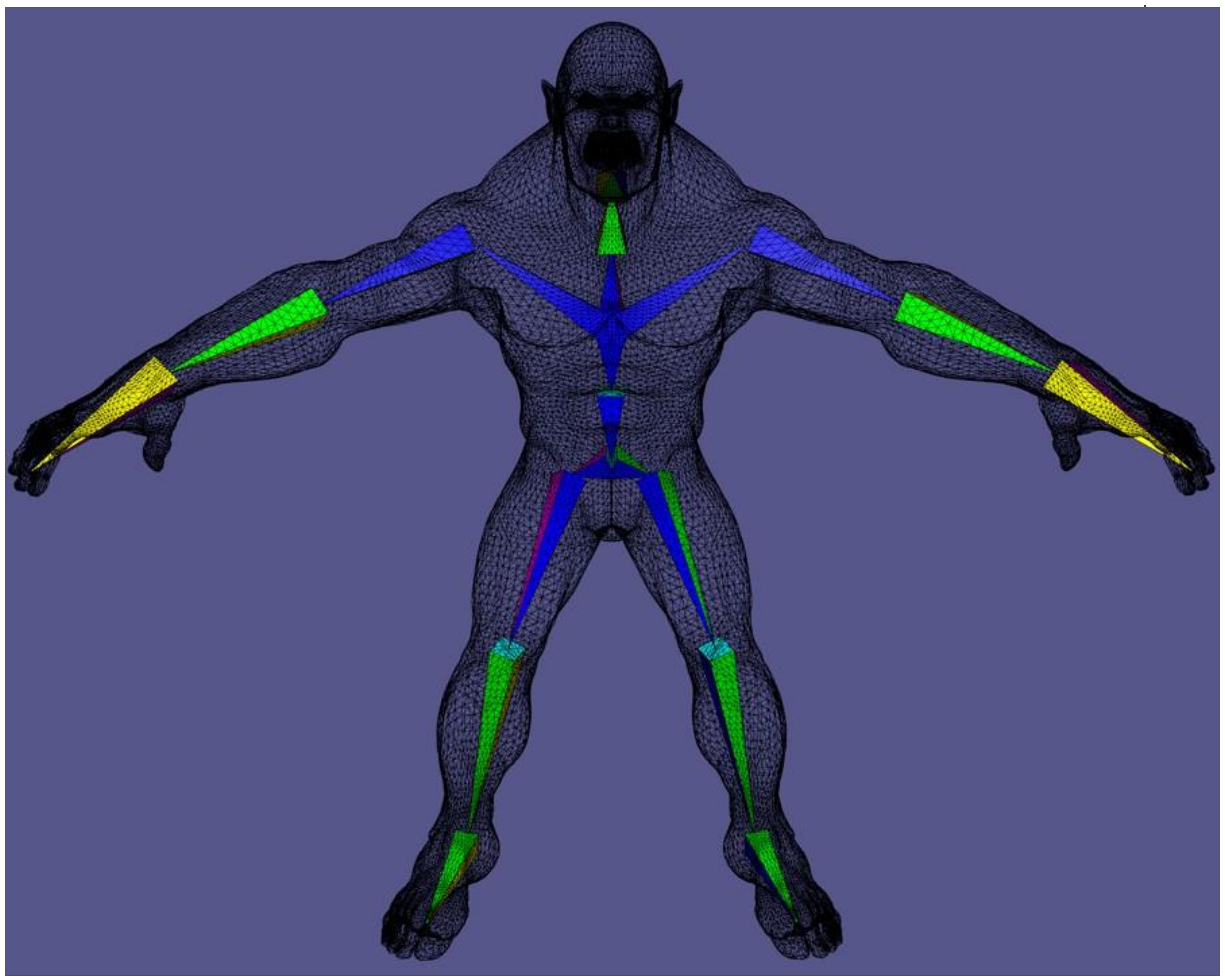
Lecture 22:

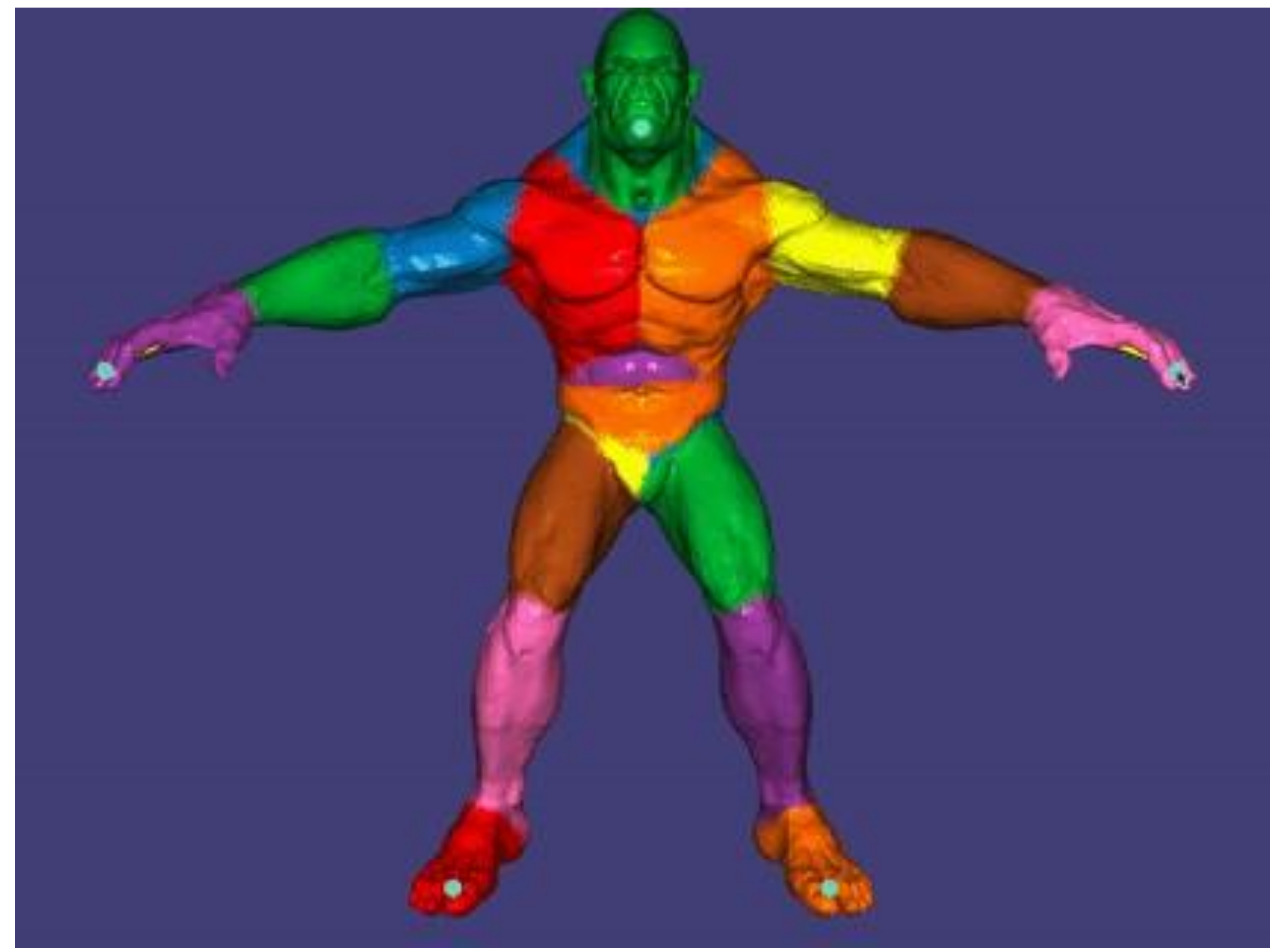
Intro to Animation

Computer Graphics and
Imaging UC Berkeley
CS184/284A

Principles of Animation

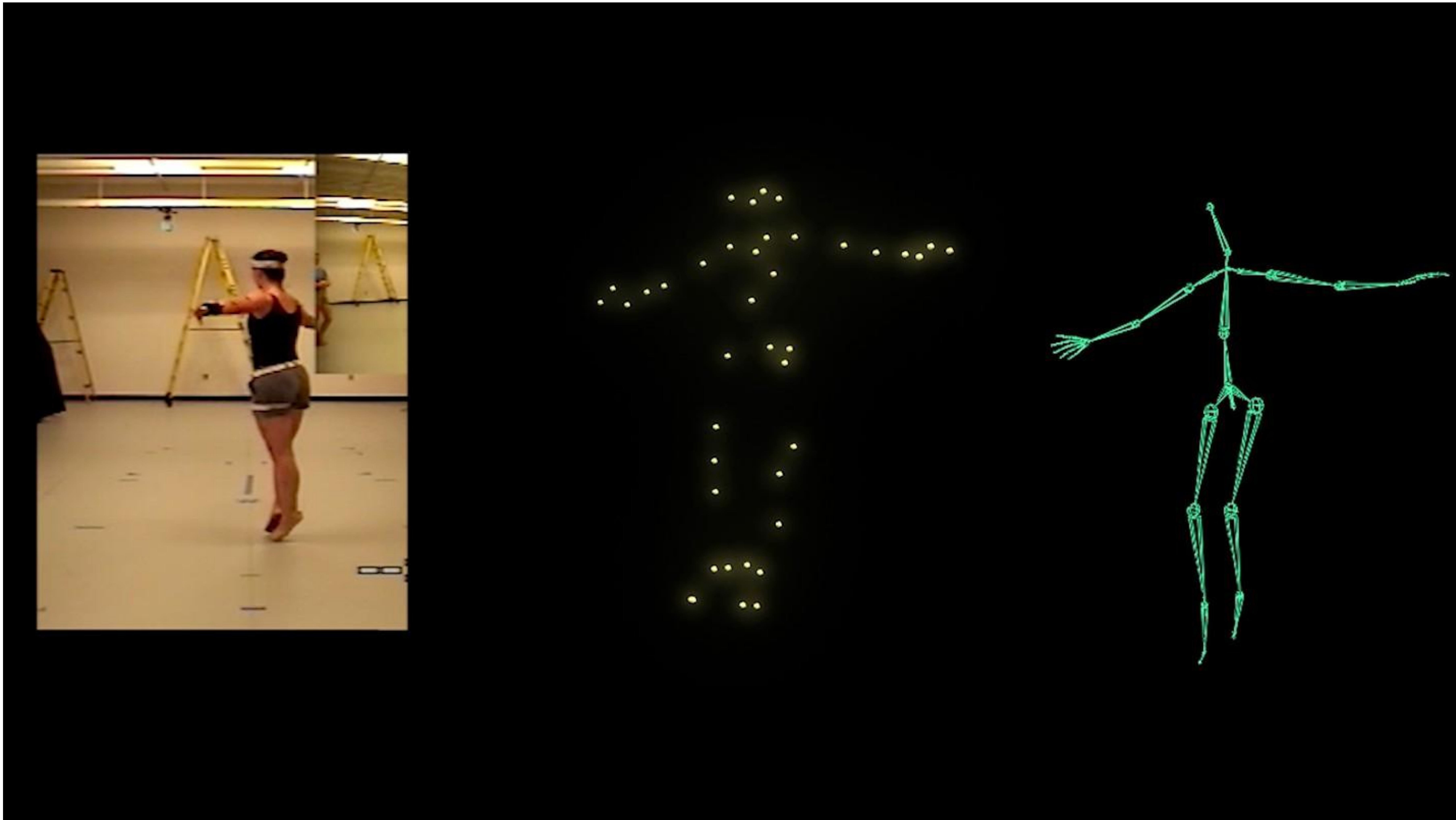
Rigging & Skinning





Courtesy of libigl / Alec Jacobson

Motion Capture



Physical Simulation: Cloth

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

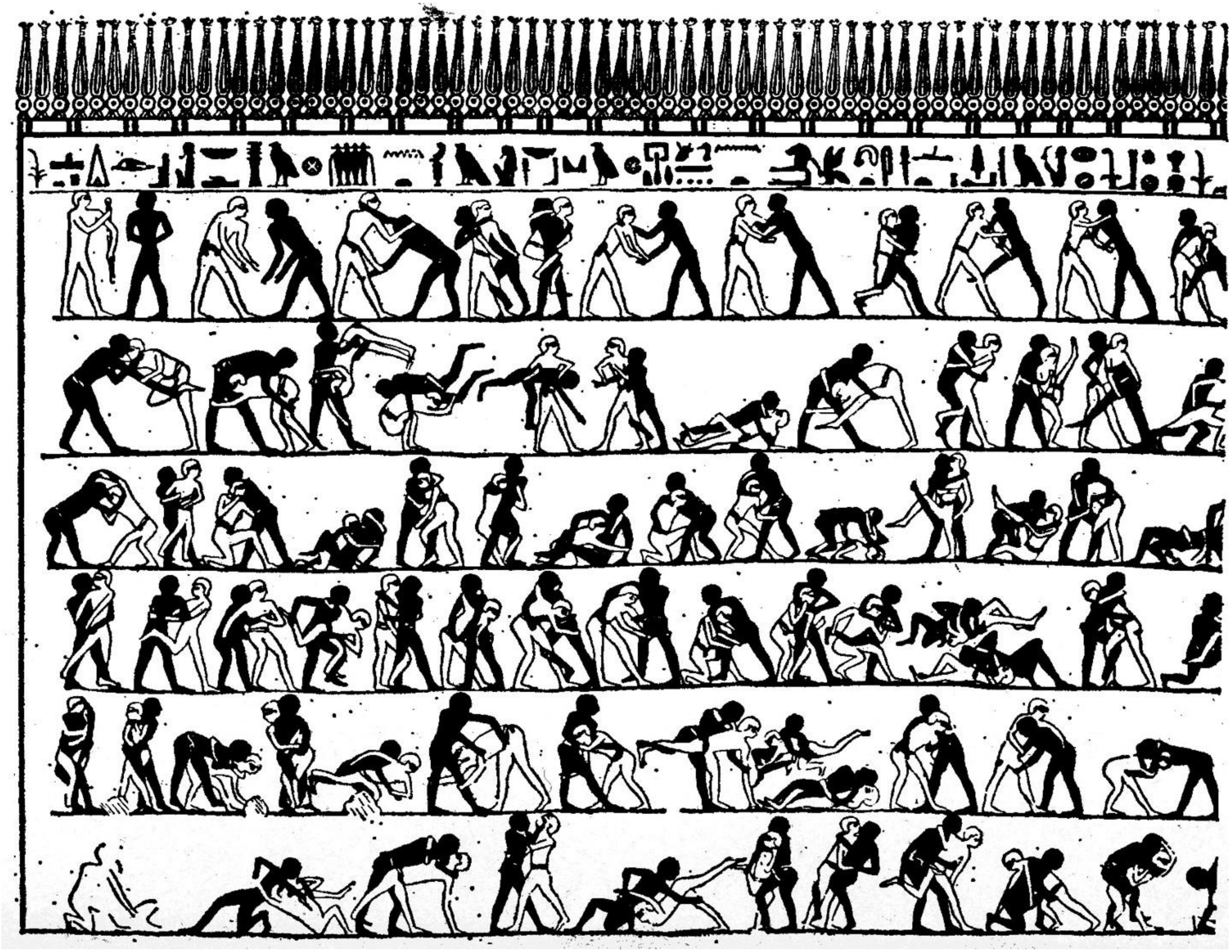
Historical Points in Animation

(slides courtesy Keenan Crane)

First Animation

(Shahr-e Sukhteh, Iran 3200 BCE)

History of Animation



(tomb of Khnumhotep, Egypt 2400 BCE)

