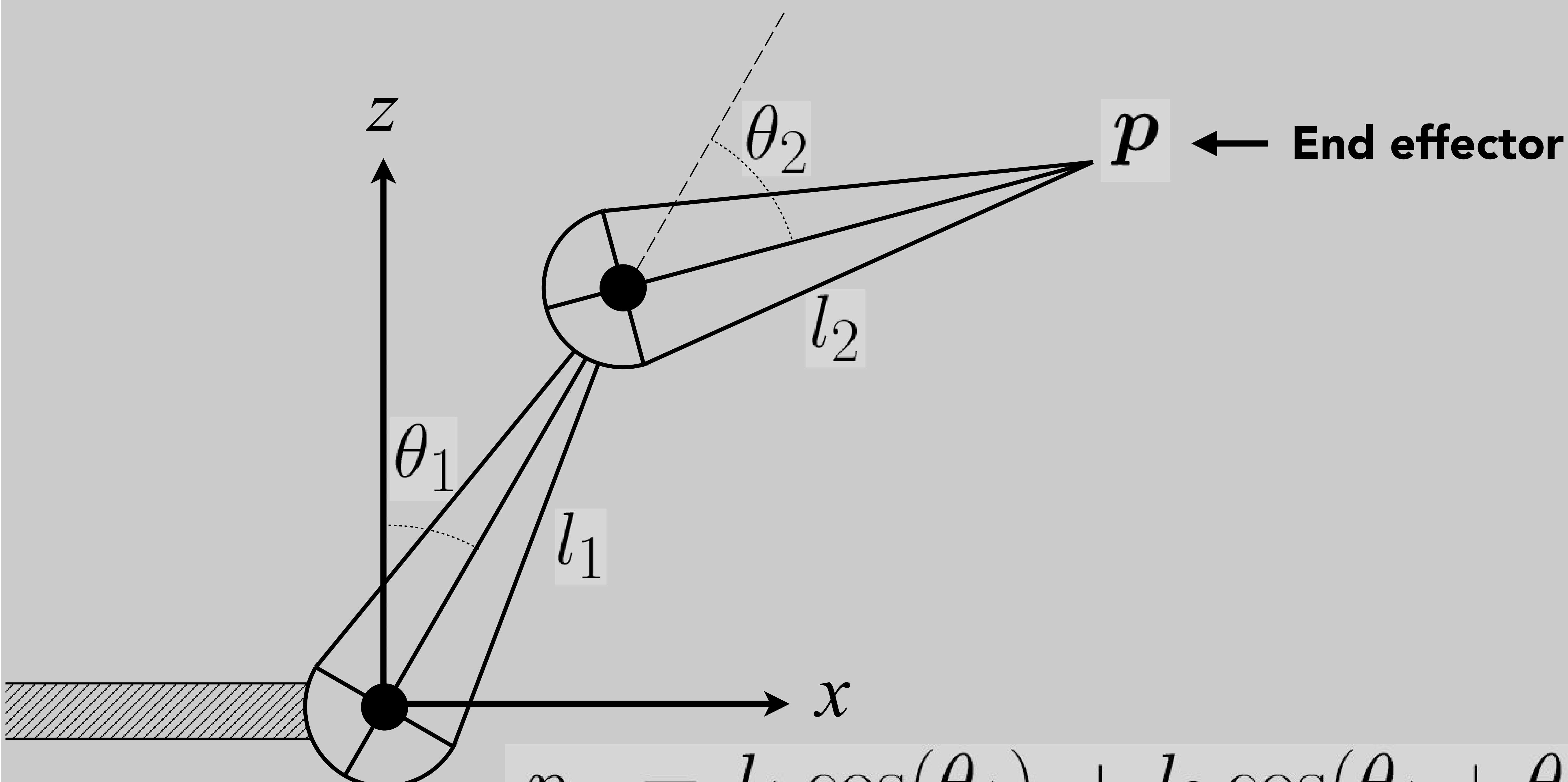
Forward Kinematics

Example: simple two segment arm in 2D



Forward Kinematics

Animator provides angles, and computer determines position *p* of end-effector



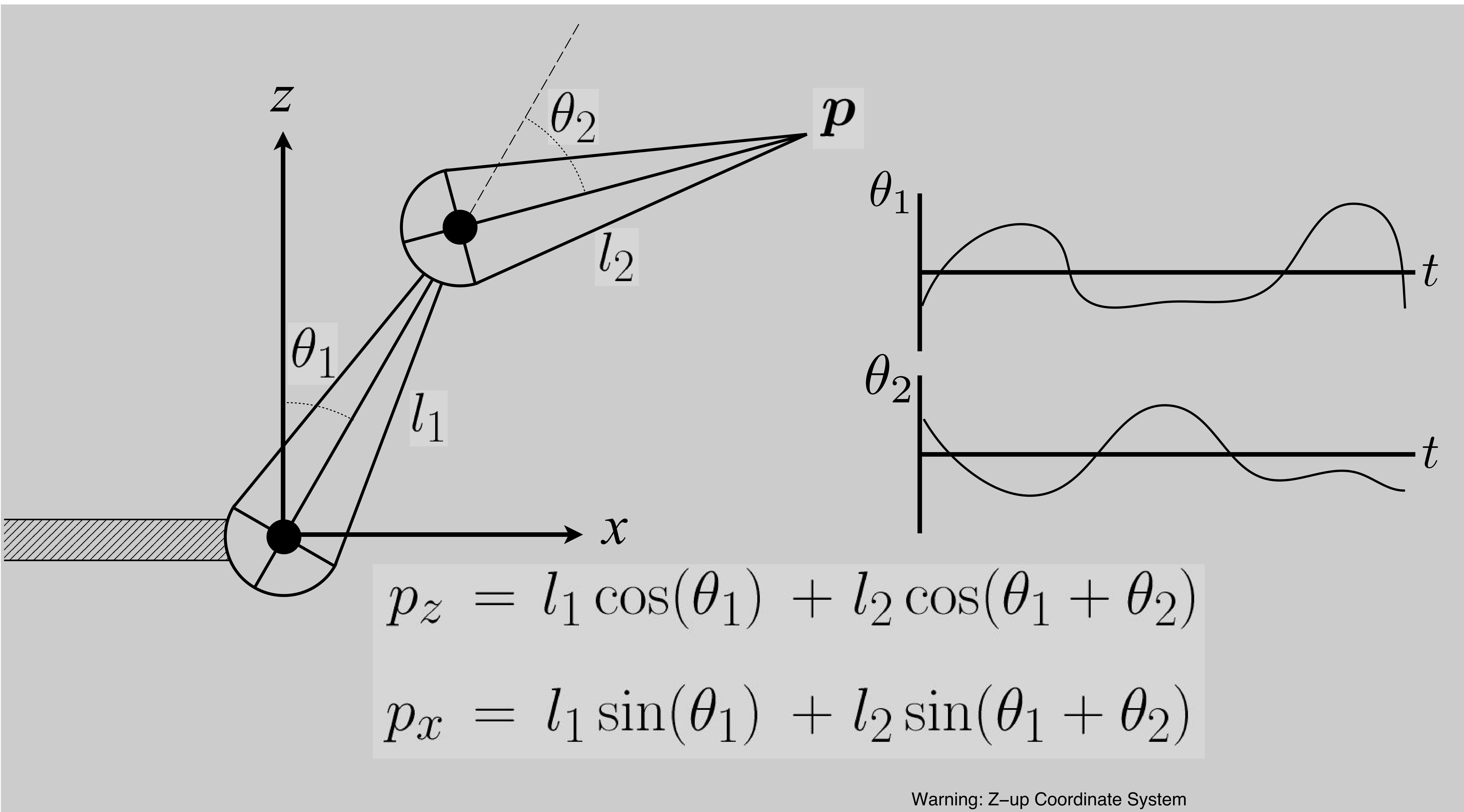
$$p_z = l_1 \cos(\theta_1) + l_2 \cos(\theta_1 + \theta_2)$$