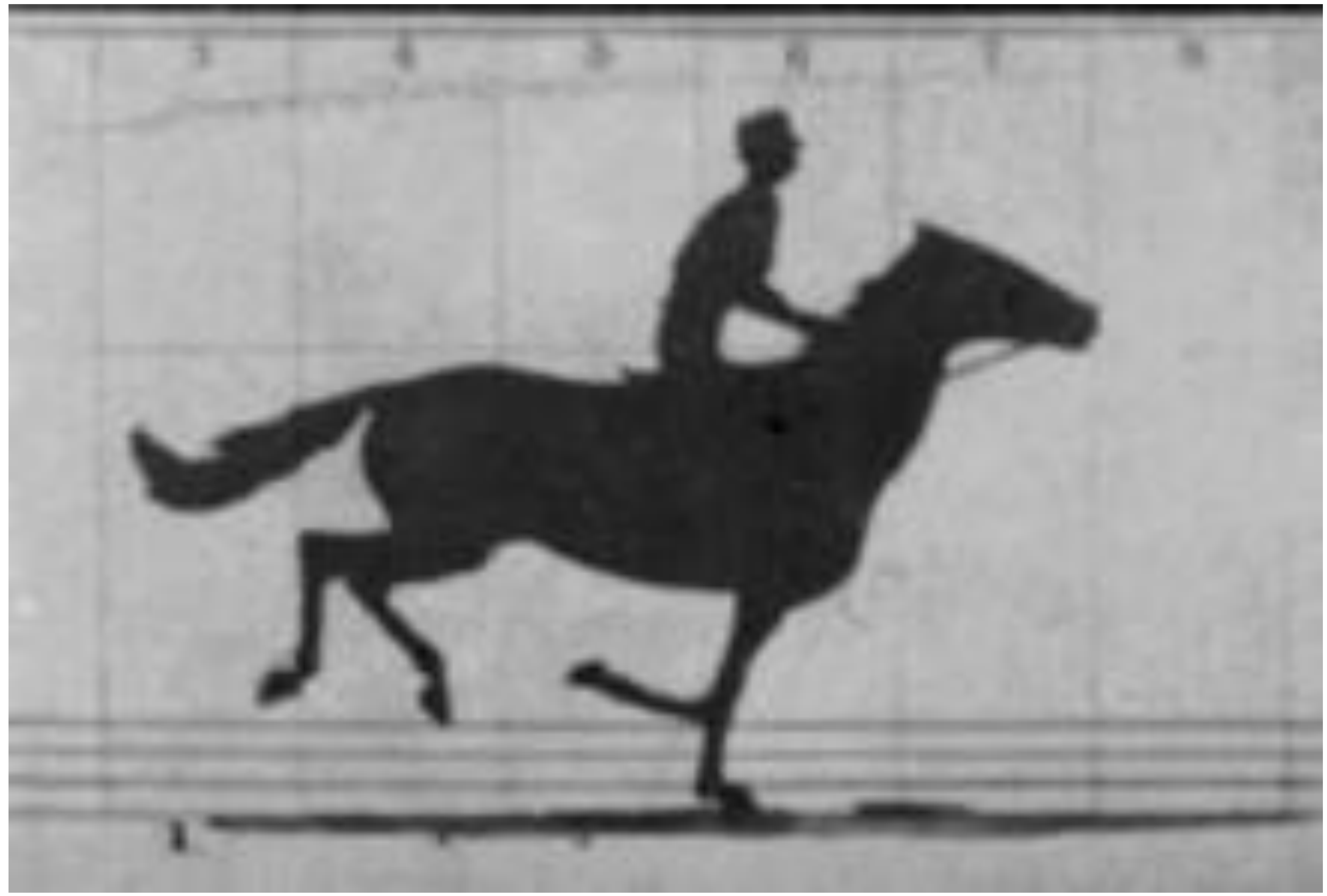
History of Animation

(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 Hand-Drawn Feature-Length Animation

Disney, “Snow White and the Seven Dwarfs” (1937)

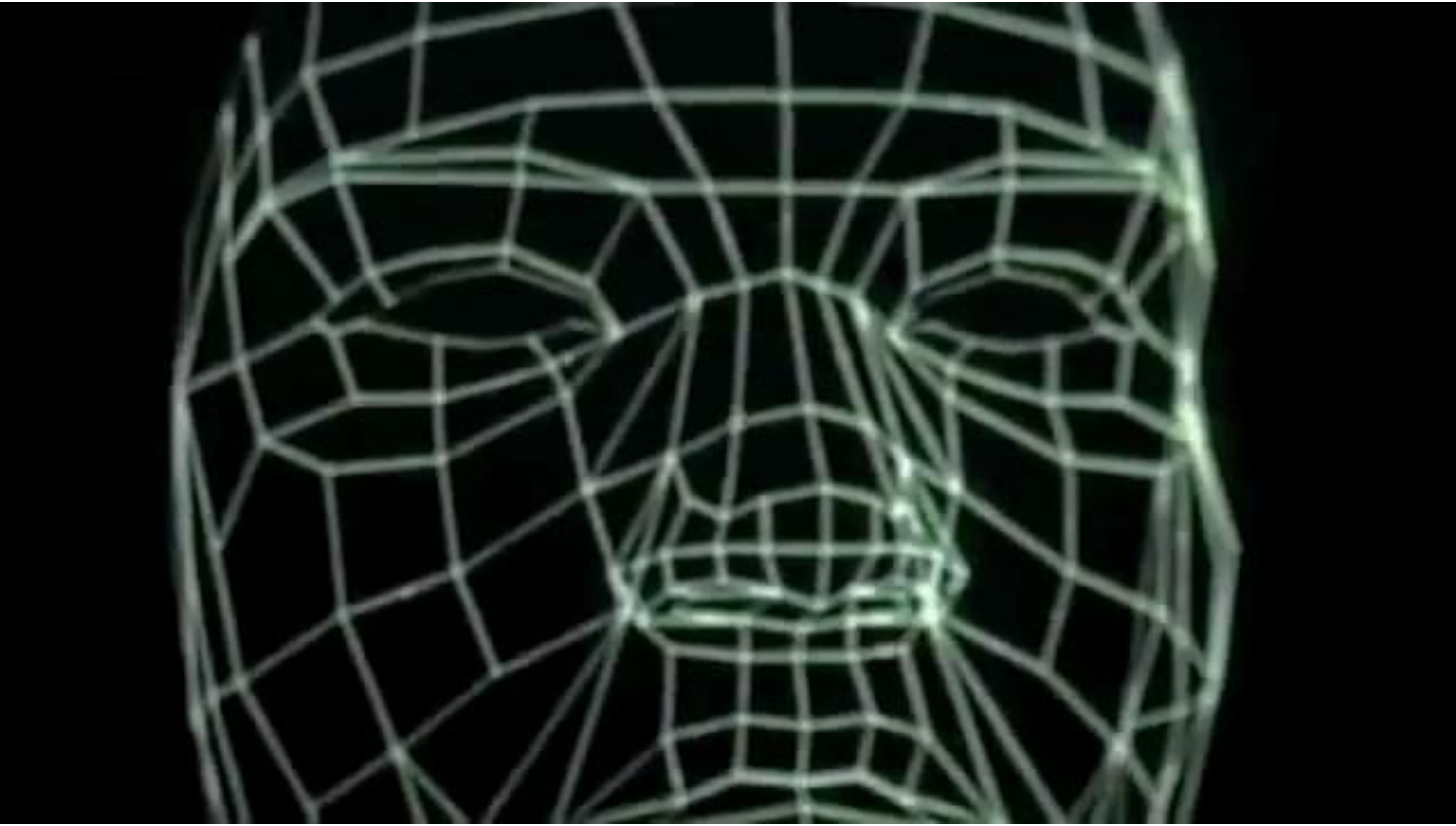
First Digital-Computer-Generated Animation

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

Early Computer Animation

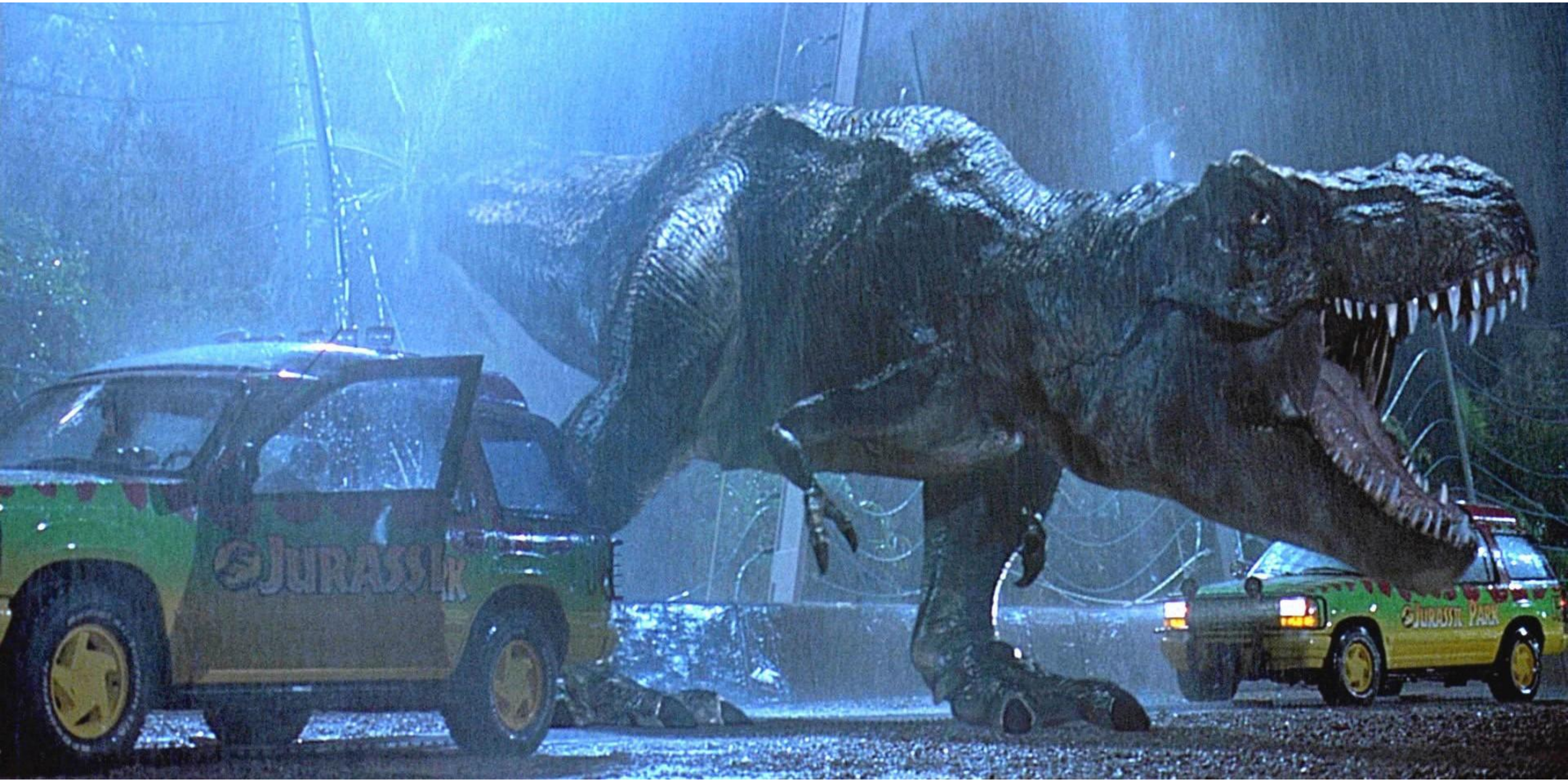
Nikolay Konstantinov, “Kitty” (1968)

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/Pixar Soul (2020)

Animation Principles

(slides courtesy Mark Pauly)

Animation Principles

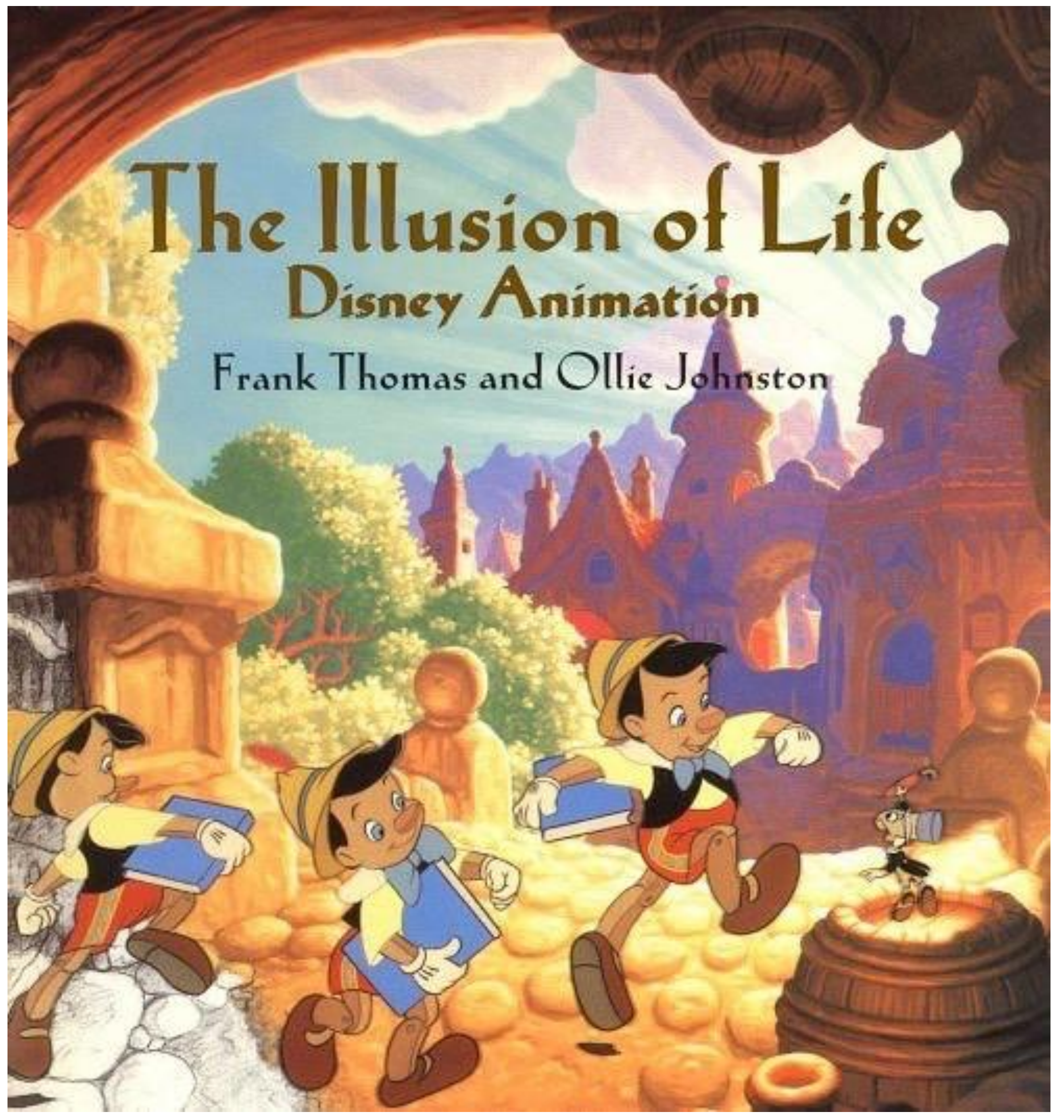
From

- “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

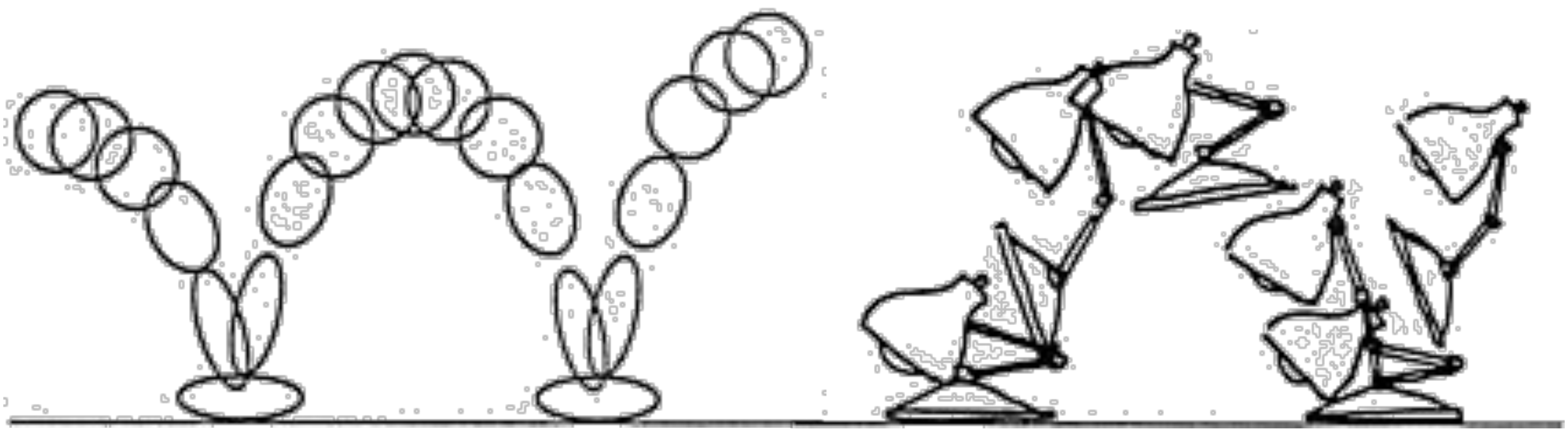


http://www.siggraph.org/education/materials/HyperGraph/animation/character_animation/principles/prin_trad_anim.htm

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

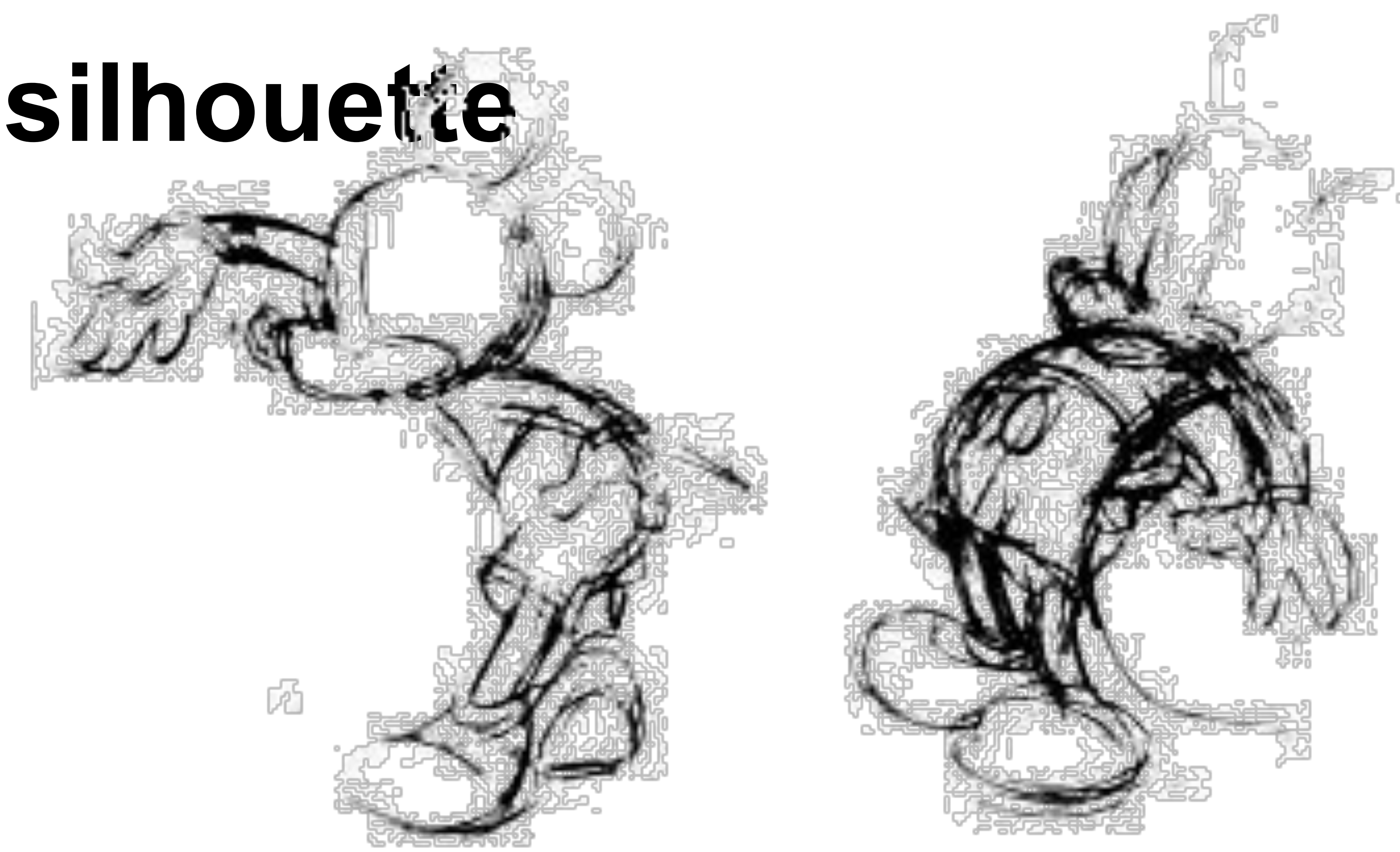
Staging

Picture is 2D

Make situation clear
Audience looking in right

place Action clear in

silhouette



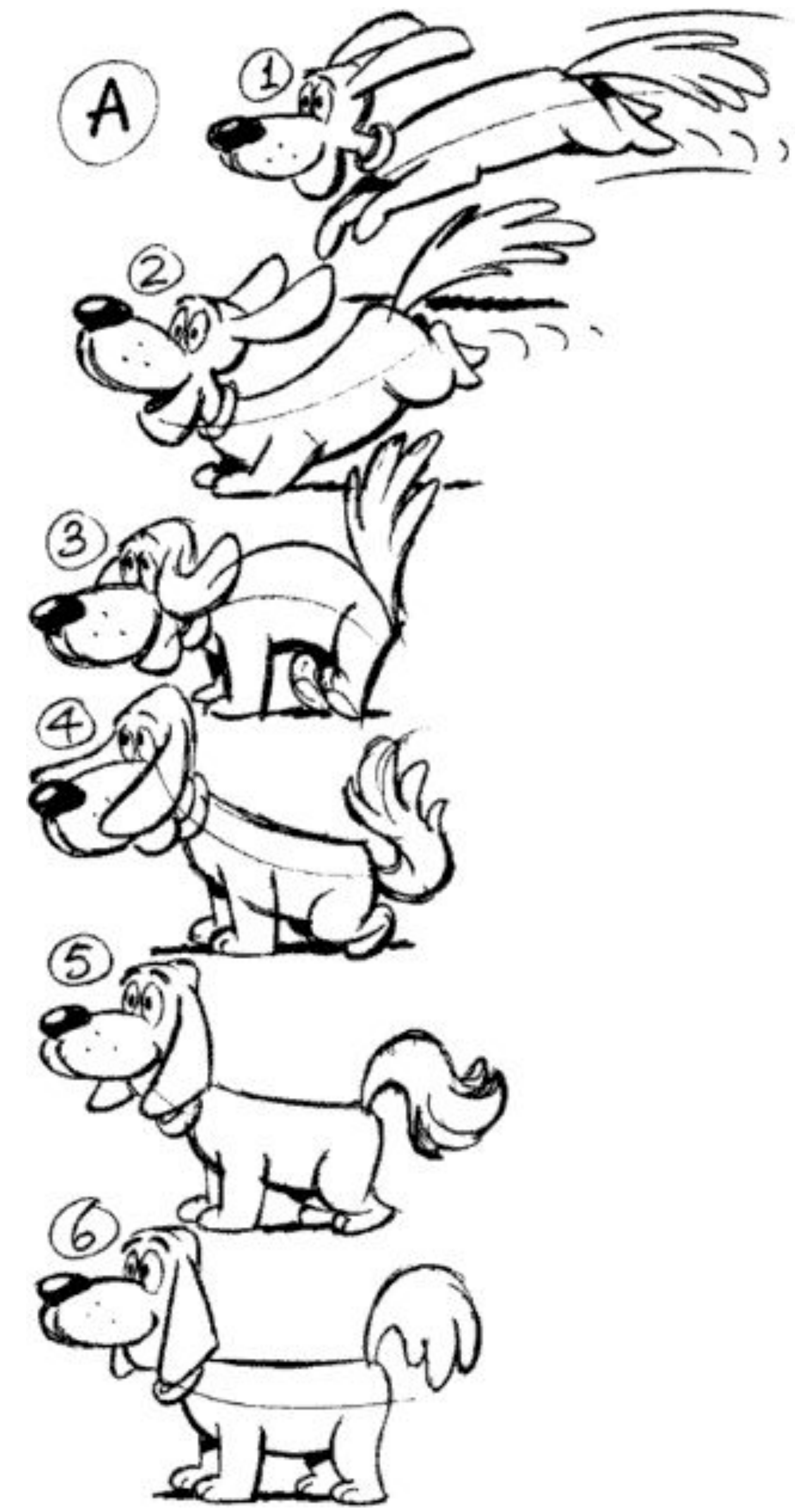
Disney Animation: The Illusion of Life

Follow Through

Overlapping motion
Motion doesn't stop suddenly

Pieces continue at different rates

One motion starts while previous is finishing, keeps animation smooth

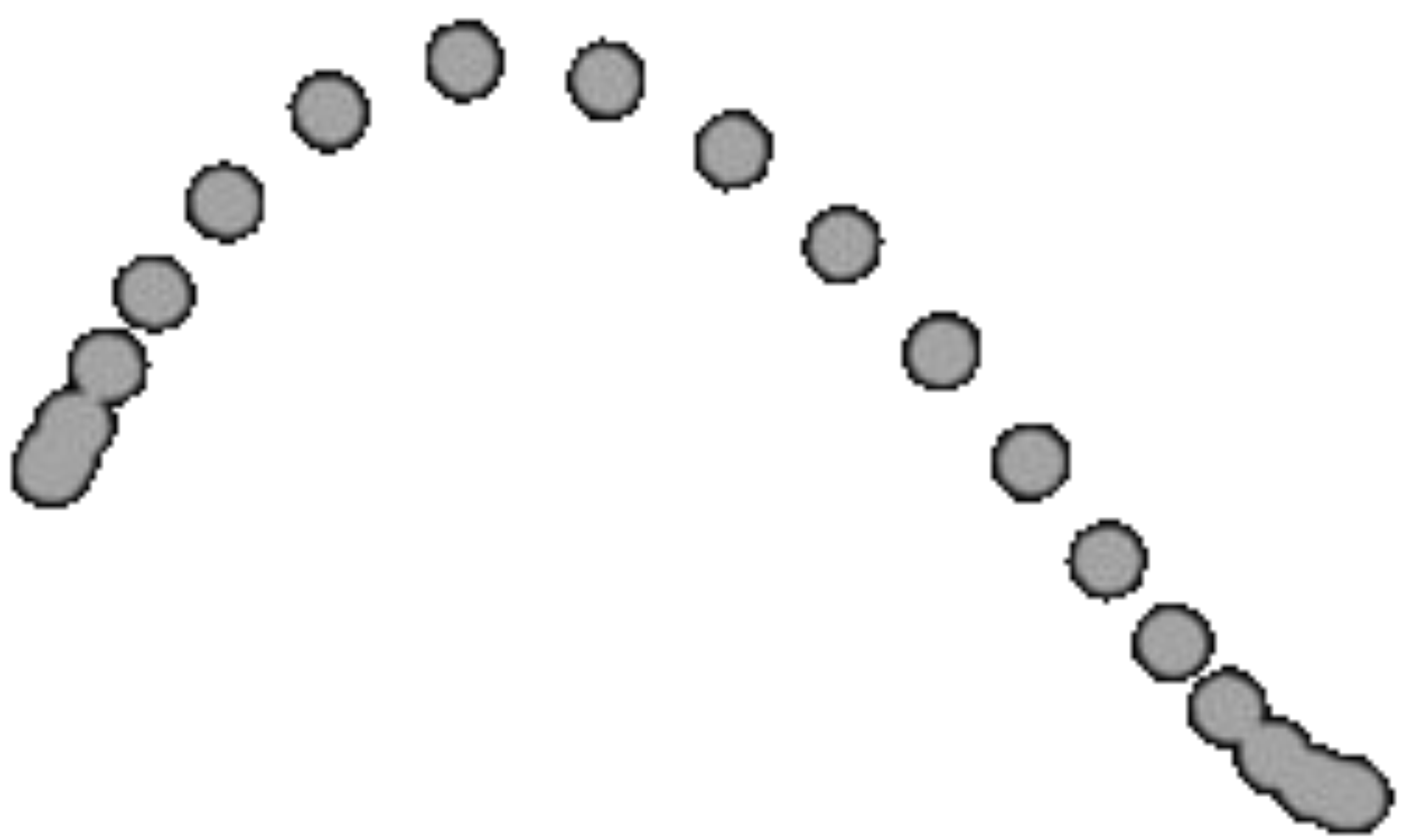


Timing for Animation, Whitaker & Halas

Ease-In and Ease-Out

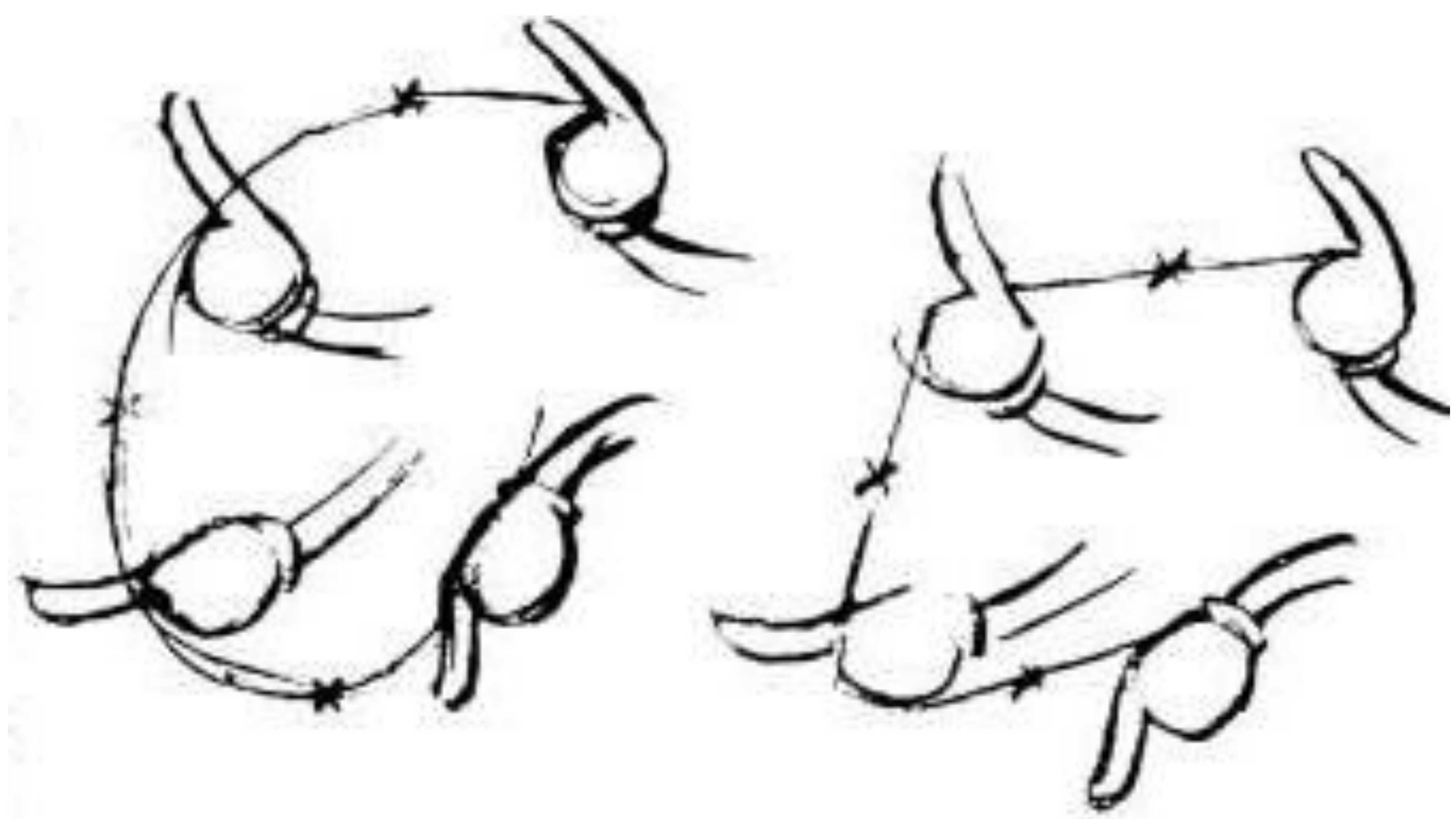
Movement doesn't start & stop abruptly.