$$p_x = l_1 \sin(\theta_1) + l_2 \sin(\theta_1 + \theta_2)$$

Warning: Z–up Coordinate System

Forward Kinematics

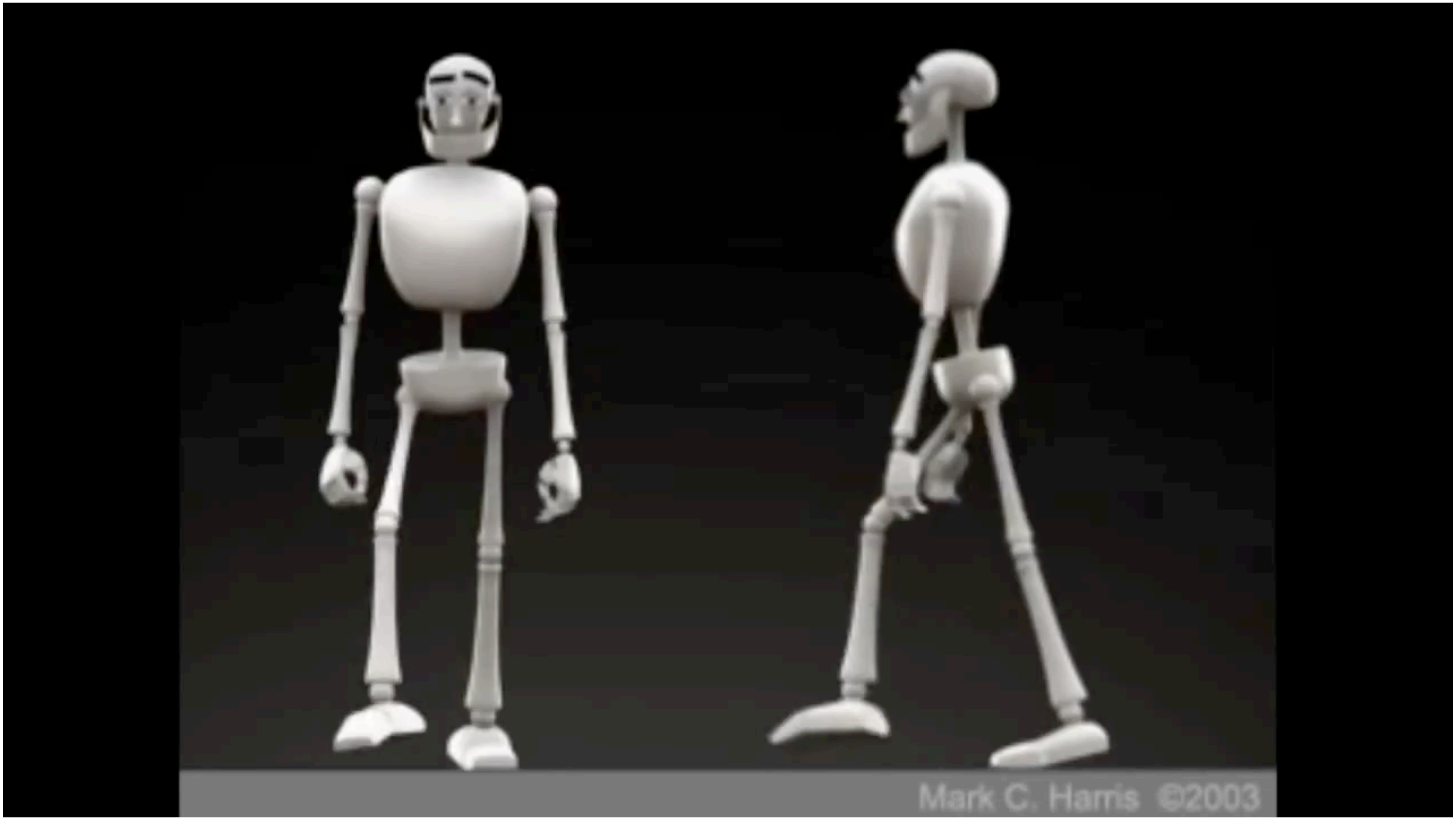
Animation is described as angle parameter values as a function of time



$$p_z = l_1 \cos(\theta_1) + l_2 \cos(\theta_1 + \theta_2)$$

$$p_x = l_1 \sin(\theta_1) + l_2 \sin(\theta_1 + \theta_2)$$

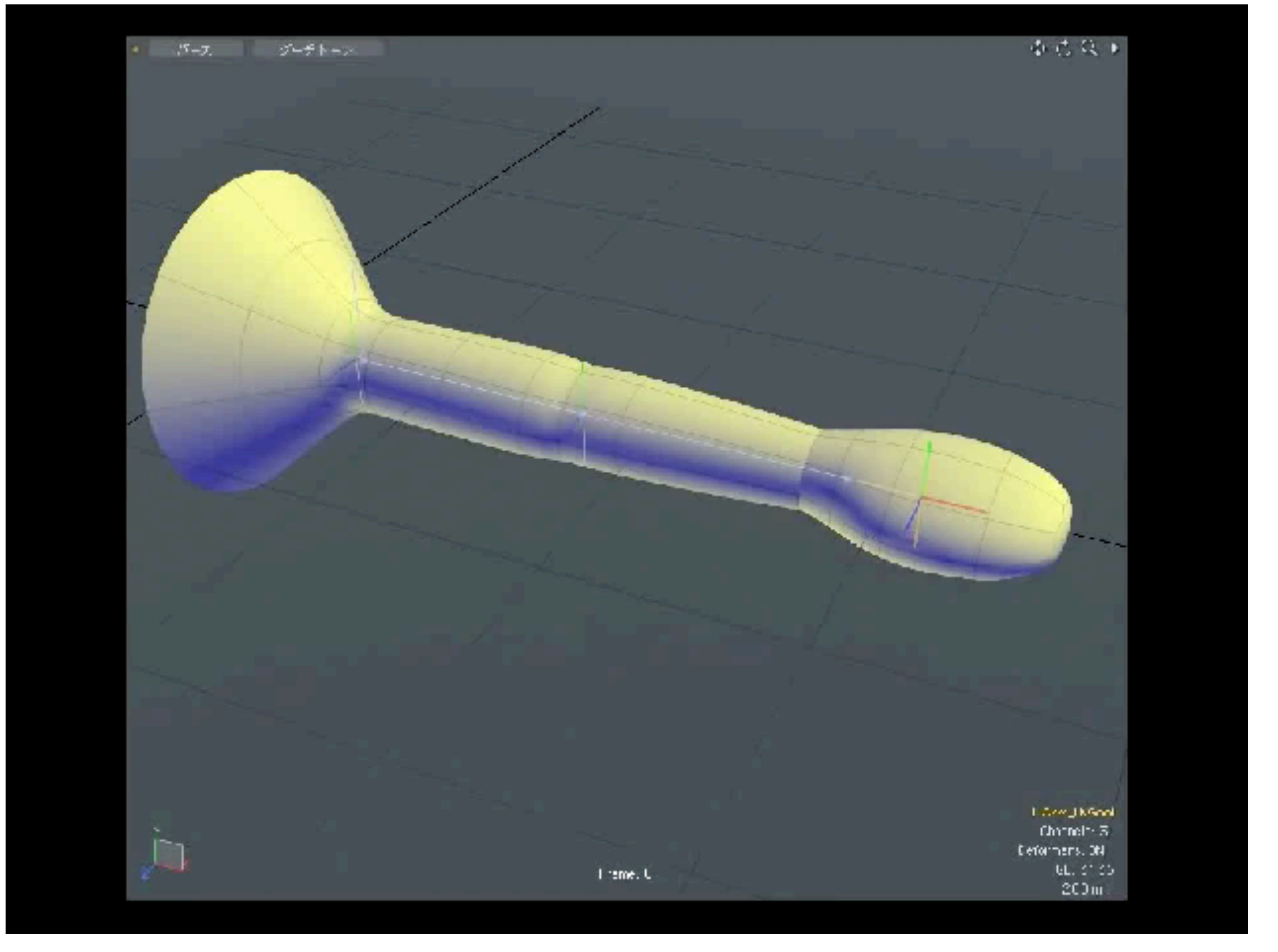
Example Walk Cycle



Inverse Kinematics

Inverse Kinematics

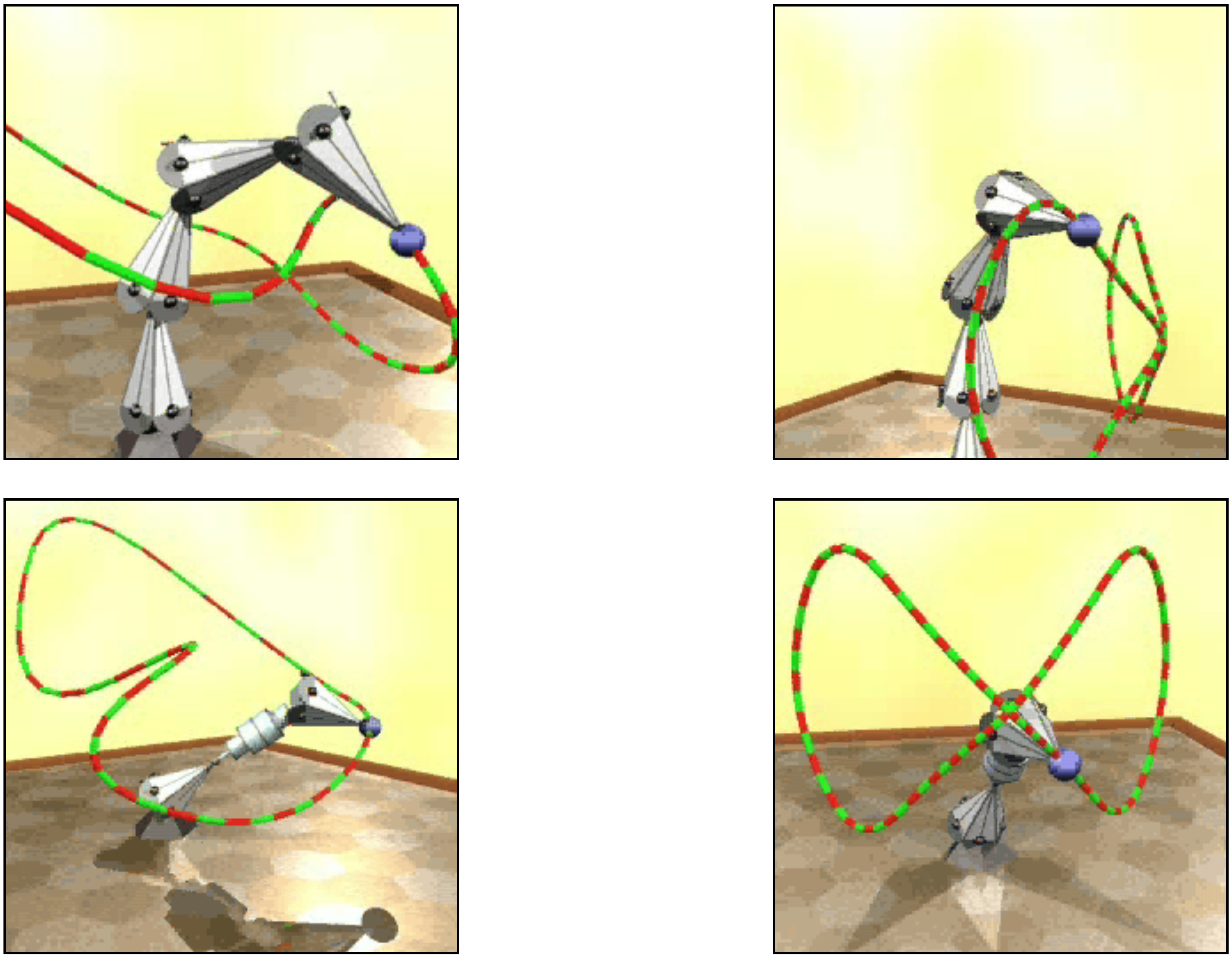
Given the end effector position, find the joint angles.