Also contributes to weight and emotion



Arcs

Move in curves, not in straight lines This is how living creatures move

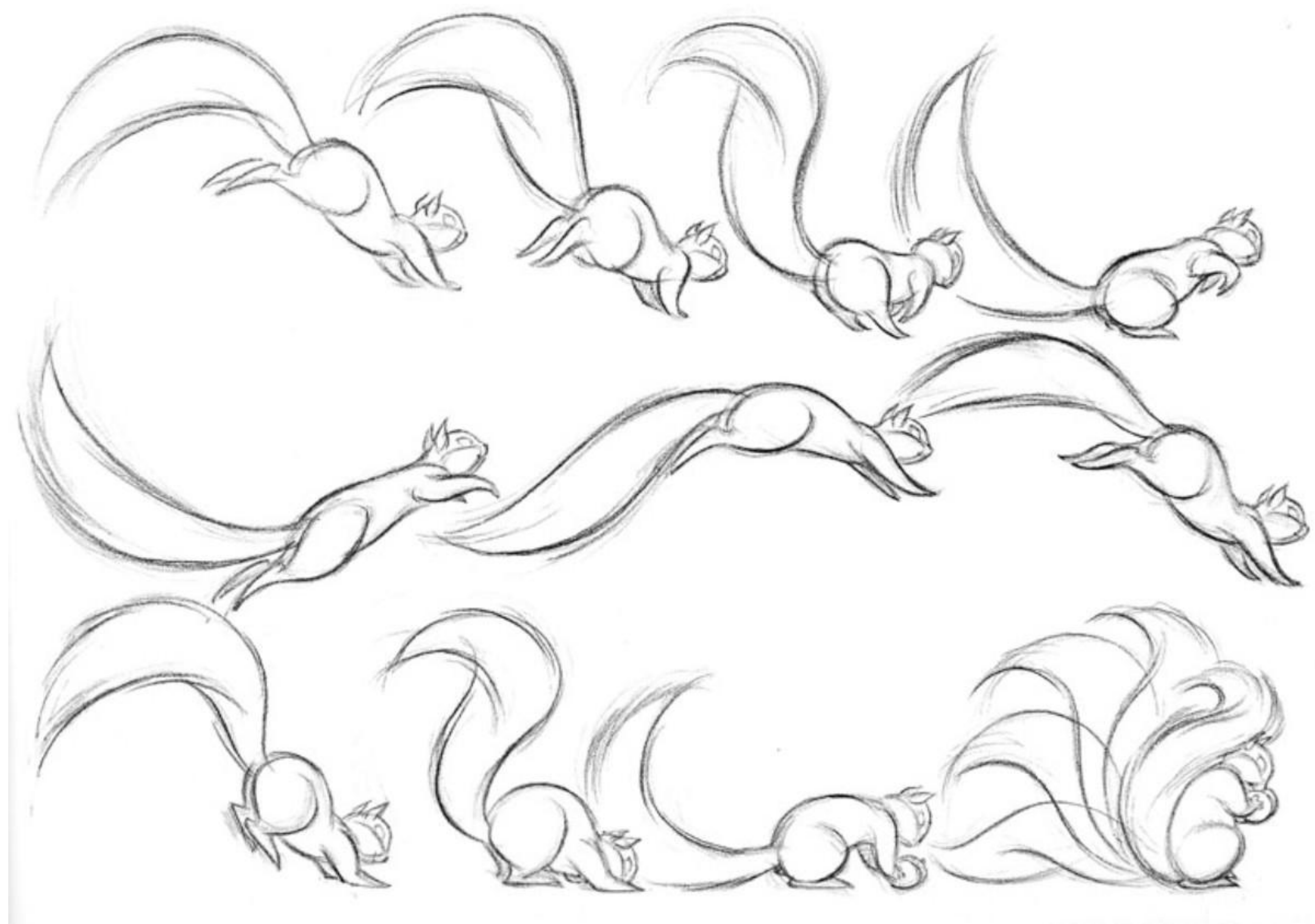


Disney Animation: The Illusion of Life

Secondary Action

Motion that results from some other action Needed for interest and realism

Shouldn't distract from primary motion

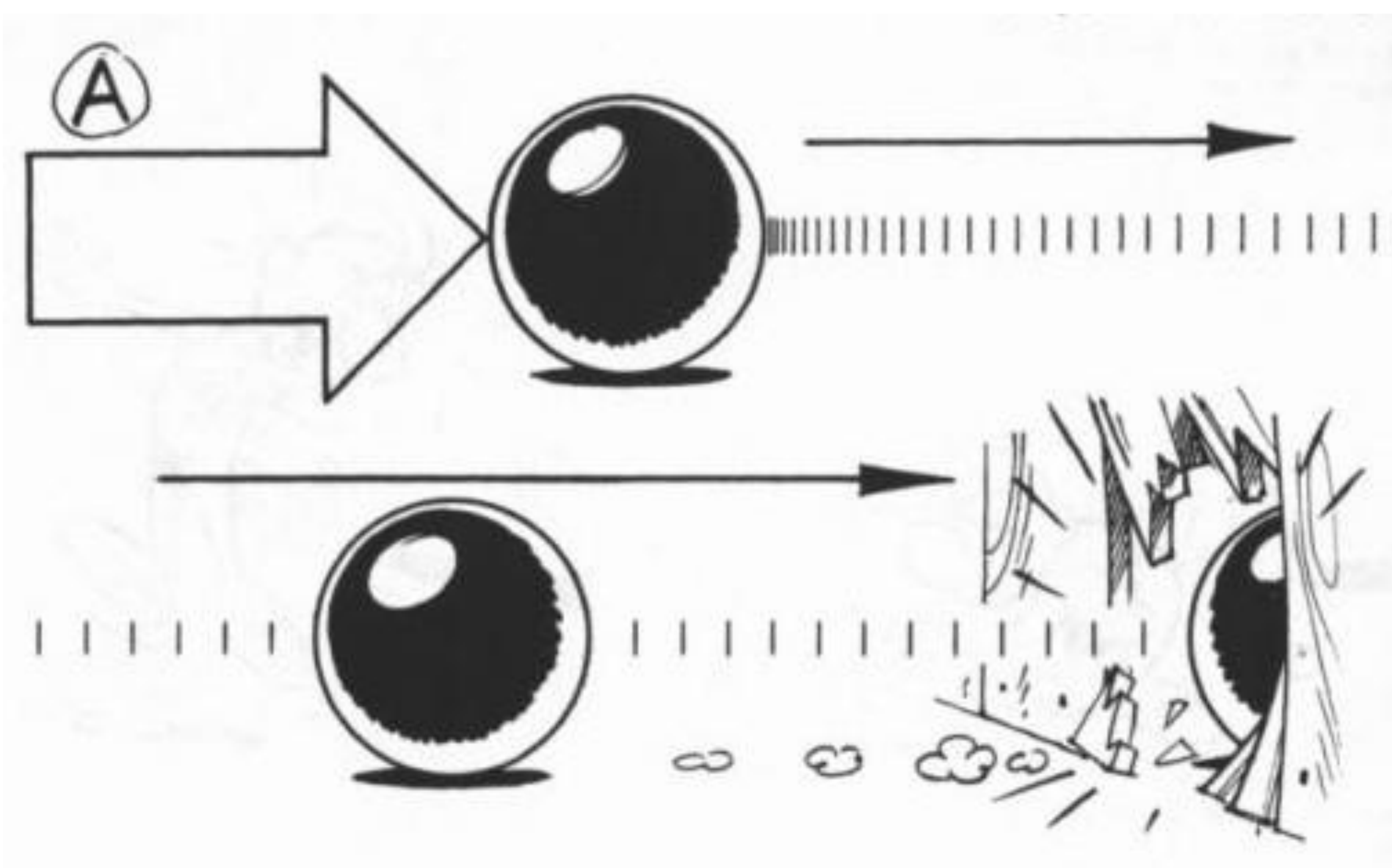


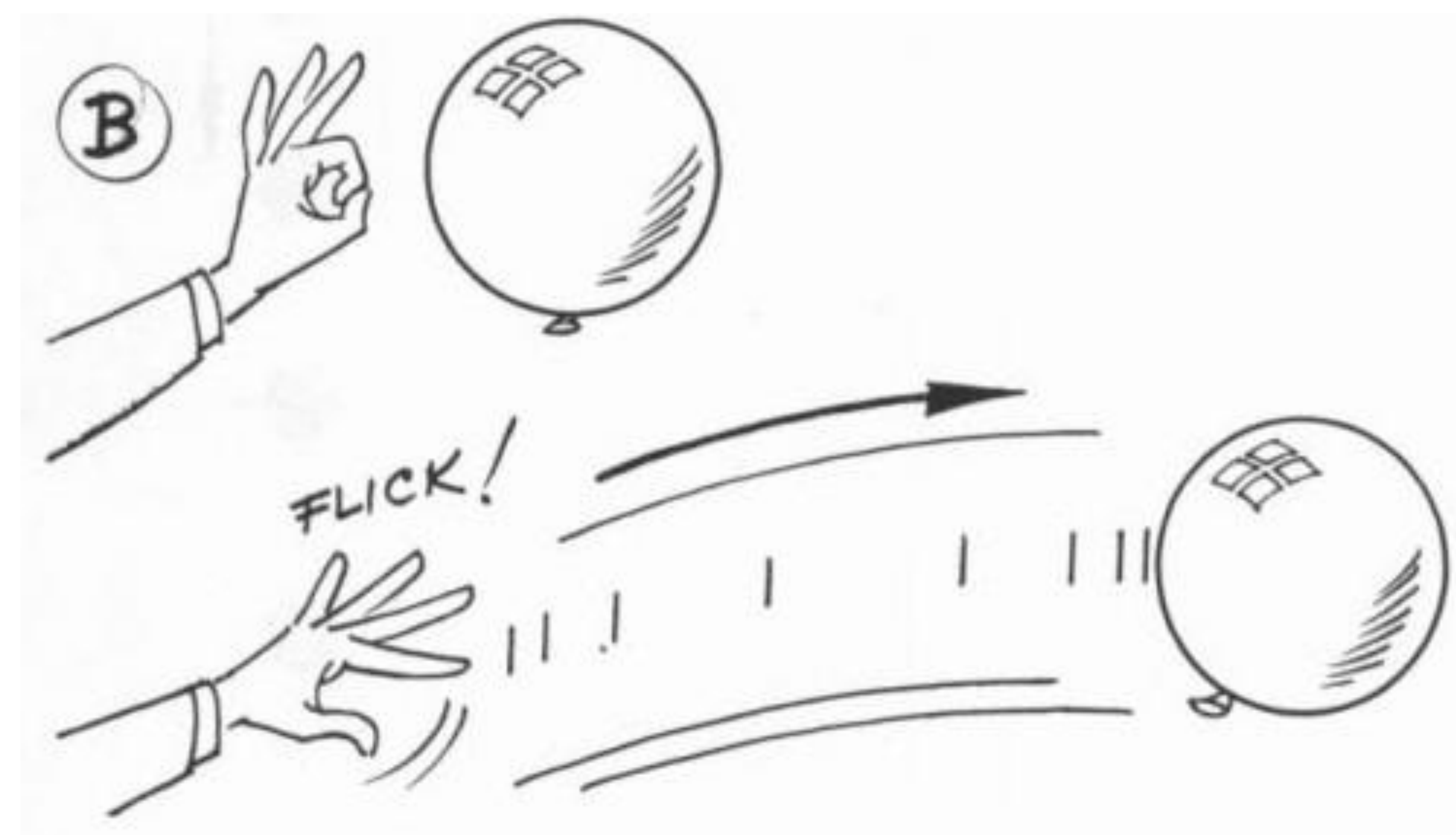
Cartoon Animation, Preston Blair

Timin
g

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

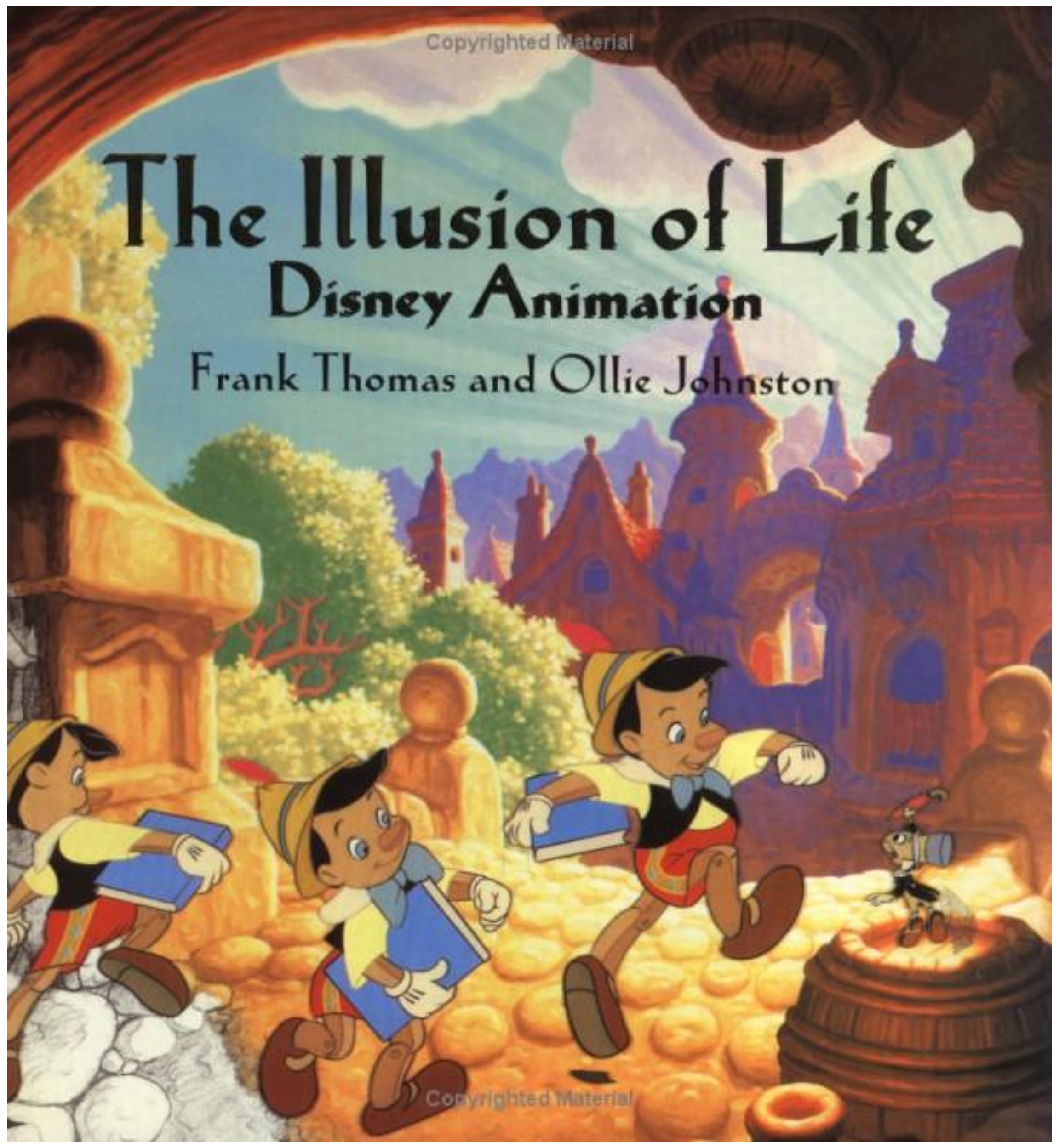
Disney Animation: The Illusion of Life

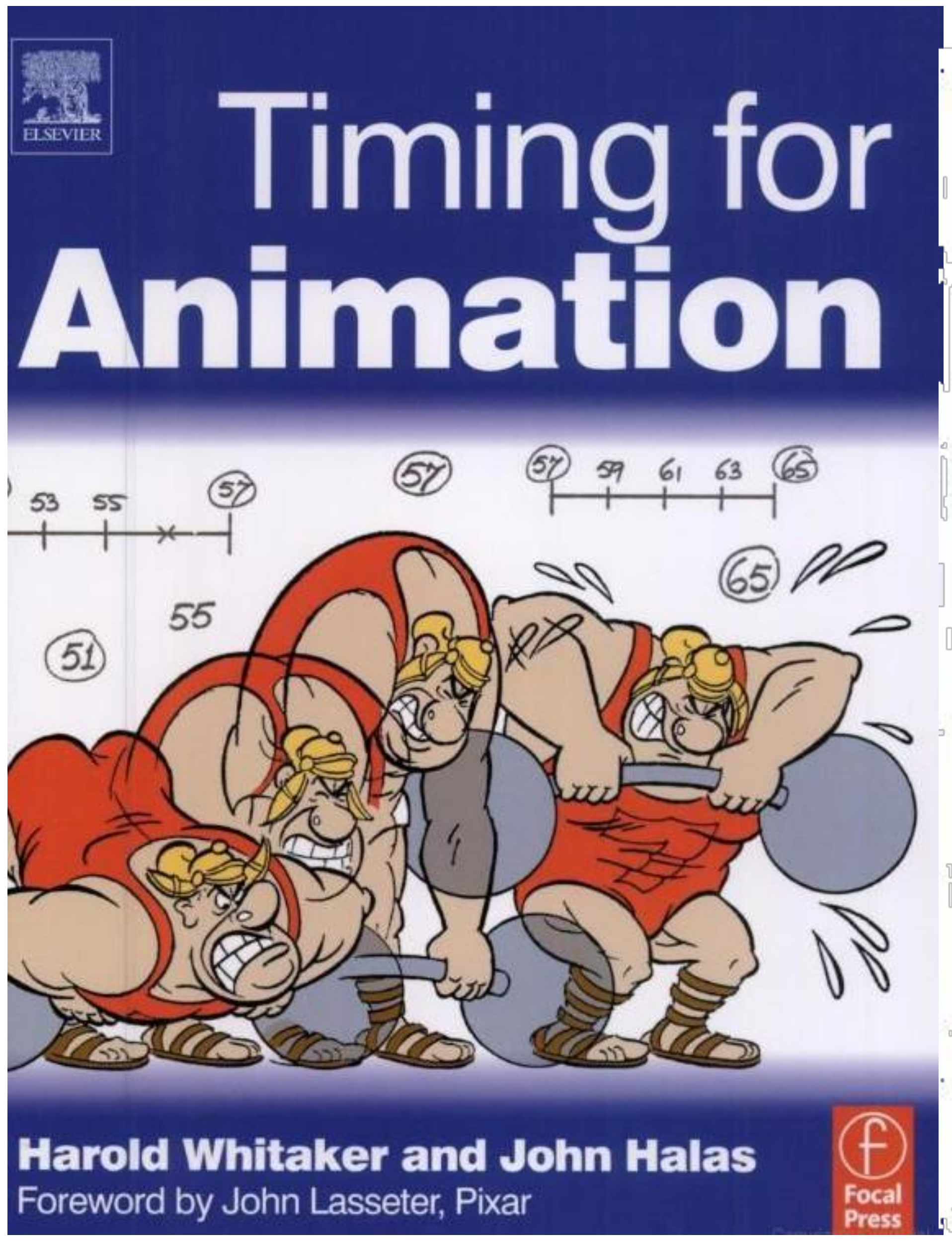
Personality

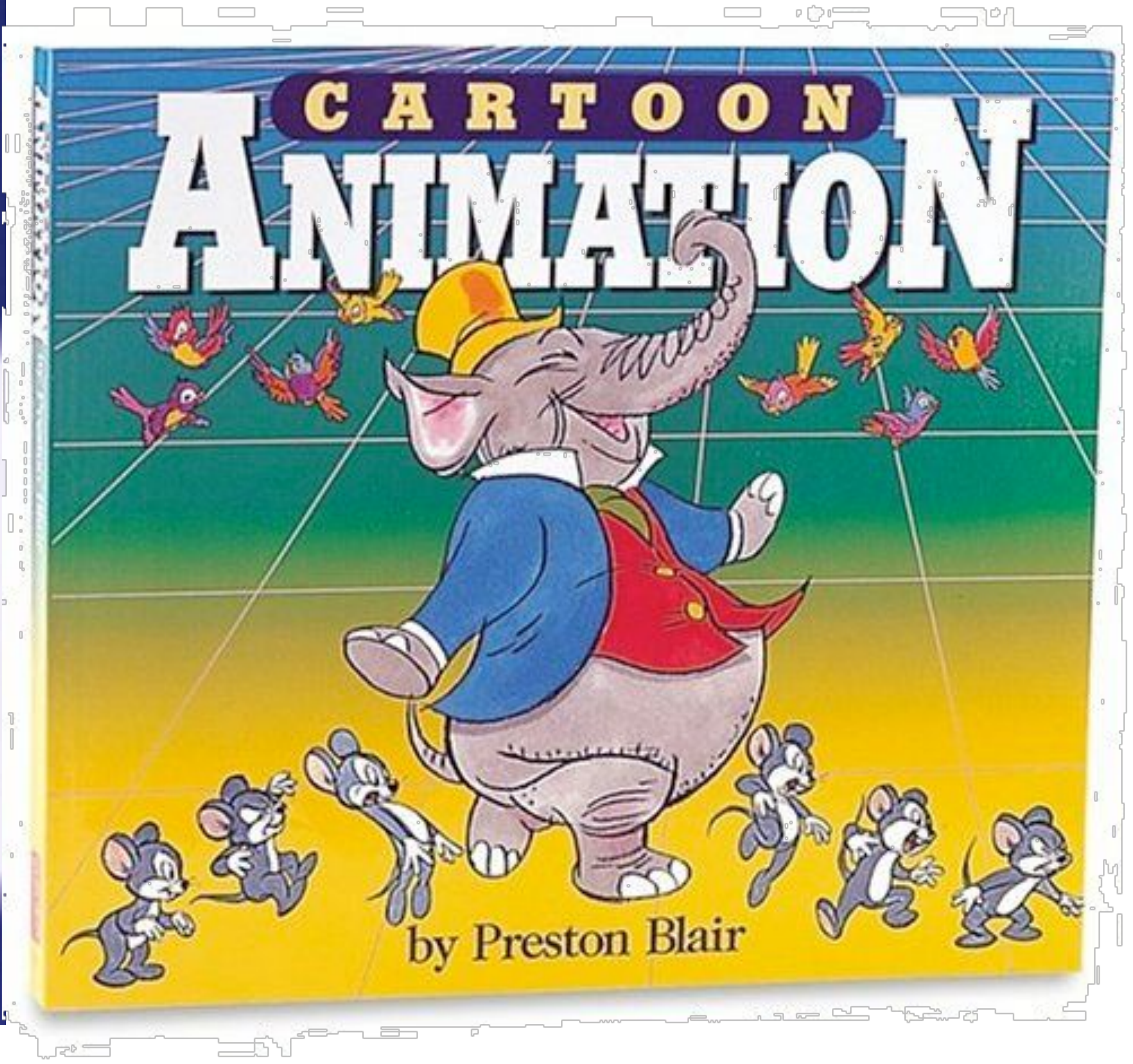