Goals

- Keep end of limb fixed while body moves
- Position end of limb by direct manipulation
- (More general: arbitrary constraints)

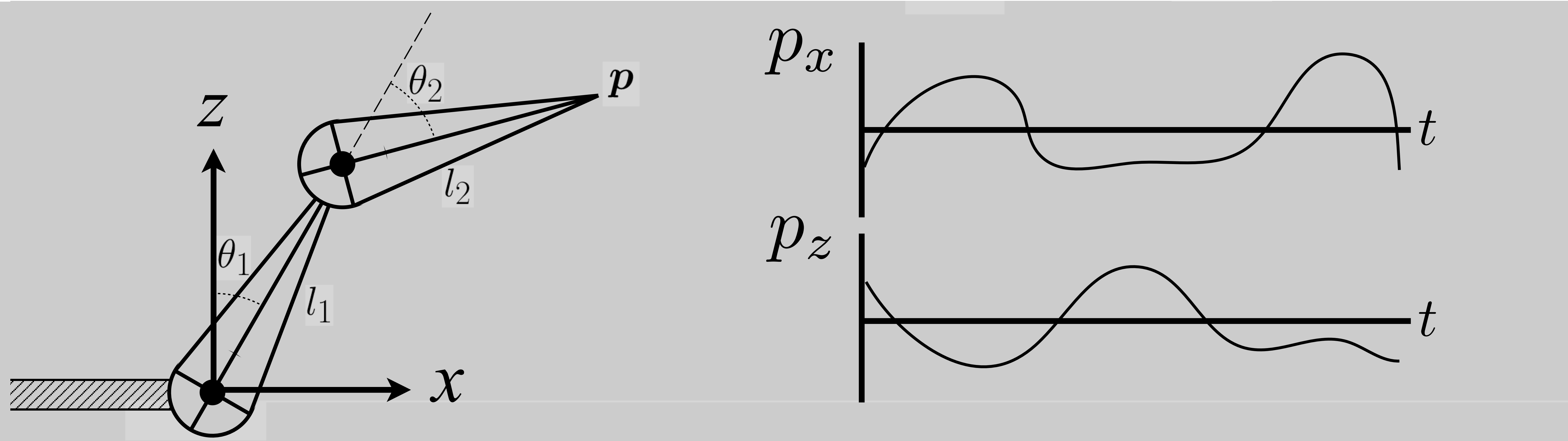
Inverse Kinematics



Egon Pasztor

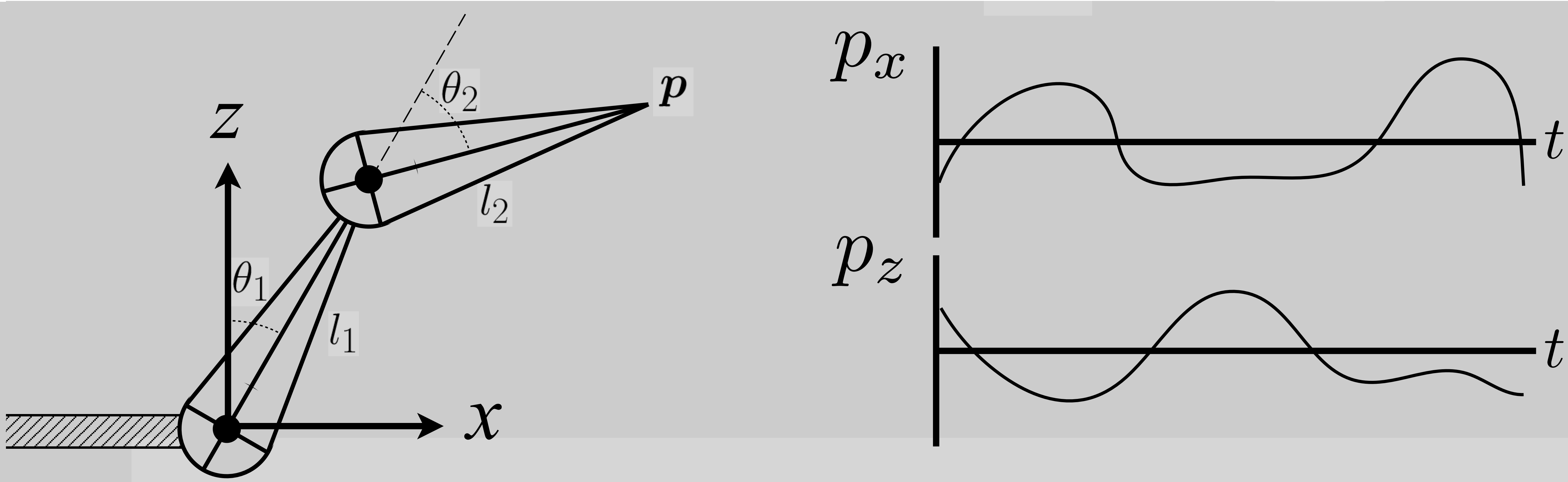
Inverse Kinematics

Animator provides position of end-effector, and computer must determine joint angles that satisfy constraints



Inverse Kinematics

Direct inverse kinematics: for two-segment arm, can solve for parameters analytically



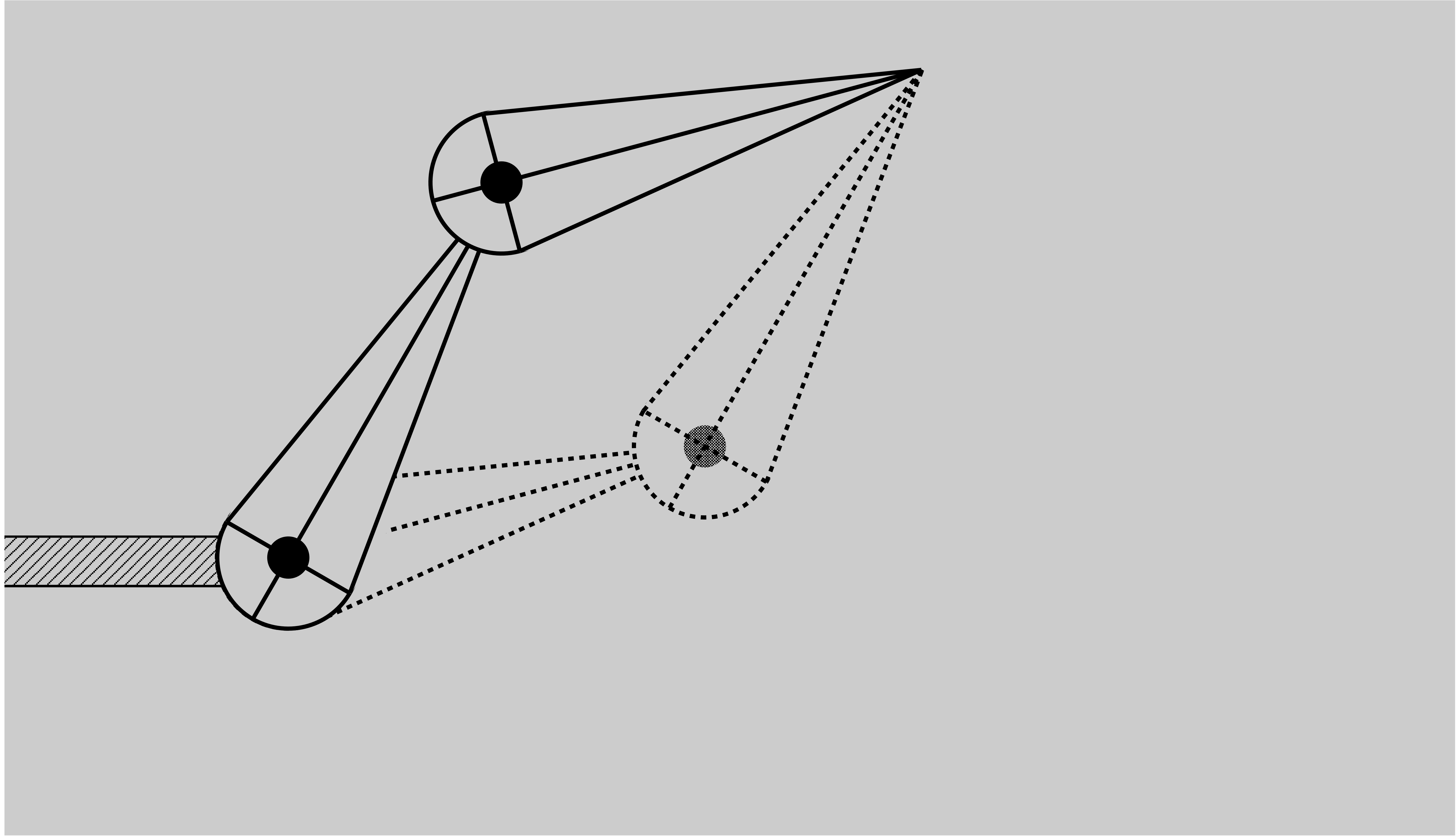
$$\theta_2 = \cos^{-1}\left(\frac{p_z^2 + p_x^2 - l_1^2 - l_2^2}{2l_1l_2}\right)$$

$$\theta_1 = \frac{-p_z l_2 \sin(\theta_2) + p_x(l_1 + l_2\cos(\theta_2))}{p_x l_2 \sin(\theta_2) + p_z(l_1 + l_2\cos(\theta_2))}$$

Inverse Kinematics

Why is the problem hard?

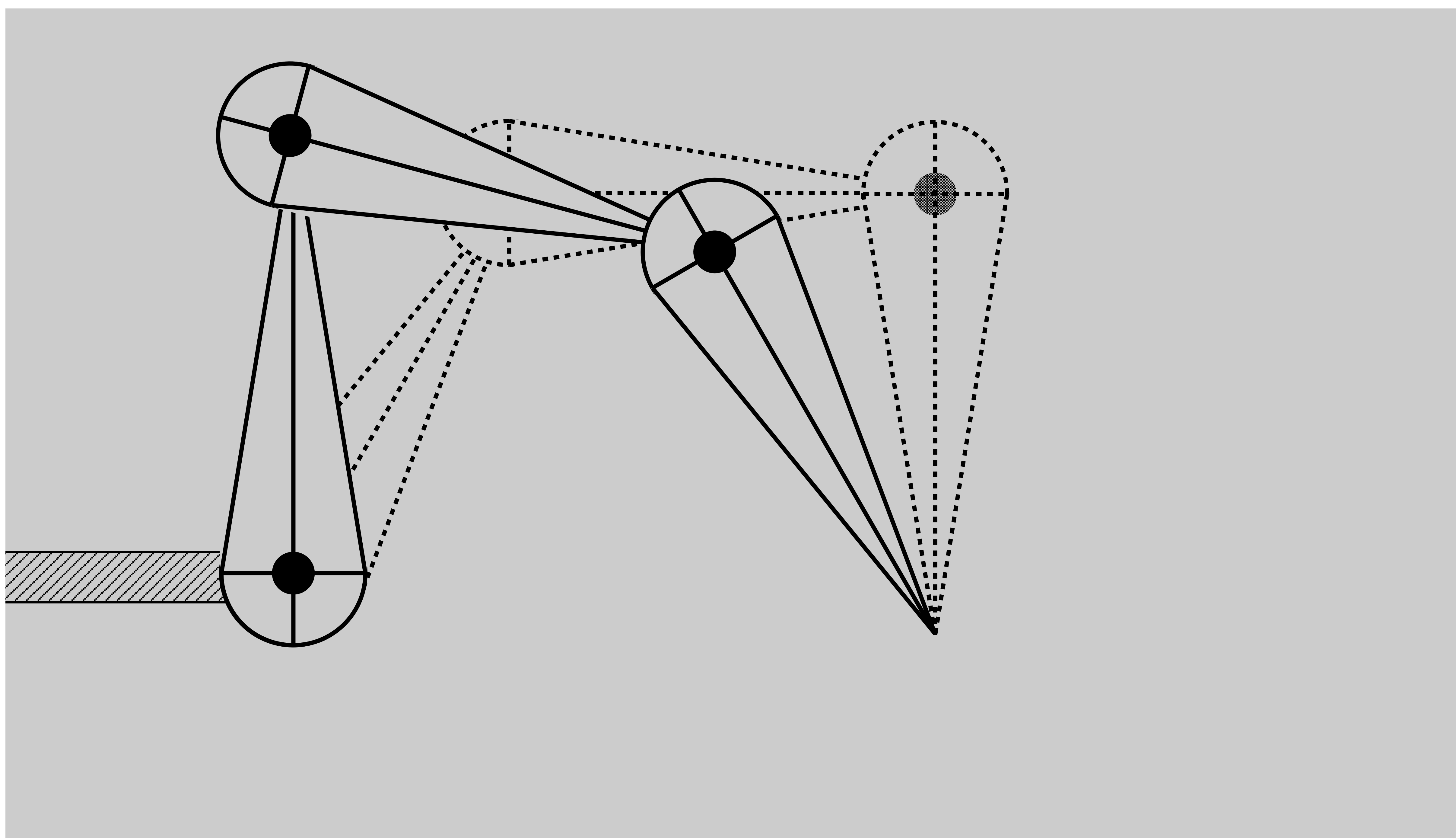
- Multiple solutions separated in configuration space



Inverse Kinematics

Why is the problem hard?

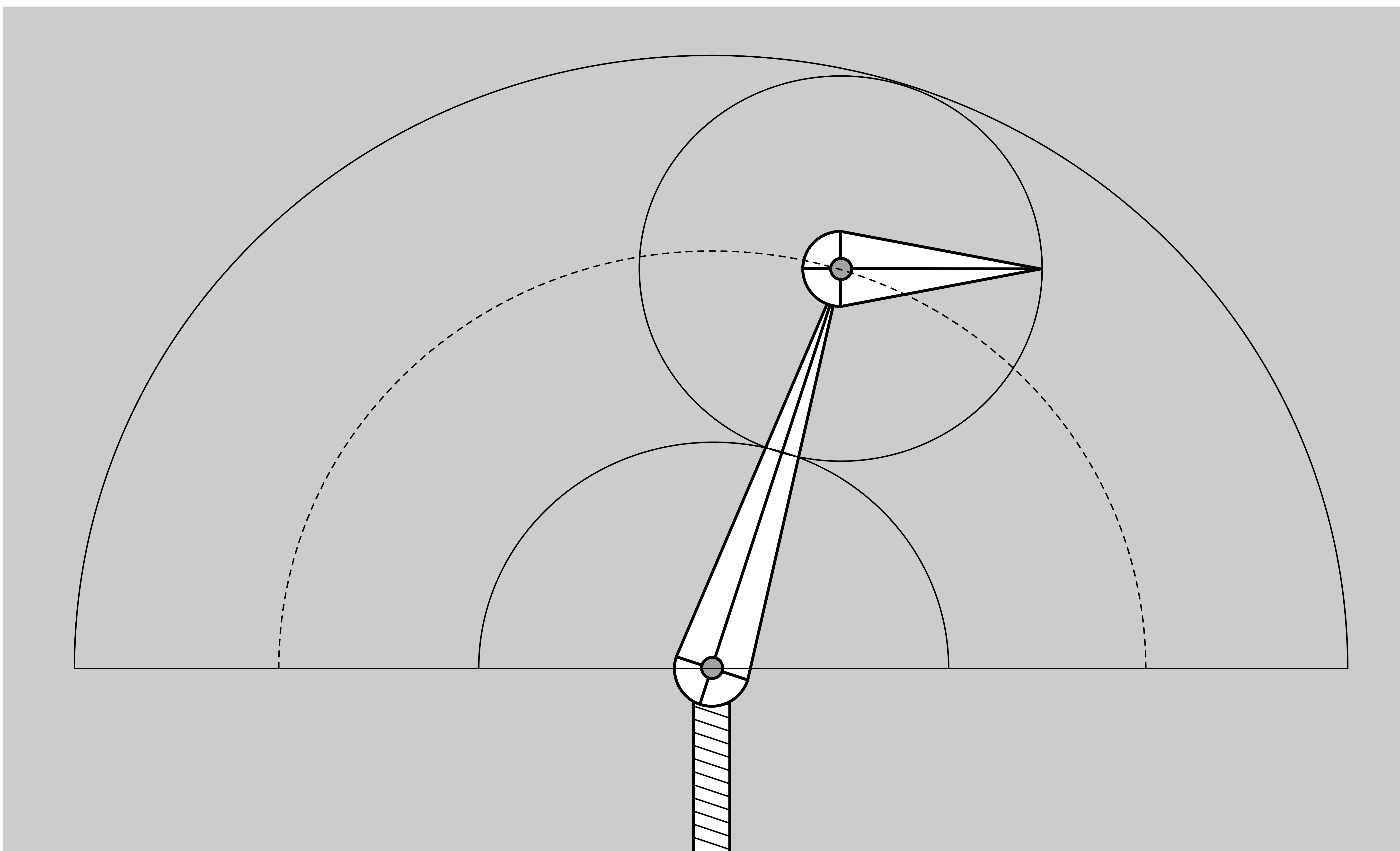
- Multiple solutions connected in configuration space



Inverse Kinematics

Why is the problem hard?