Action of character is result of its thoughts
Know purpose & mood before animating each action

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

Keyframe
s

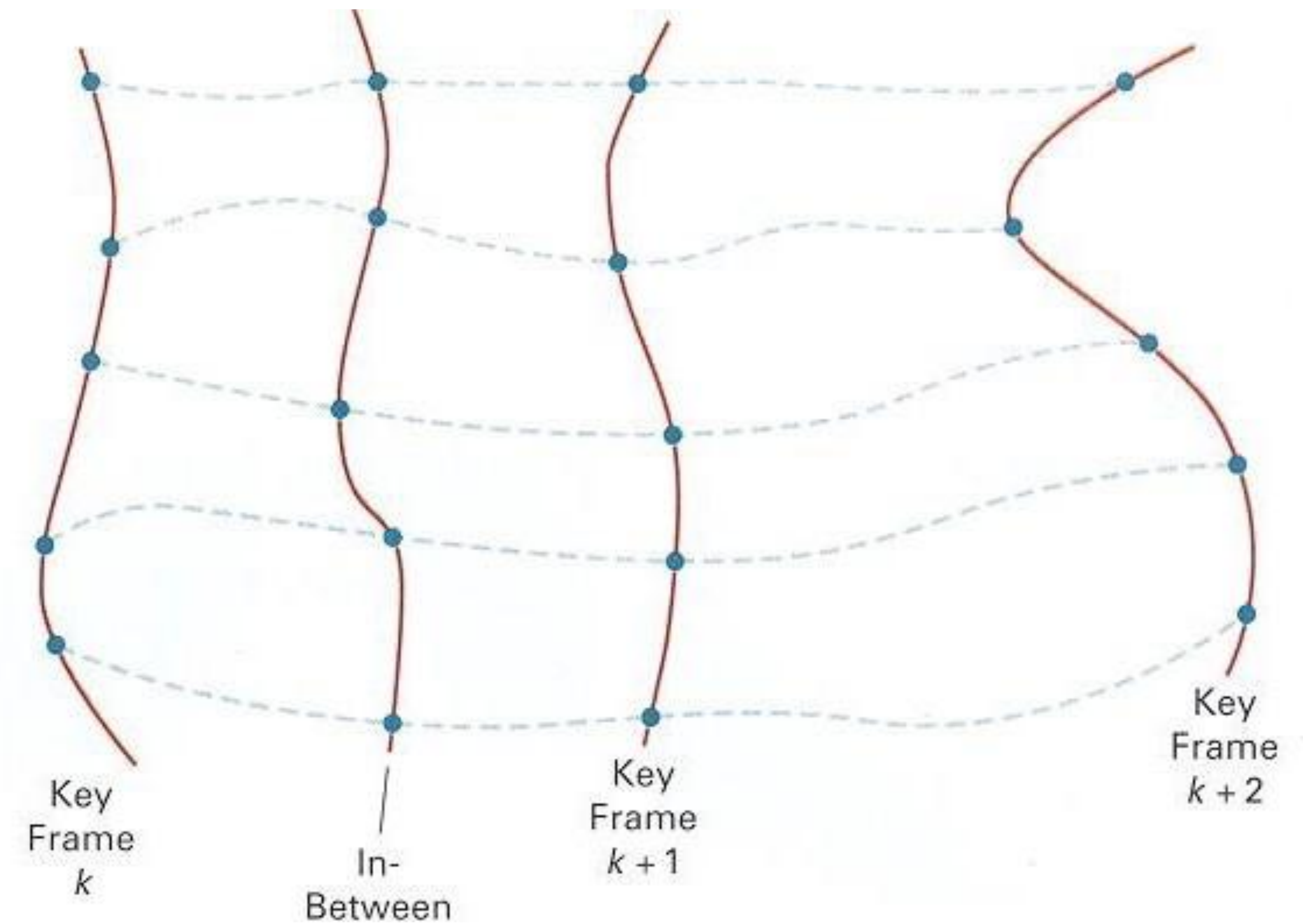
“Tweens
”

Animator (e.g. lead animator) creates keyframes

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

Keyframe Interpolation

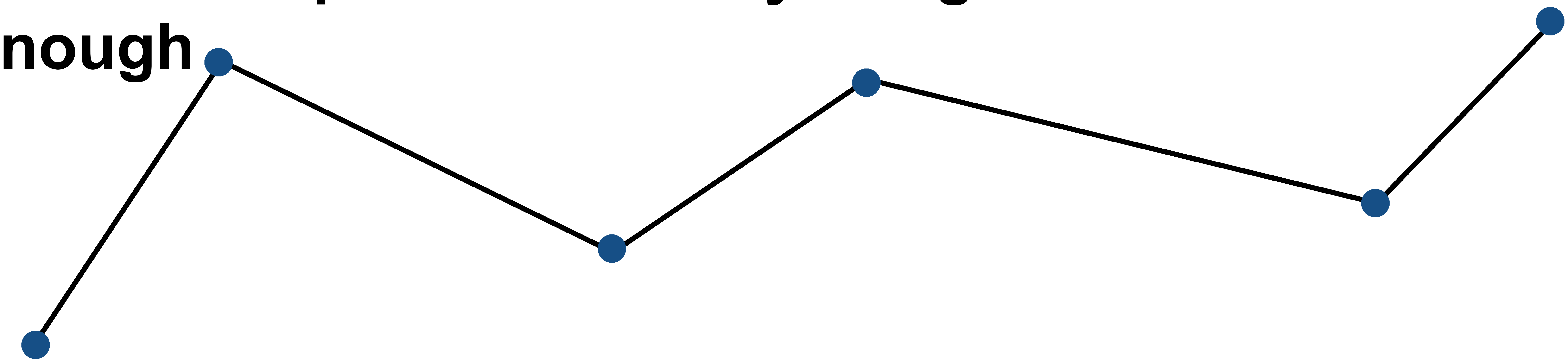
Think of each frame as a vector of parameter values



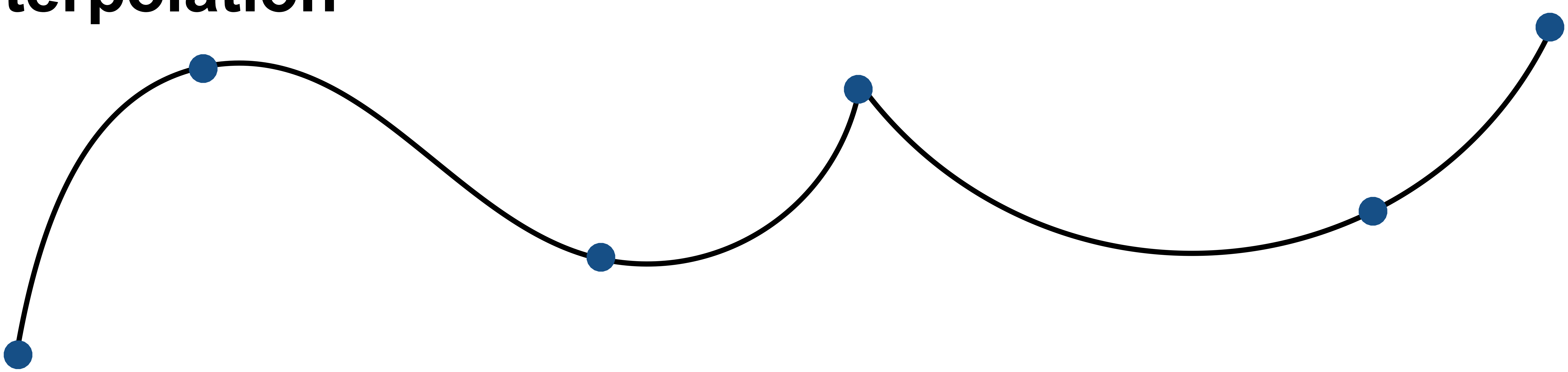
Hearn, Baker and Carithers, Figure 16.11

Keyframe Interpolation of Each Parameter

Linear interpolation usually not good enough



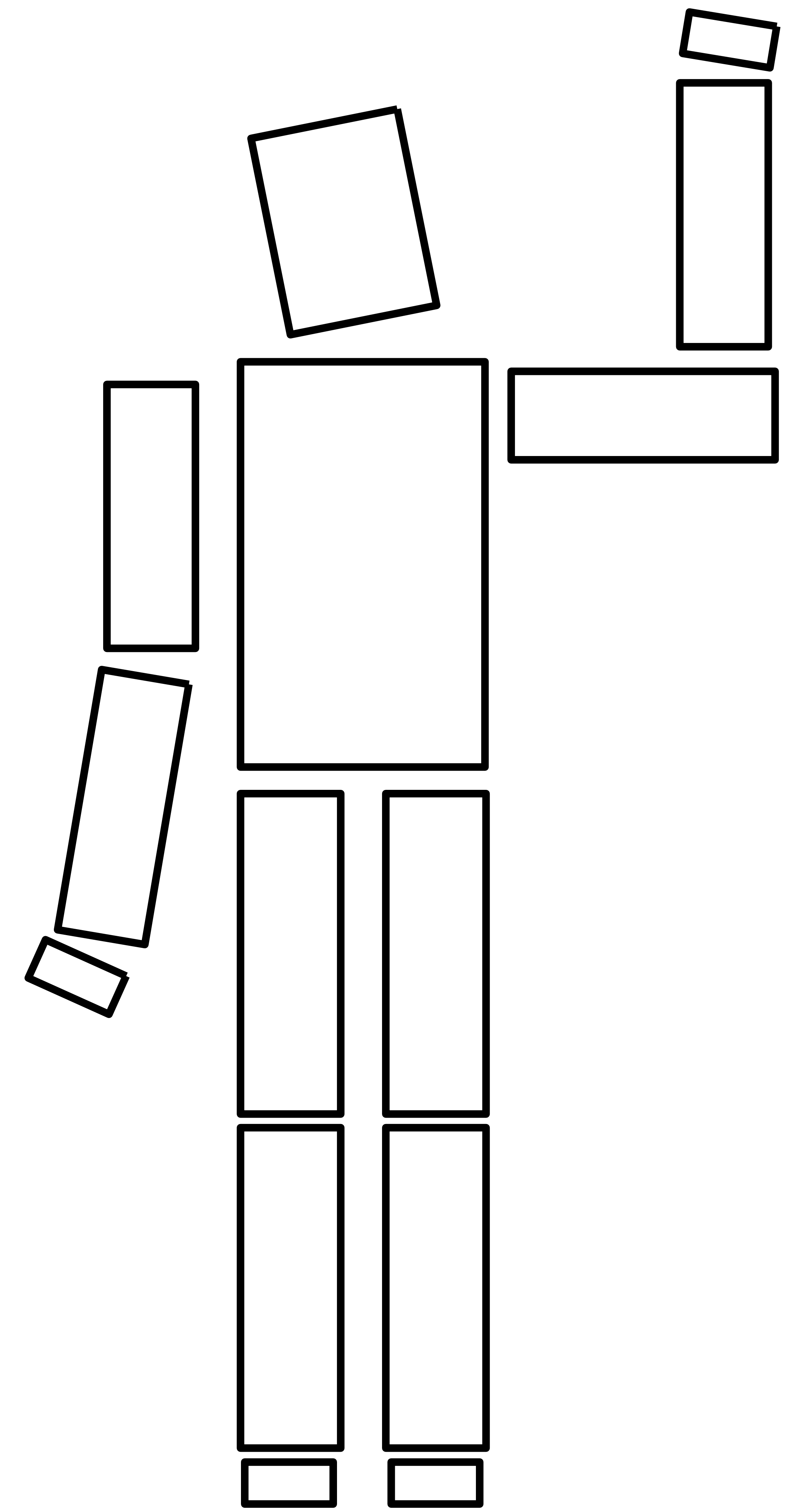
Recall splines for smooth / controllable interpolation