- Solutions may not always exist

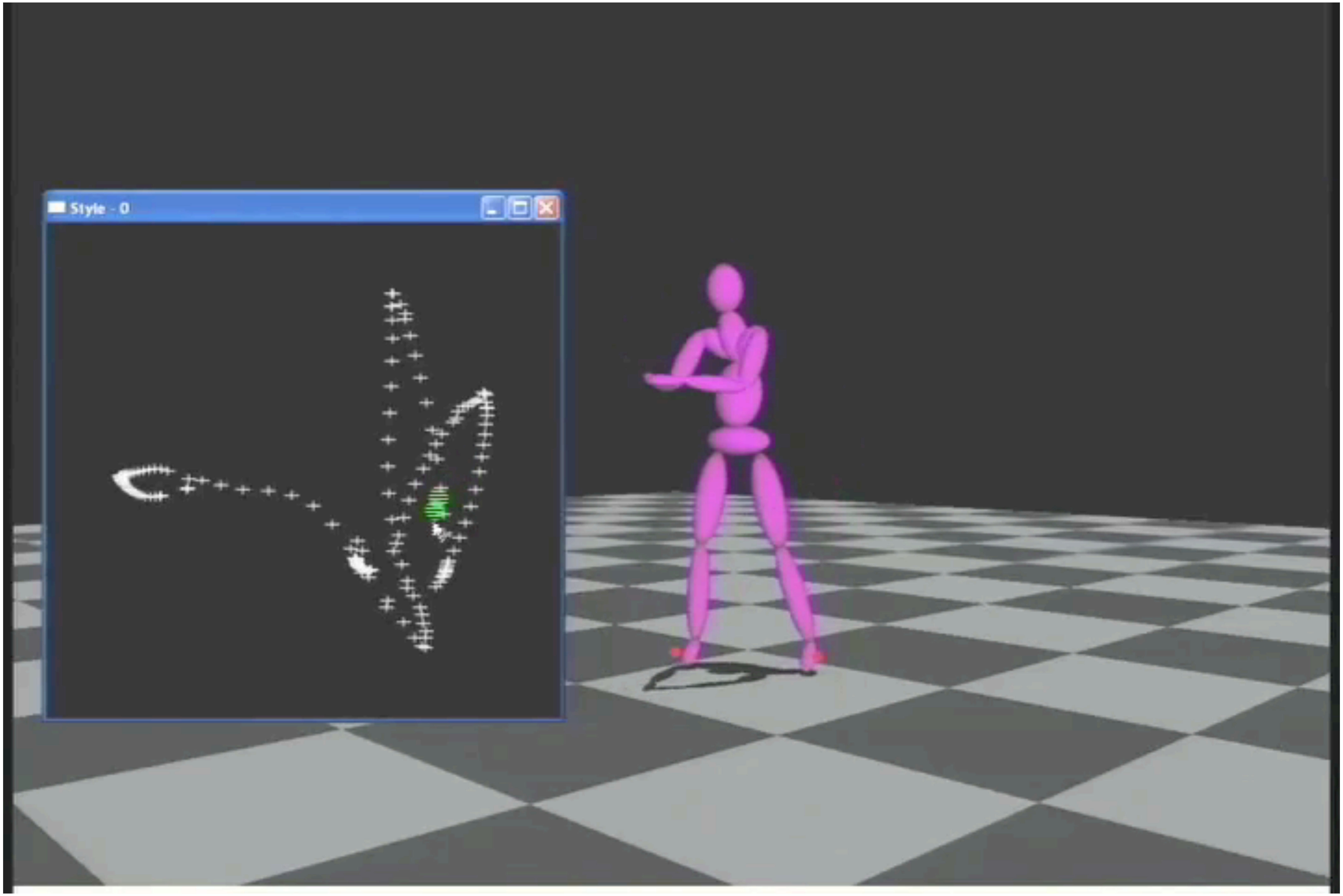


Inverse Kinematics

Numerical solution to general N-link IK problem

- Choose an initial configuration
- Define an error metric (e.g. square of distance between goal and current position)
- Compute gradient of error as function of configuration
- Apply gradient descent (or Newton's method, or other optimization procedure)

Style-Based IK



Grochow et al., Style Based Inverse Kinematics

Kinematics Pros and Cons

Strengths

- Direct control is convenient
- Implementation is straightforward

Weaknesses

- Animation may be inconsistent with physics
- Time consuming for artists

Rigging

Rigging

Rigging is a set of higher level controls on a character that allow more rapid & intuitive modification of pose, deformations, expression, etc.

Important

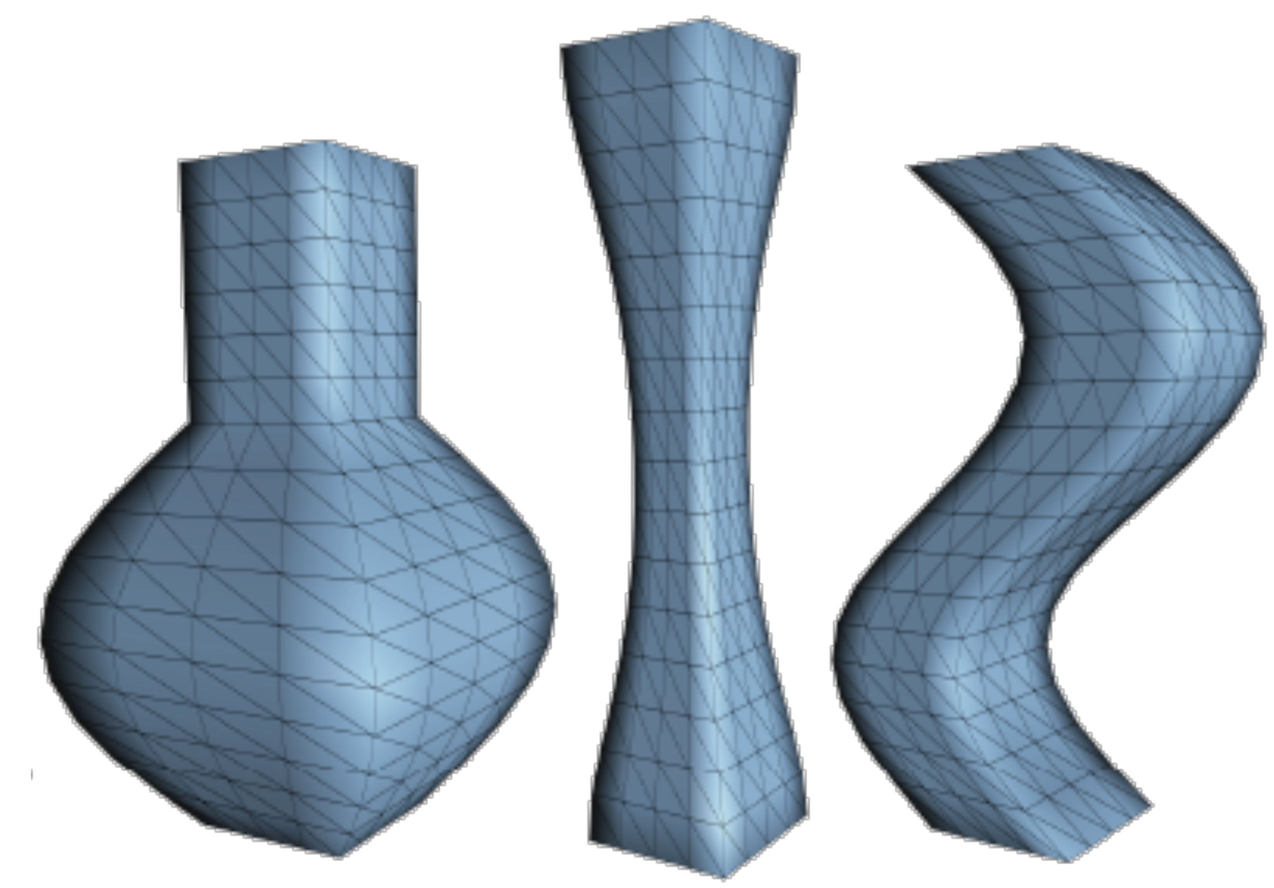
- Like strings on a puppet
- Captures all meaningful character changes
- Varies from character to character

Expensive to create

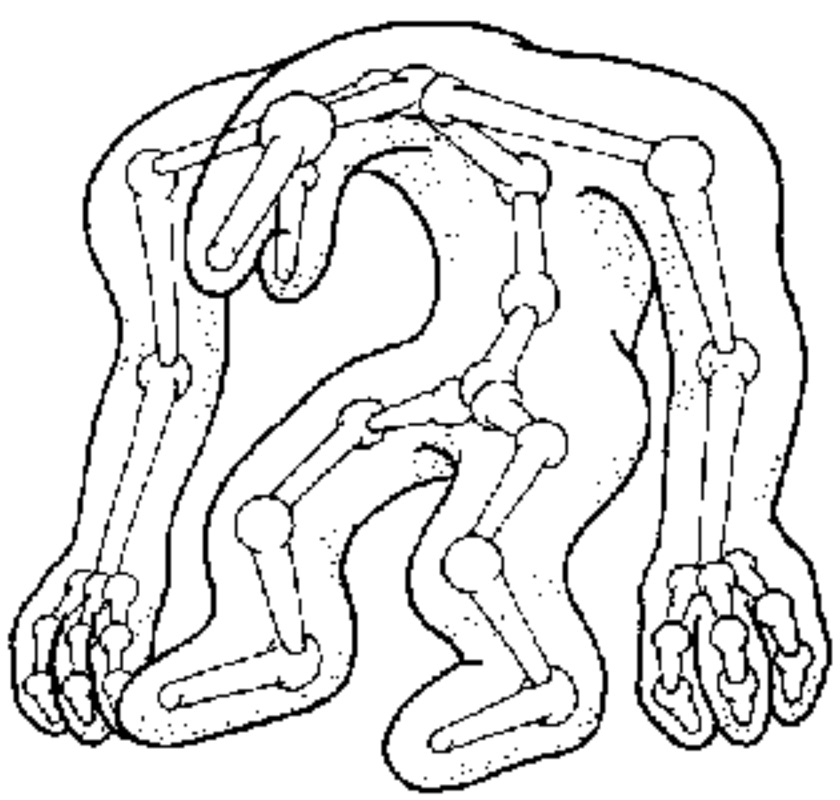
- Manual effort
- Requires both artistic and technical training