Forward Kinematics

Recall this skeleton from Transforms lecture

torso
    head
    right arm
        upper arm
            lower arm
                han
    d left
    arm
        upper arm
            lower arm
                han
    d right
    leg
        upper leg
            lower leg
                foot
    left leg
        upper leg



Ren Ng

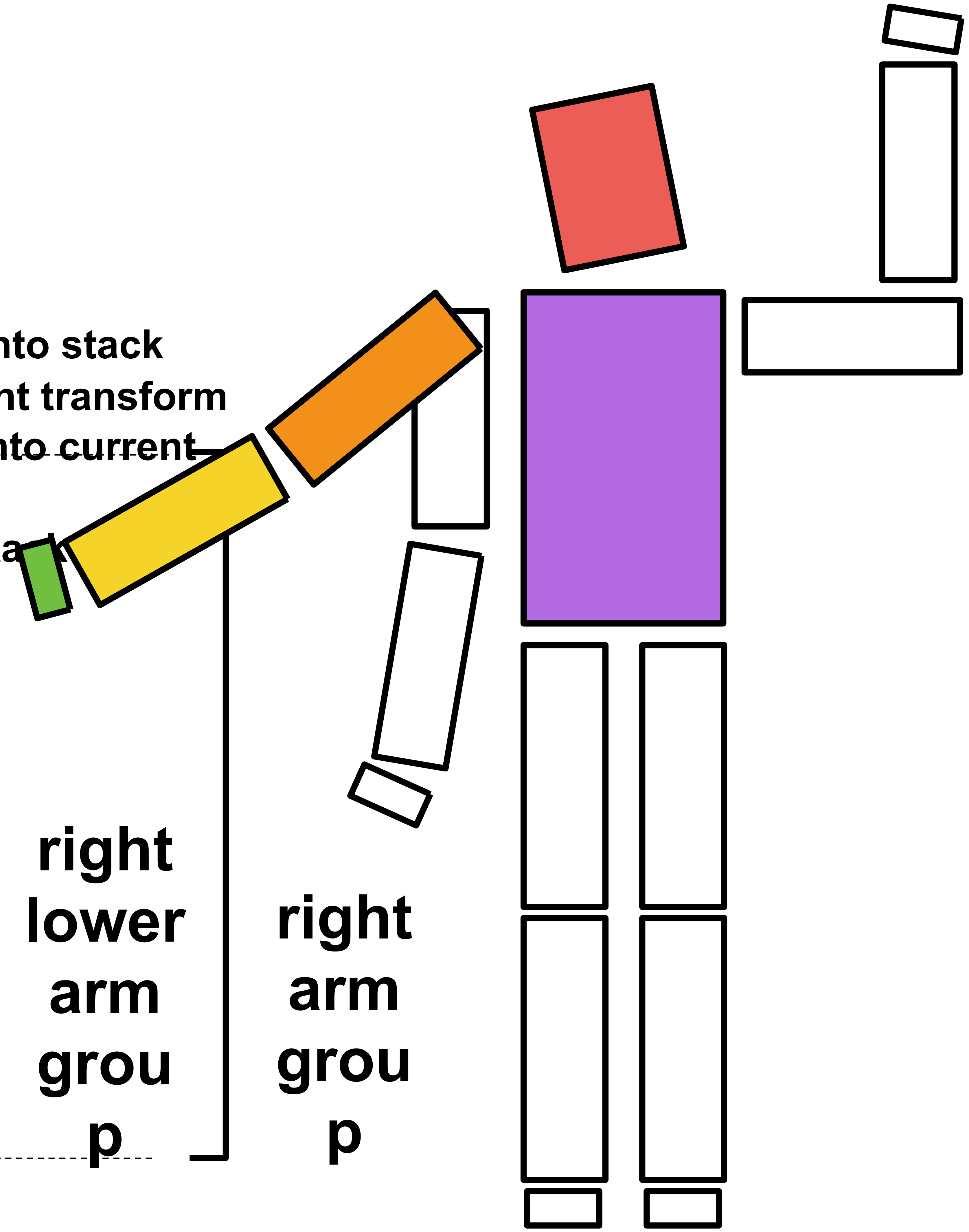
Skeleton - Hierarchical Representation

```
translate(0, 10);
drawTorso();
  pushmatrix();  // push a copy of transform onto stack
    translate(0, 5); // right-multiply onto current transform
    rotate(headRotation);   // right-multiply onto current transform
    drawHead();
  popmatrix();    // pop current transform off stack
  pushmatrix();
    translate(-2, 3);
    rotate(rightShoulderRotation);
    drawUpperArm();
    pushmatrix();
      translate(0, -3);
      rotate(elbowRotation);
      drawLowerArm()
      pushmatrix()
        translate(0, -3);
        rotate(wristRotation)
        drawHand()
      popmatrix();
    popmatrix();
  popmatrix();
....
```

right hand

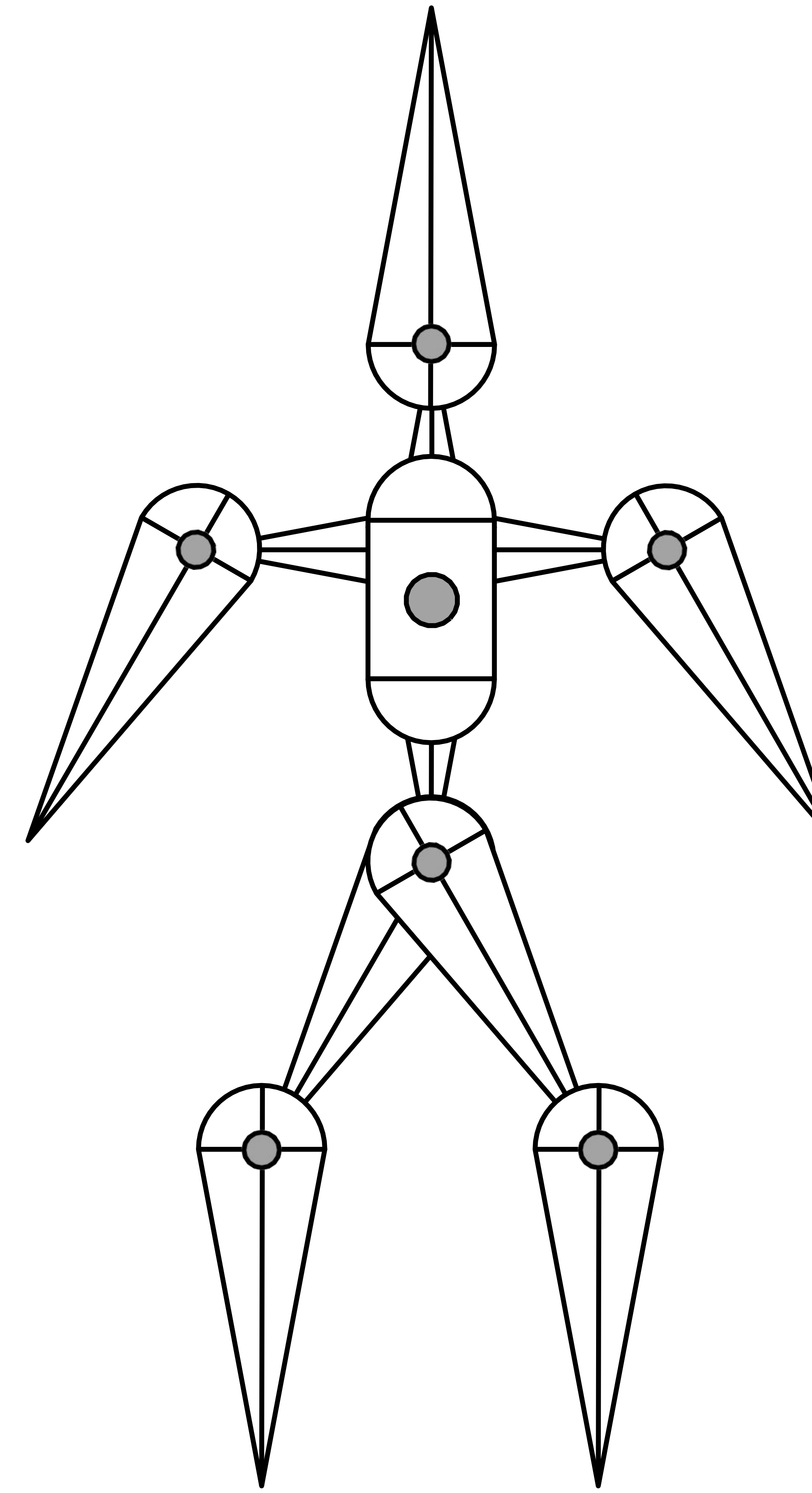
right lower arm group

right arm group



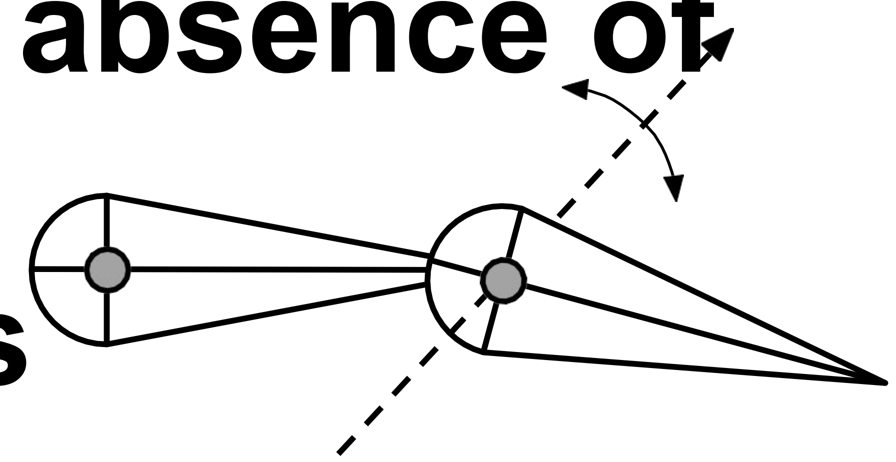
Ren Ng

Forward Kinematics

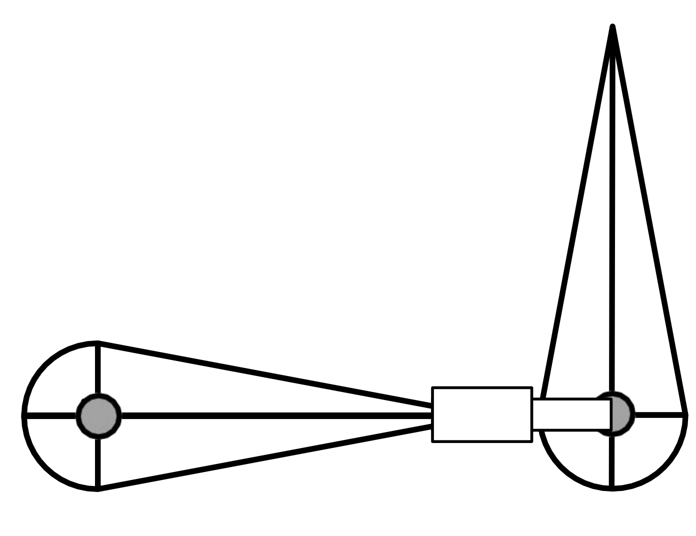


Articulated skeleton

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



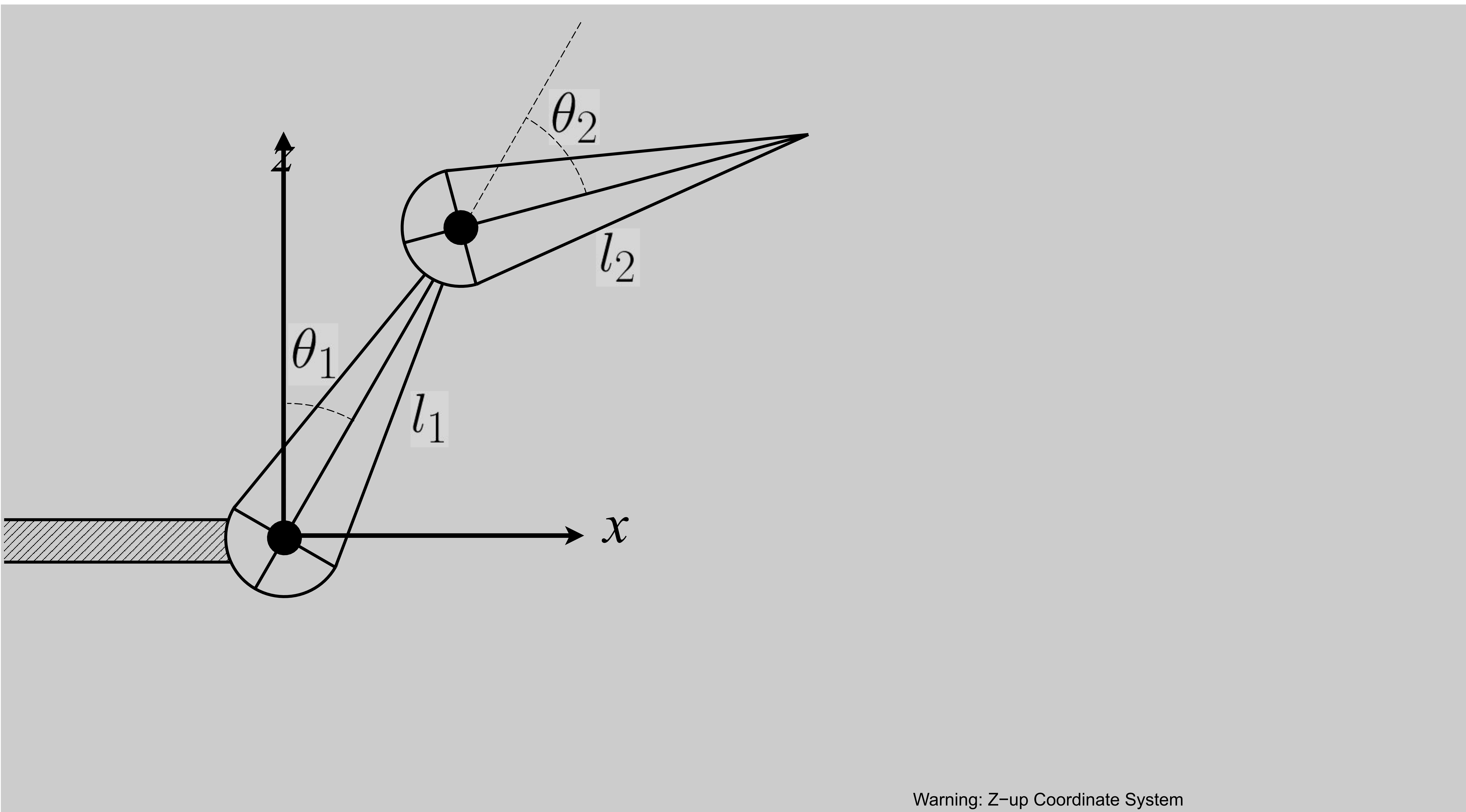
- Pin (1D rotation)
- Ball (2D rotation)



- Prismatic joint (translation)