Types of Rigging

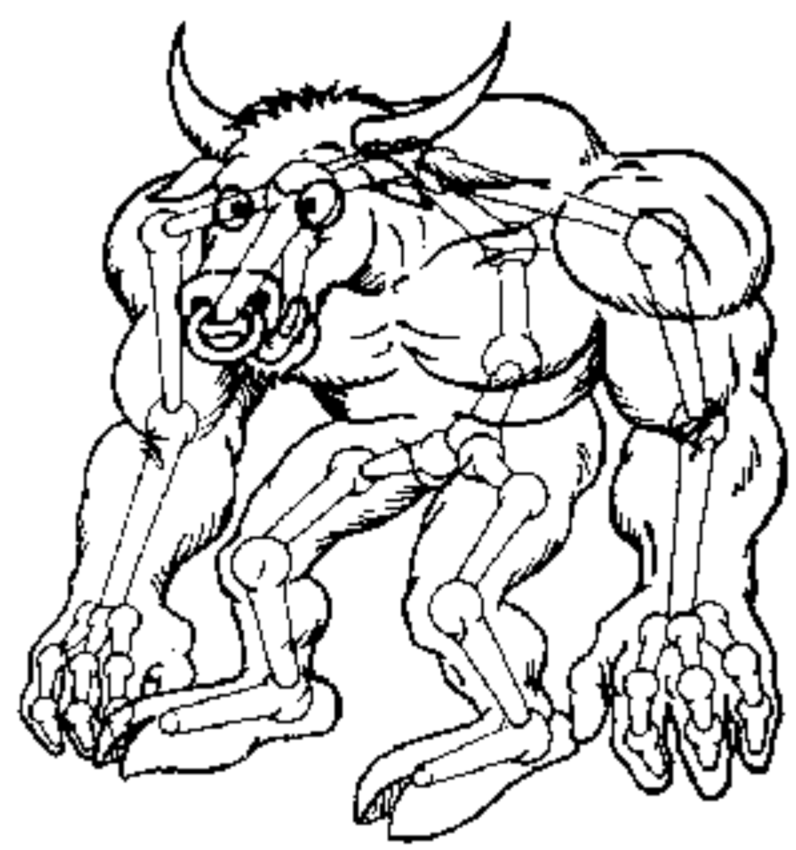
- Procedural Rigging
- Skeletal Rigging
- Anatomical Rigging



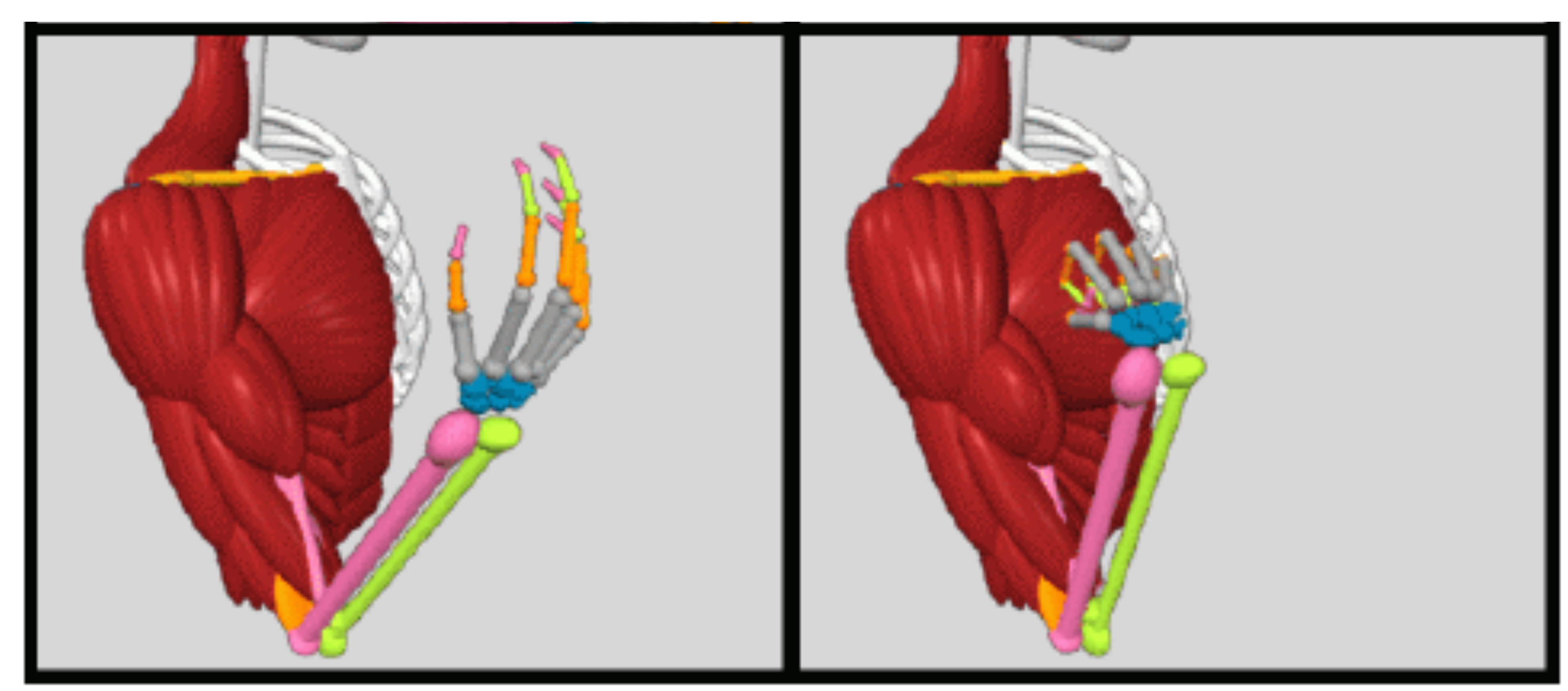
Al Barr. Global and Local Deformations of Solid Primitives. SIGGRAPH 1984.



Skeleton



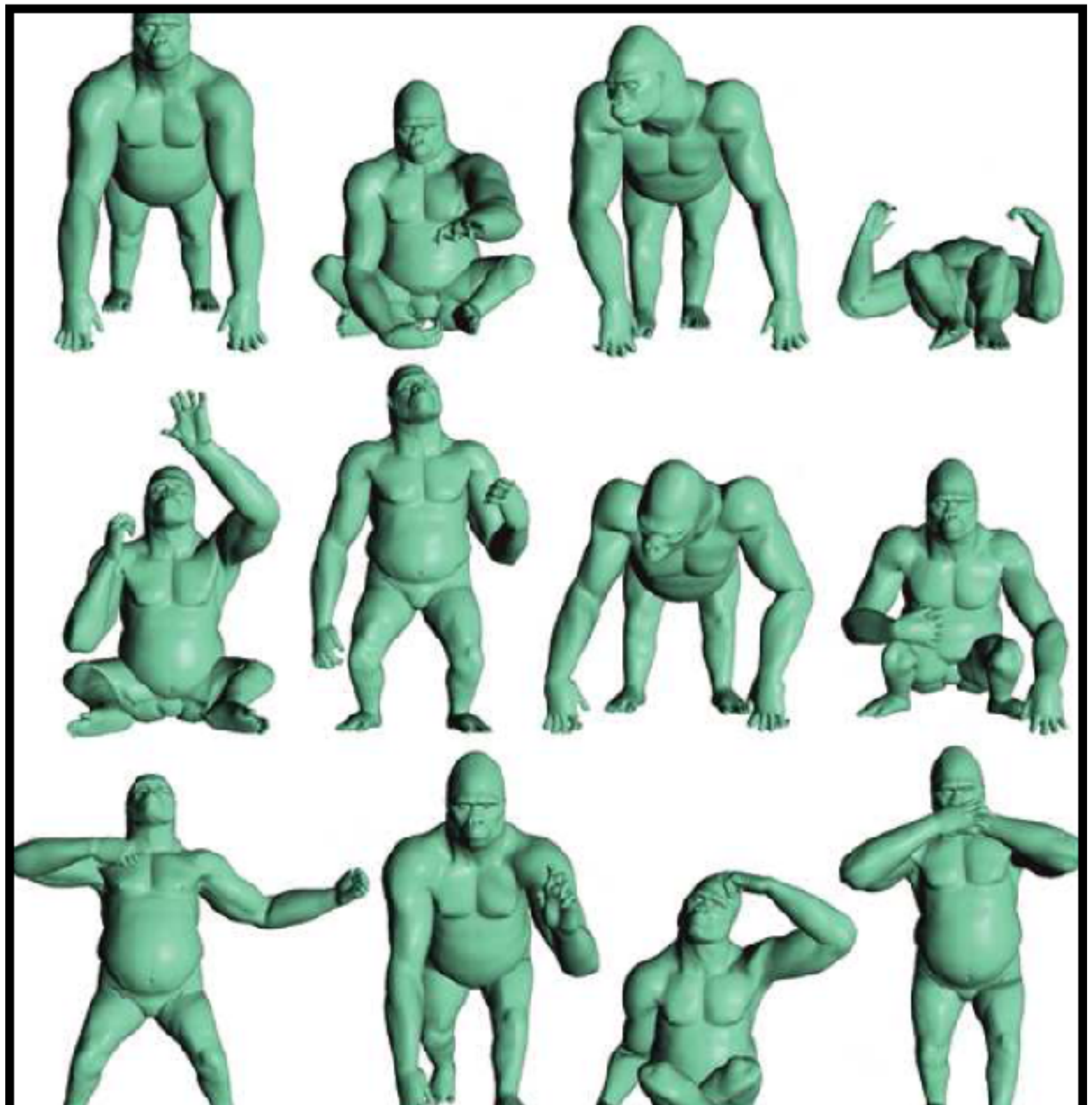
Skinning on top



Anatomy-Based Modeling of the Human Musculature. Scheepers et al. SIGGRAPH 1997.

Posing

Use the rigging controls to put the character into a given pose.



Rigging Example

Courtesy Matthew Lailler via Keenan Crane

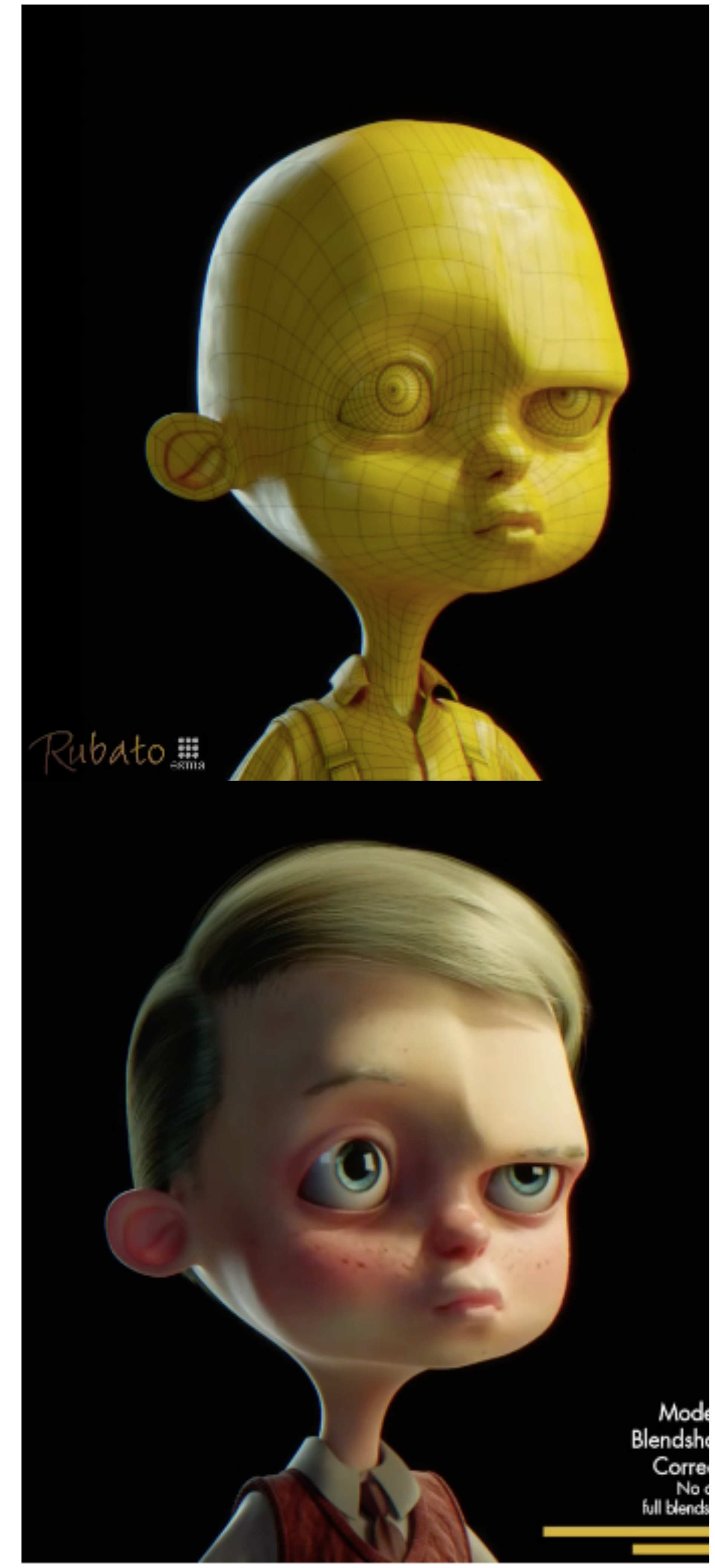
Blend Shapes

Instead of skeleton, interpolate directly between surfaces

E.g., model a collection of facial expressions:

Simplest scheme: take linear combination of vertex positions

Spline used to control choice of weights over time



Courtesy Félix Ferrand

Blend Shapes

Courtesy Félix Ferrand

Motion Capture

Motion Capture

Data-driven approach to creating animation sequences

- Record real-world performances (e.g. person executing an activity)
- Extract pose as a function of time from the data collected

Motion capture room for ShaqFu

Motion Capture Pros and Cons

Strengths

- Can capture large amounts of real data quickly
- Realism can be high

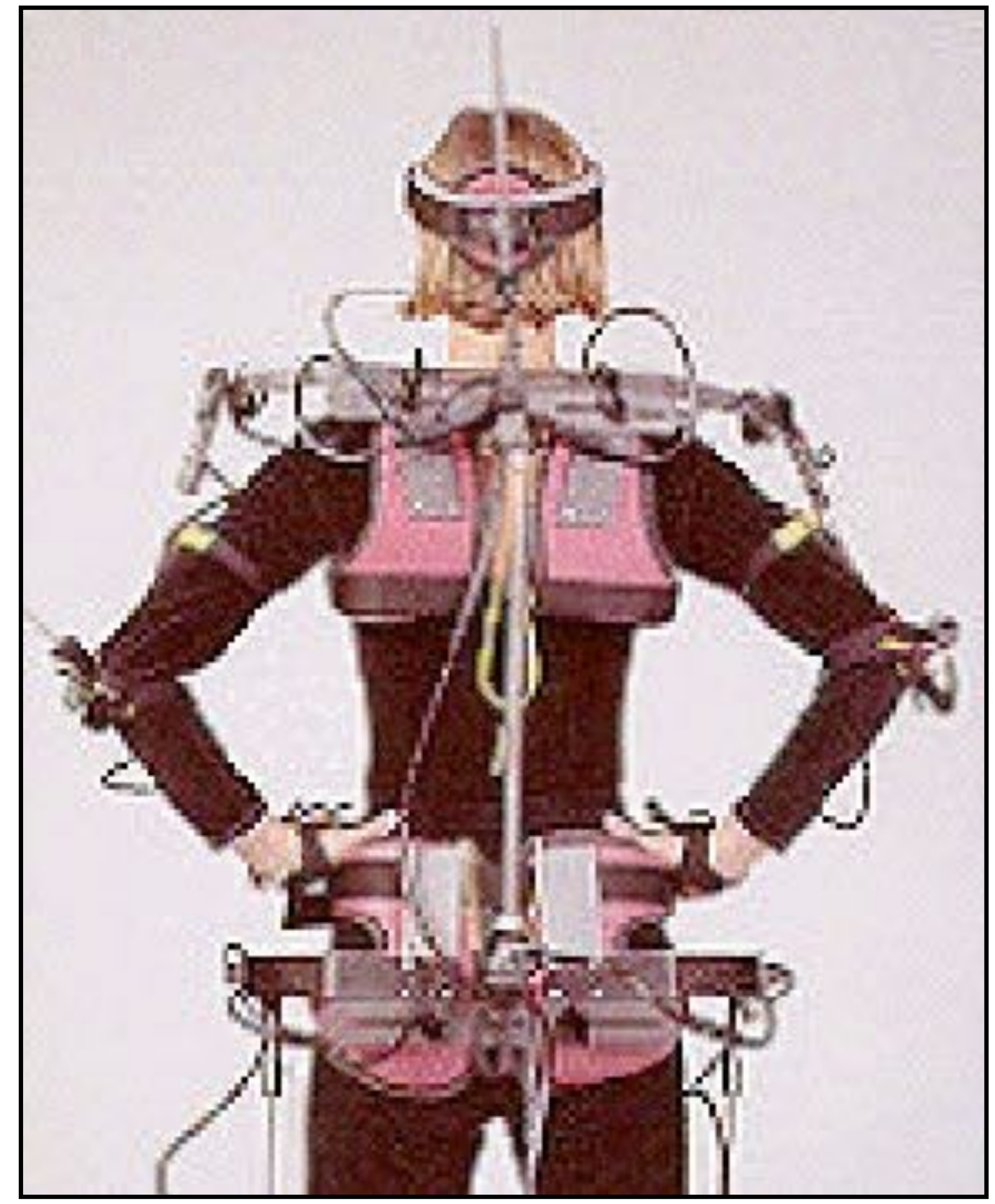
Weaknesses

- Complex and costly set-ups
- Captured animation may not meed artistic needs, requiring alterations