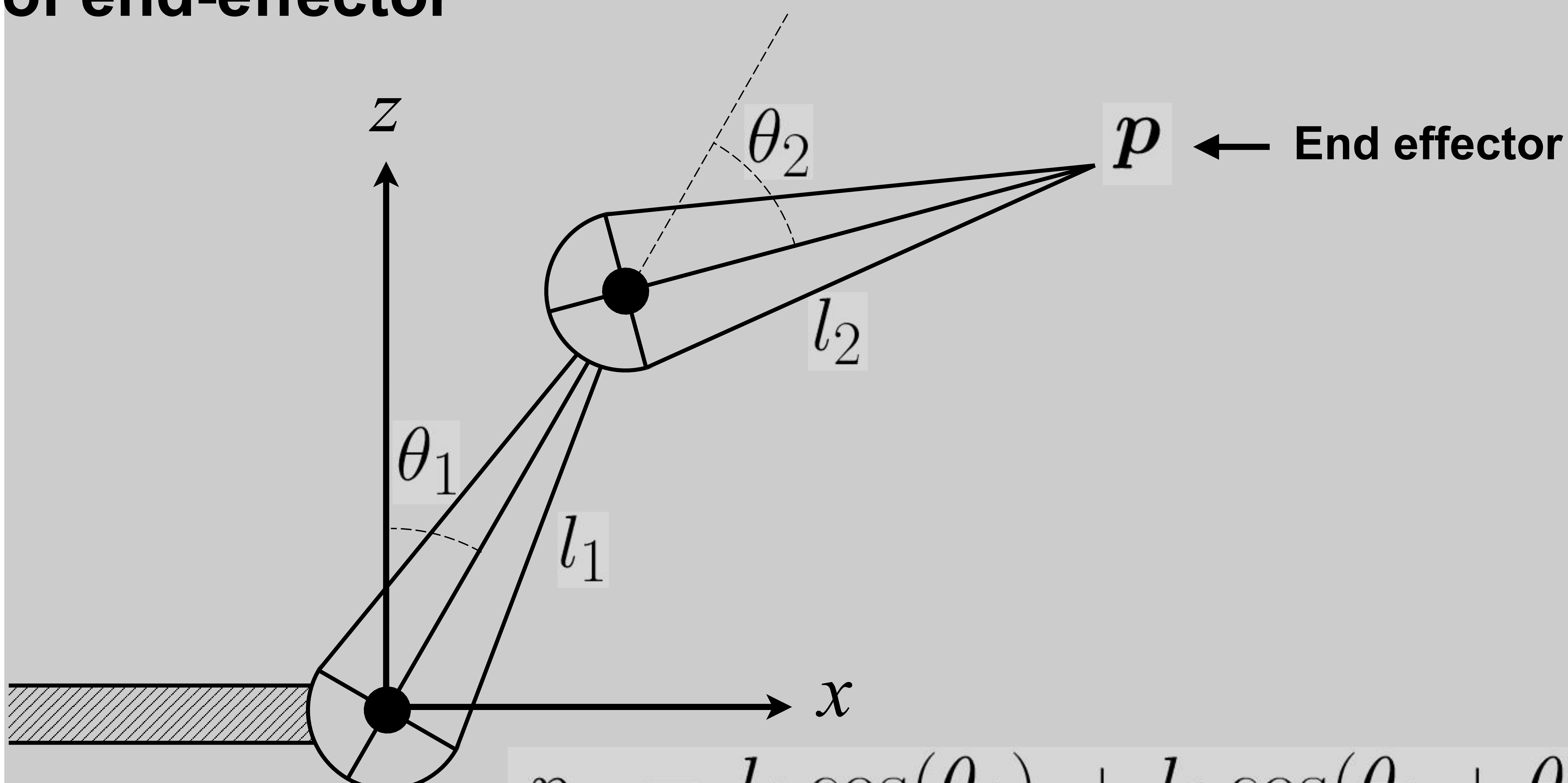
Forward Kinematics

Example: simple two segment arm in 2D



Forward Kinematics

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



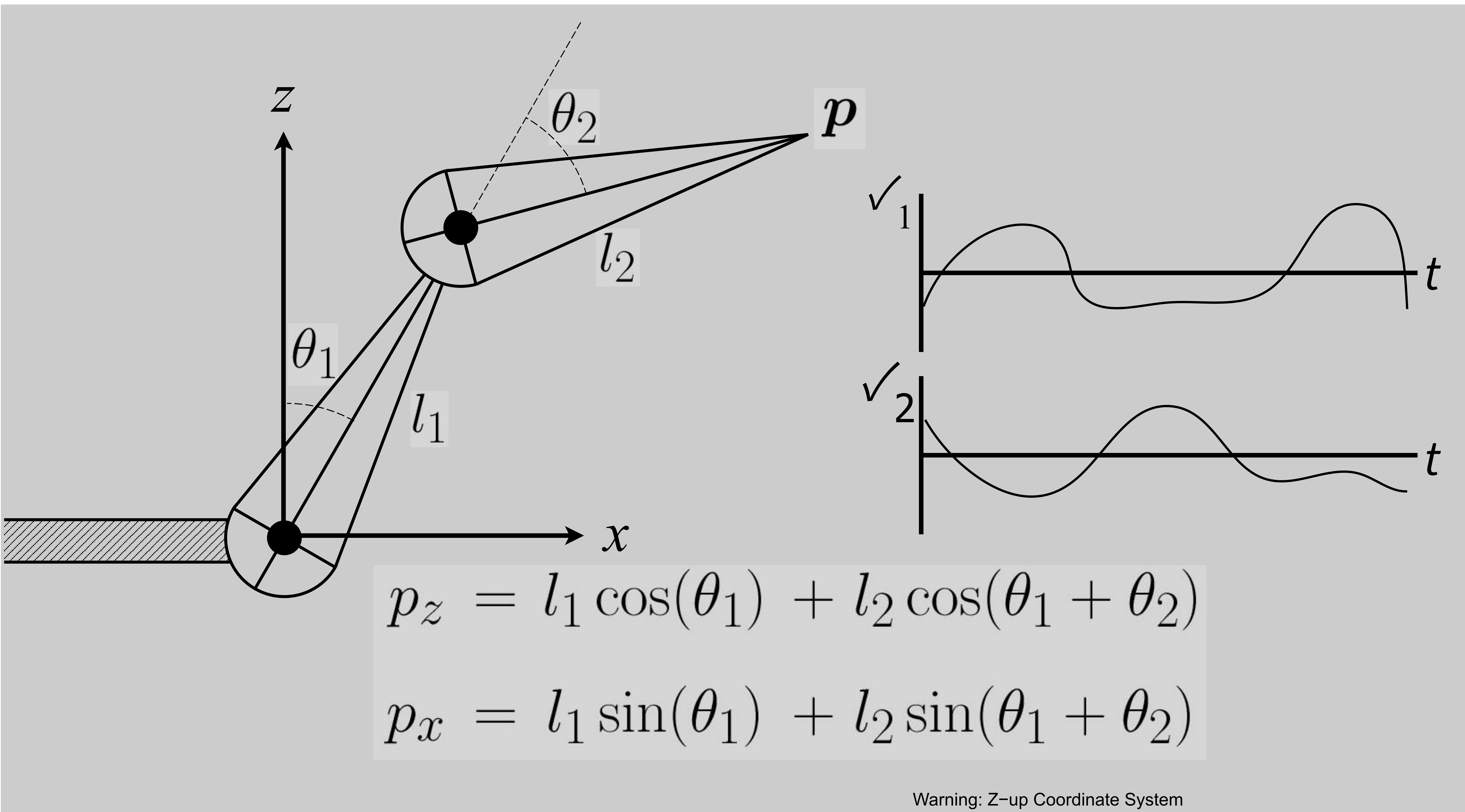
$$p_z = l_1 \cos(\theta_1) + l_2 \cos(\theta_1 + \theta_2)$$

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

Warning: Z−up Coordinate System

Forward Kinematics

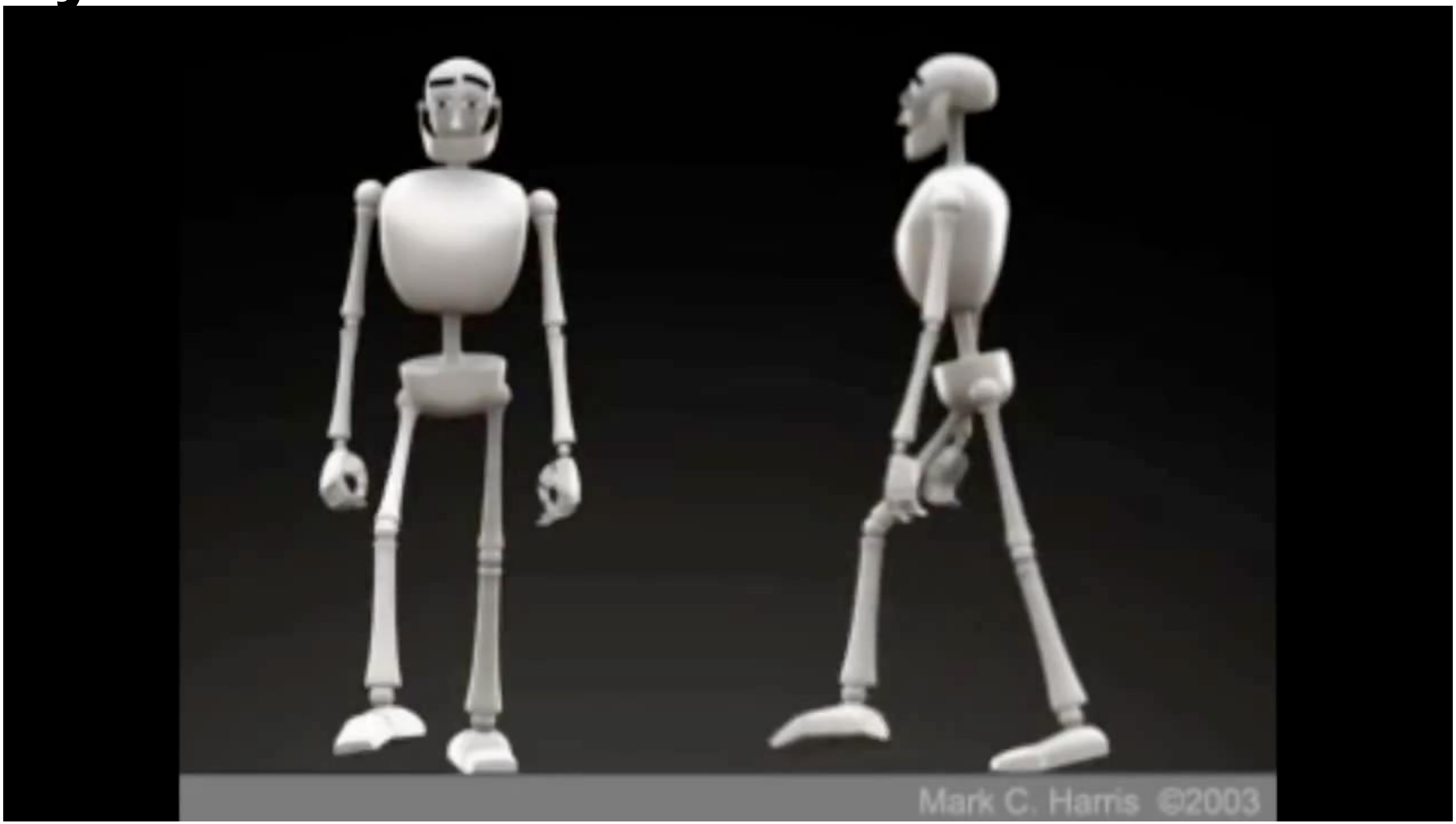
Animation is described as angle parameter values as a function of time



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

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

Example Walk Cycle



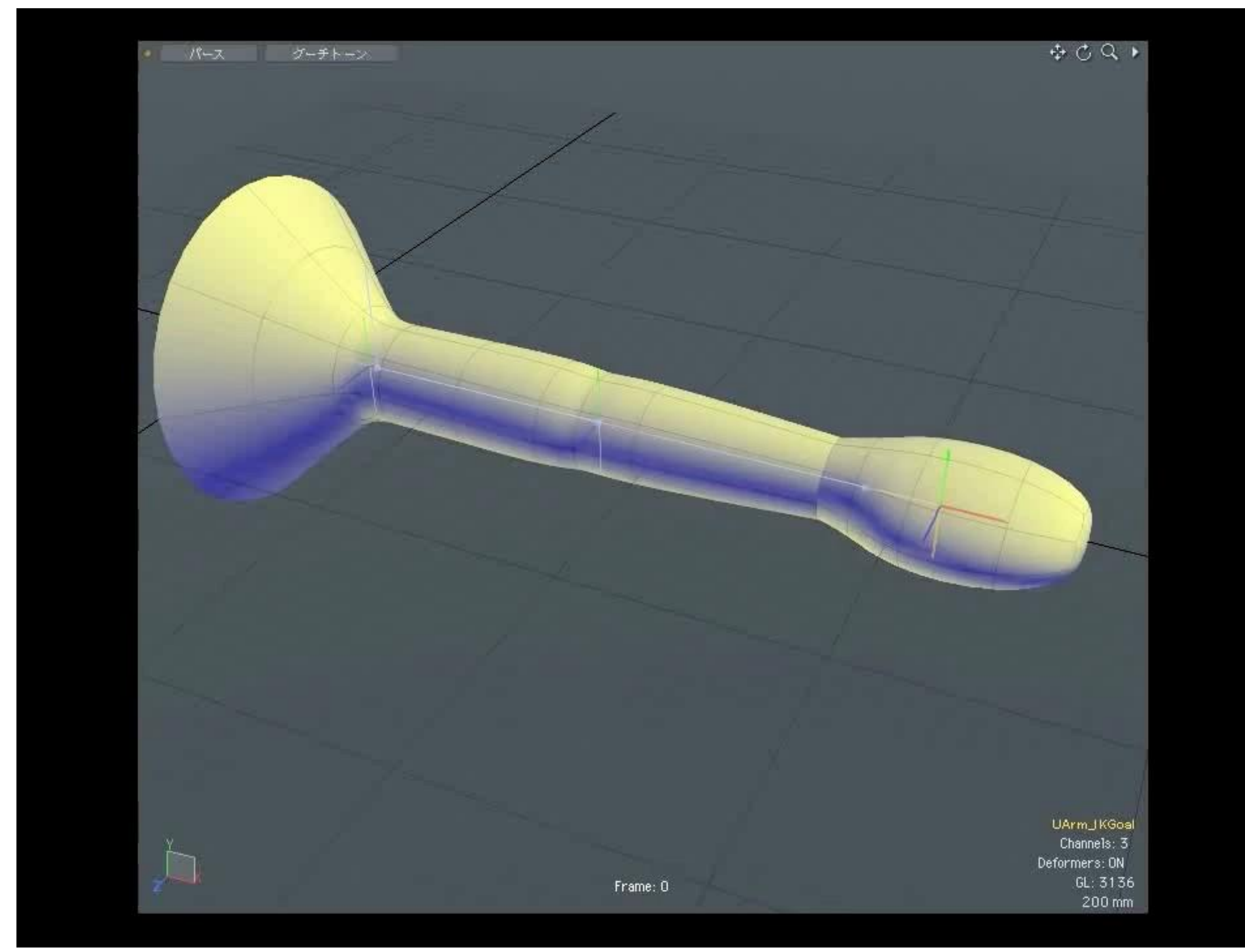
Inverse Kinematics

Inverse Kinematics

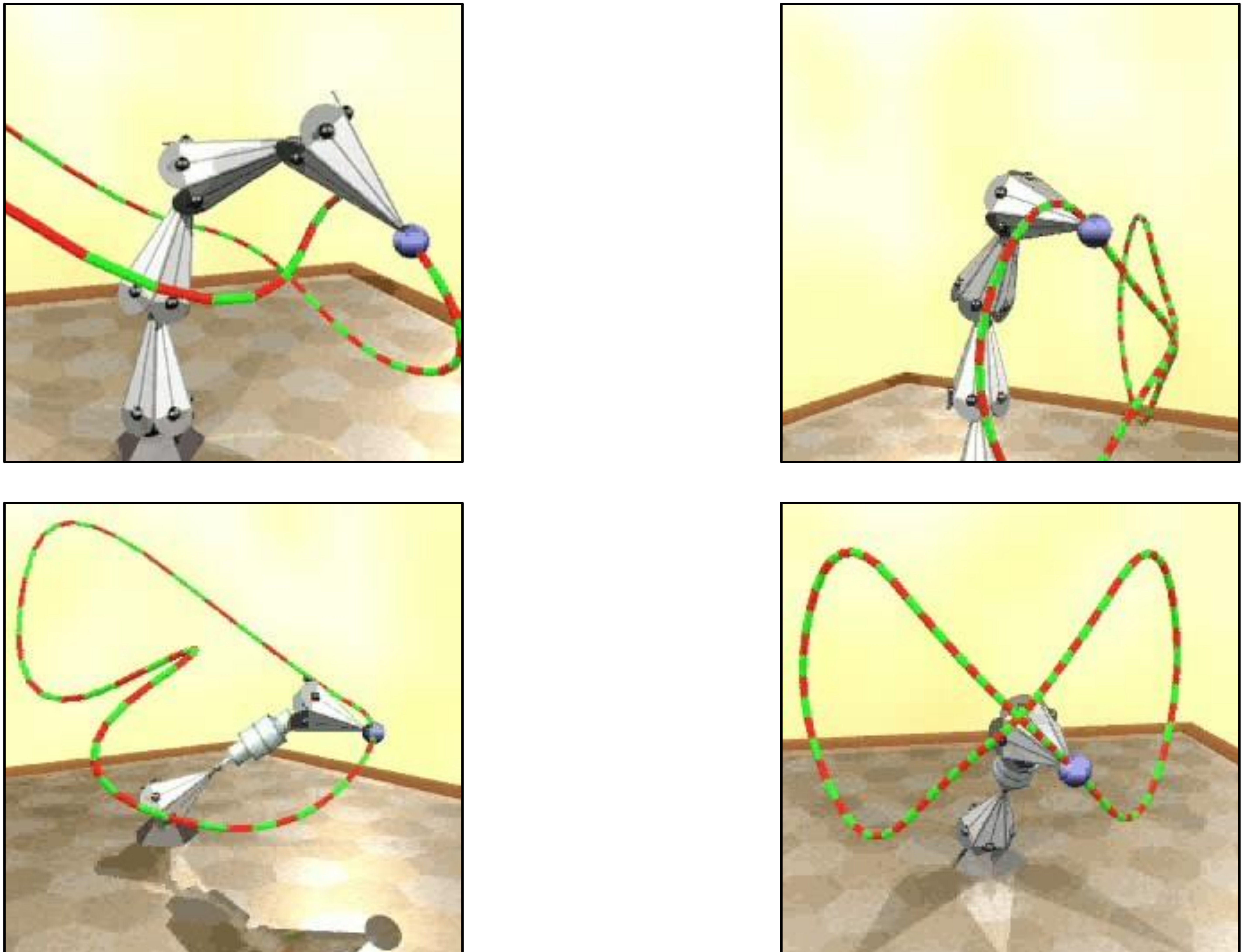
Given the end effector position, find the joint angles.