Motion Capture Equipment

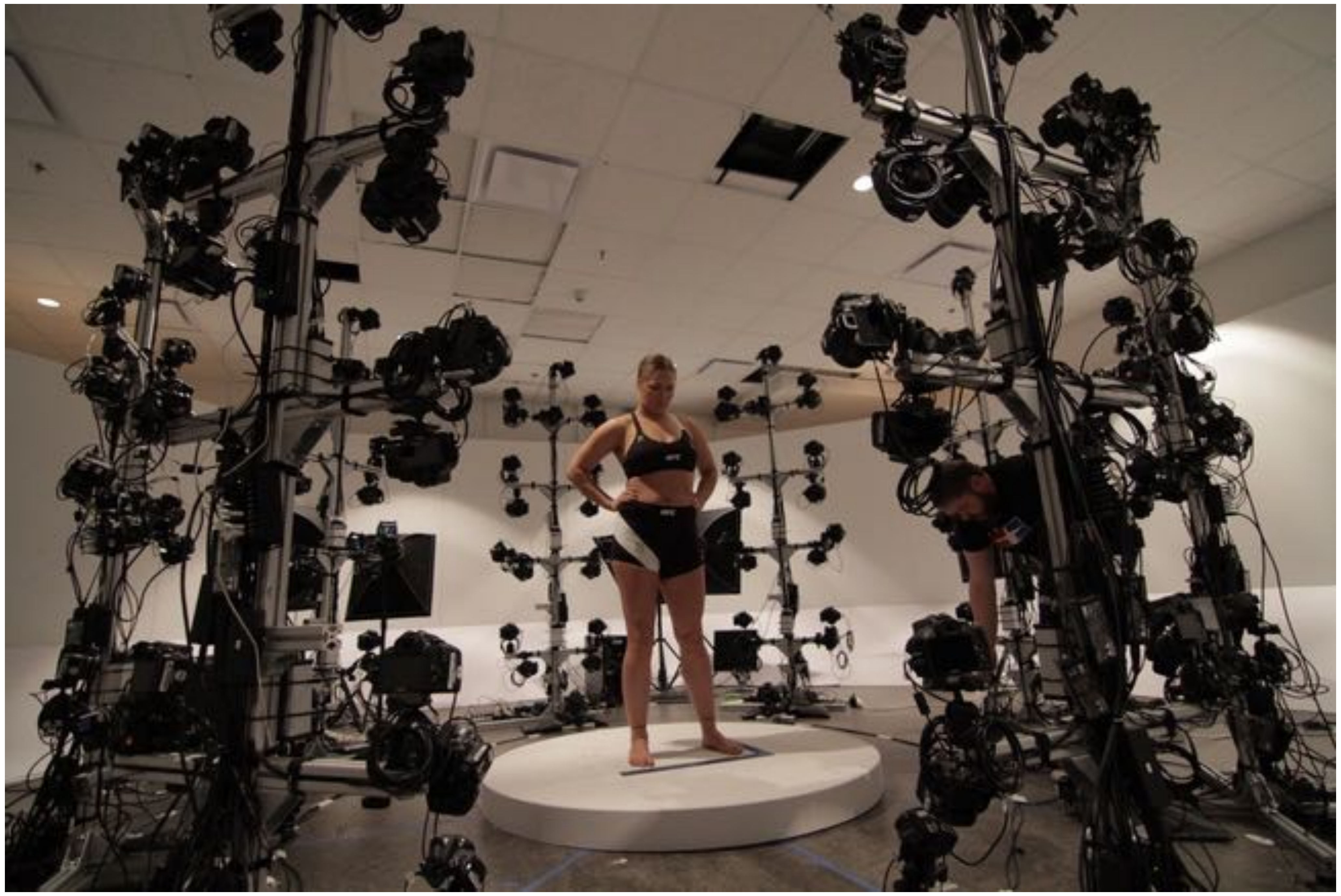
Optical
(More on following slides)

Magnetic
Sense magnetic fields to infer position / orientation. Tethered.



Mechanical
Measure joint angles directly. Restricts motion.

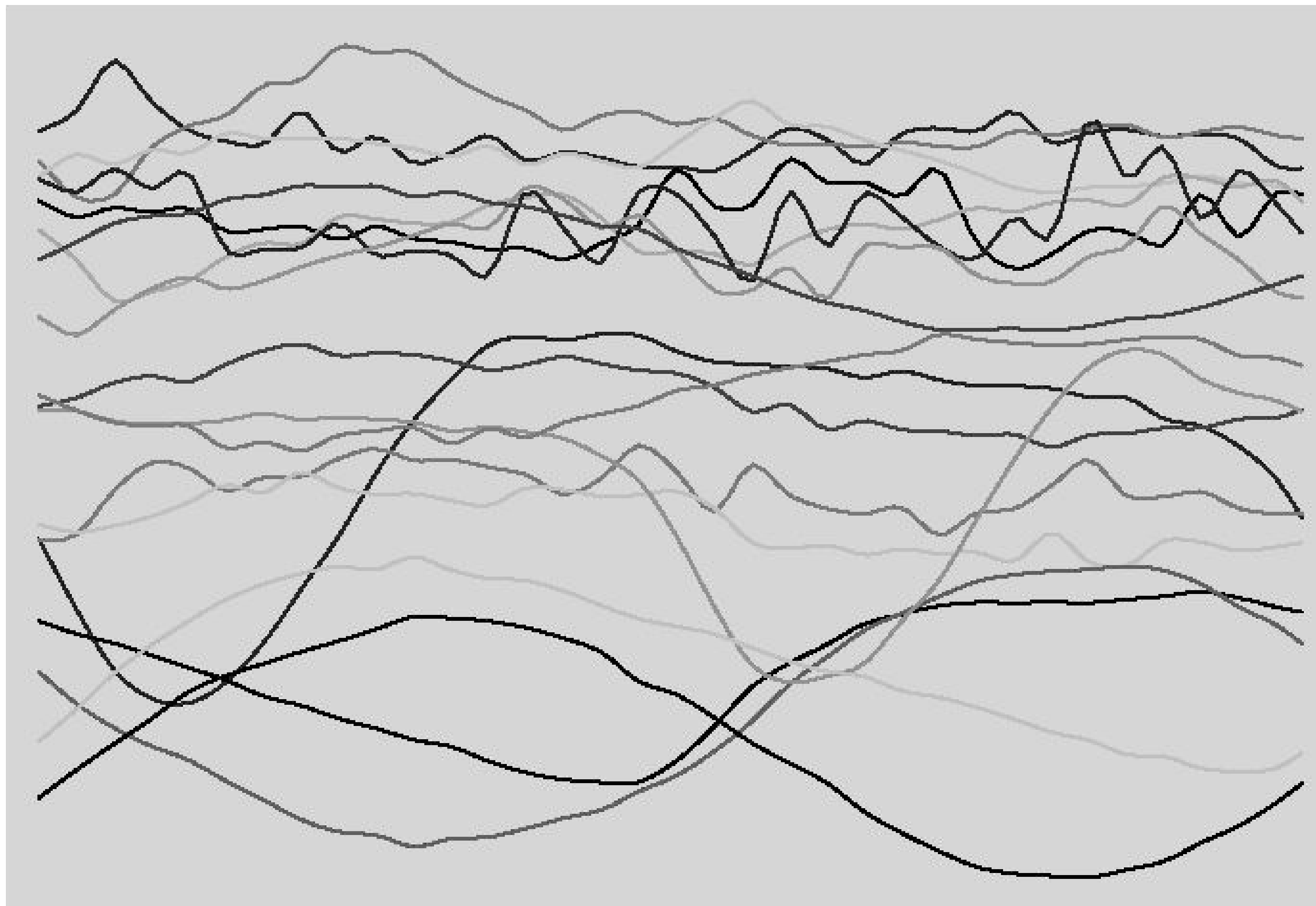
Optical Motion Capture



Source: http://fightland.vice.com/blog/ronda-rousey-20-the-queen-of-all-media

Ronda Roussey in Electronic Arts' motion capture studio

Motion Data



Subset of motion curves from captured walking motion.

From Witkin and Popovic, 1995

Alita: Performance Capture

Challenges of Facial Animation

Uncanny valley

- In robotics and graphics
- As artificial character appearance approaches human realism, our emotional response goes negative, until it achieves a sufficiently convincing level of realism in expression

Cartoon.
Brave, Pixar

Semi-realistic. Polar Express, Warner Bros.

Challenges of Facial Motion Capture

Final Fantasy Spirits Within

Facial Motion Capture

Discovery, "Avatar: Motion Capture Mirrors Emotions", https://youtu.be/1wK1Ixr-UmM

Facial Modeling

Snappers Facial Rig

Things to Remember

Principles of animation

Computer character animation

Rigging, posing, keyframes, interpolation

Forward and inverse kinematics

Motion capture: data driven animation

Next Time: Physical Simulation

Acknowledgments

Thanks to Keenan Crane and Mark Pauly for presentation resources.