Goals

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



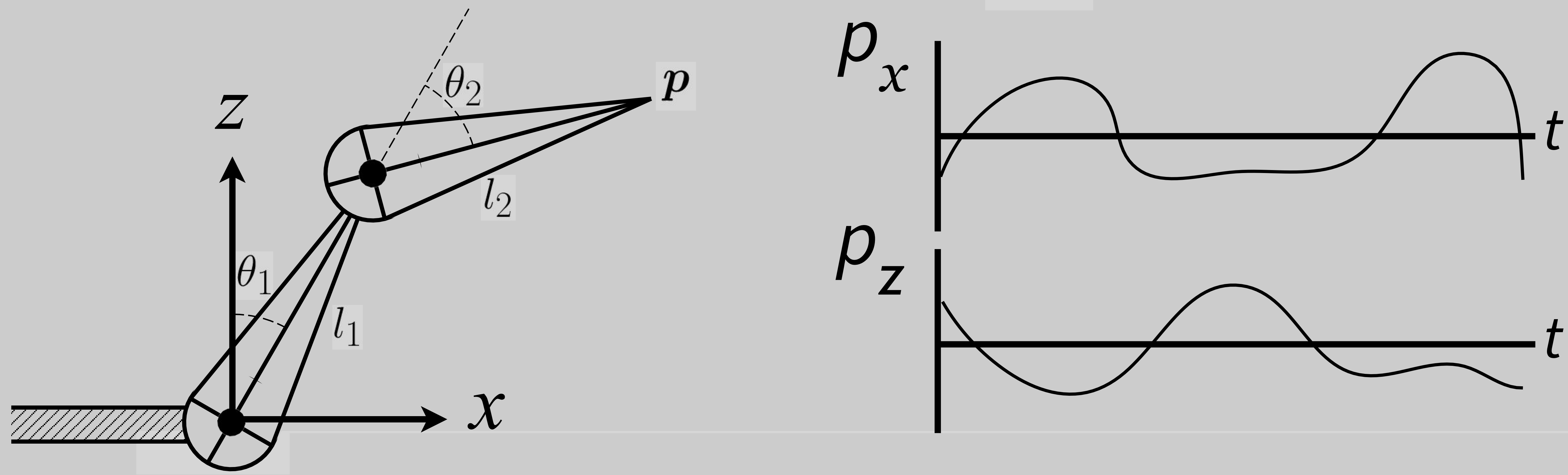
Inverse Kinematics



Egon Pasztor

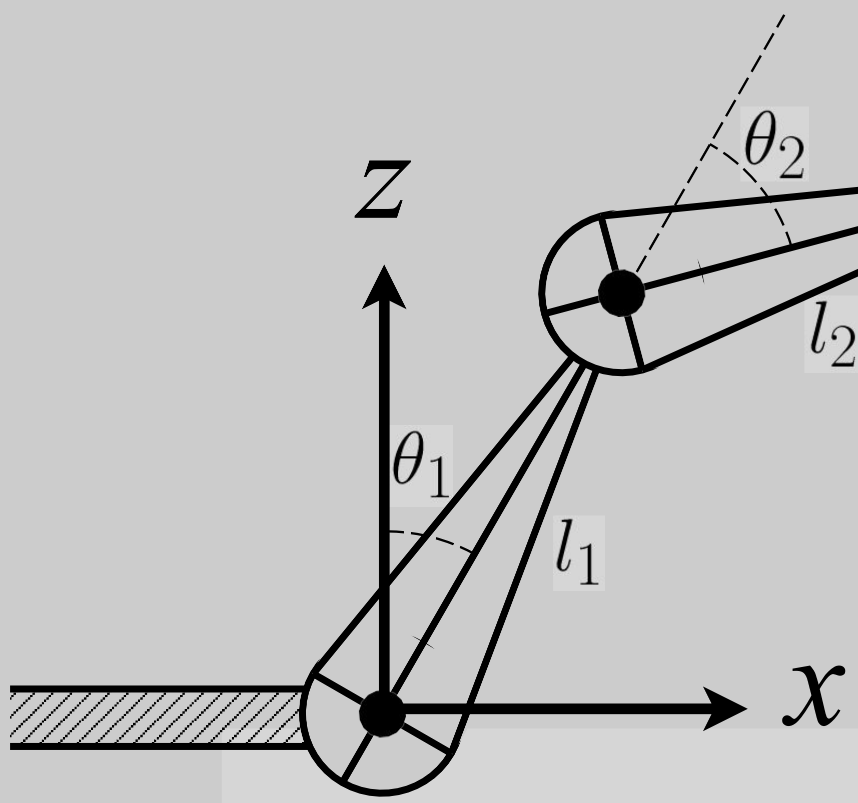
Inverse Kinematics

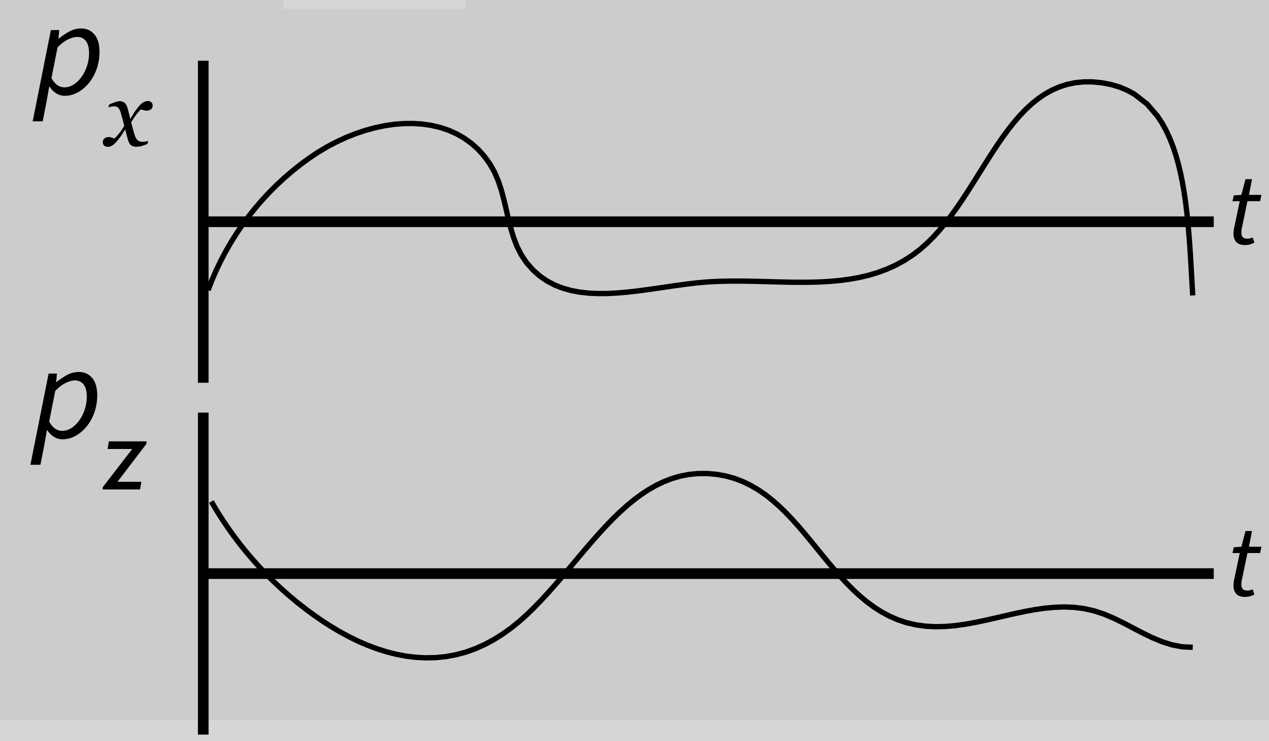
Animator provides position of end-effector, and computer must determine joint angles that satisfy constraints



Inverse Kinematics

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





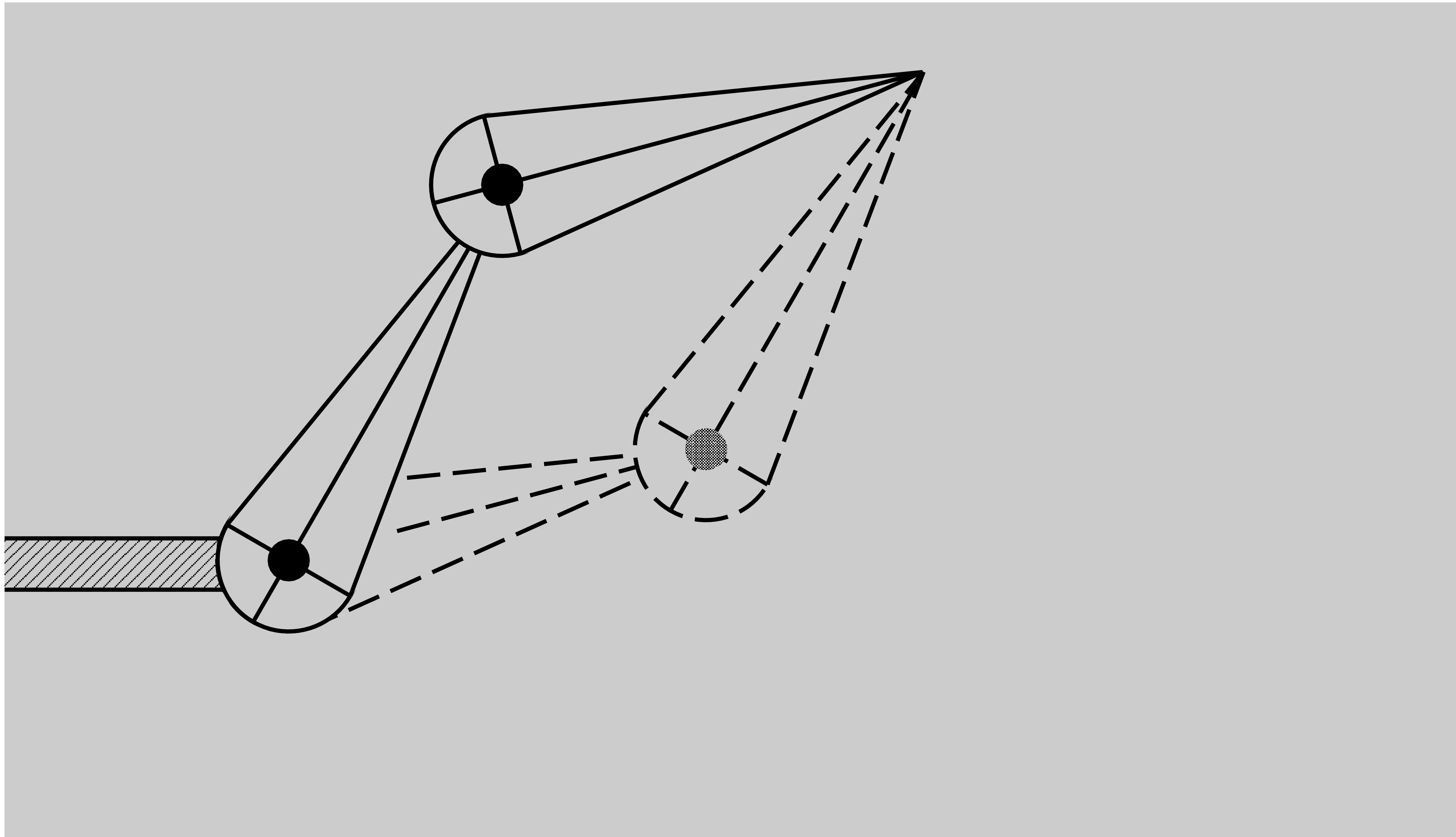
$$\theta_2 = \cos^{-1}\left(\frac{p_z^2 + p_x^2 - l_1^2 - l_2^2}{2 l_1 l_2}\right)$$

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

Inverse Kinematics

Why is the problem hard?

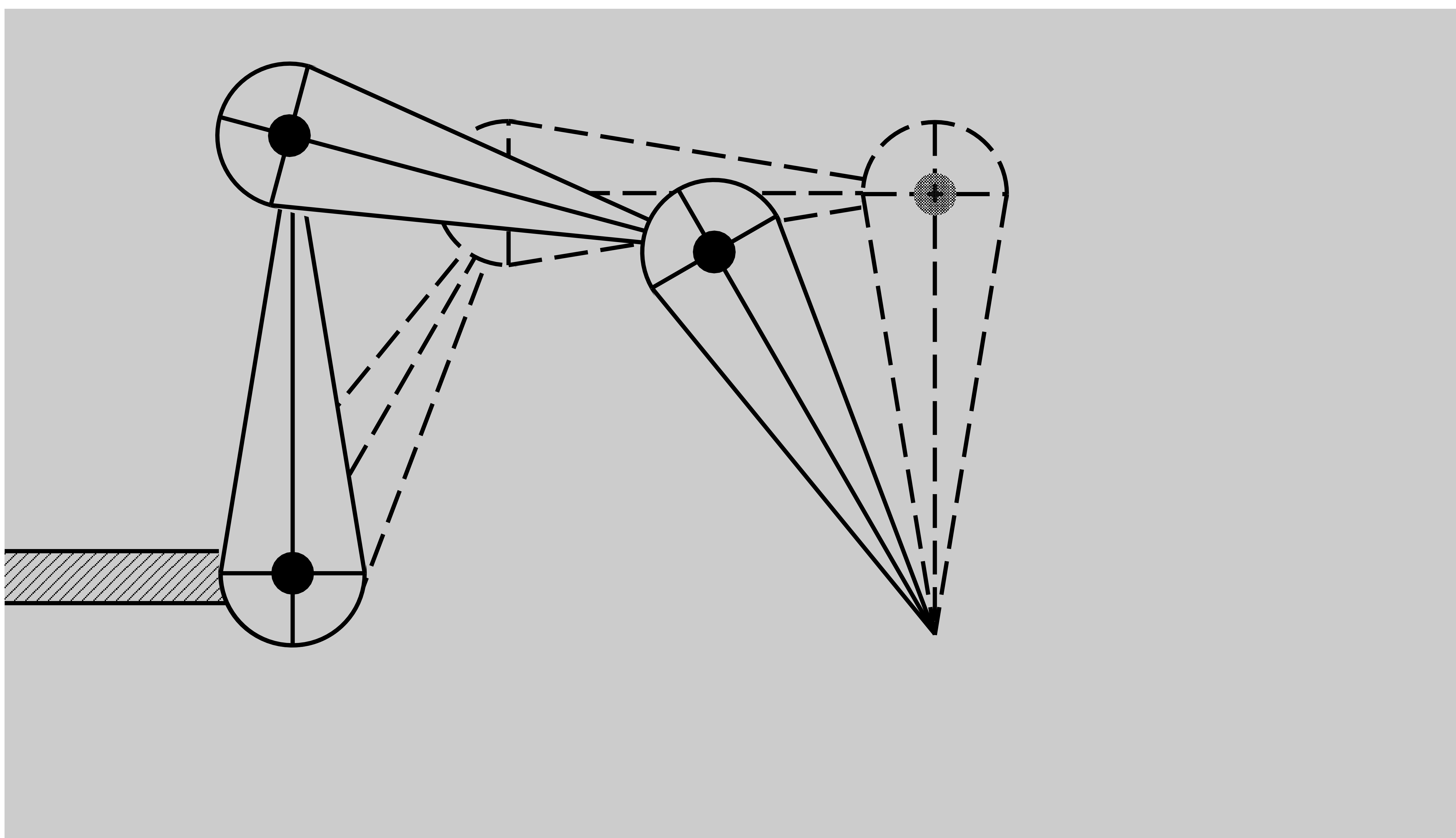
- **Multiple solutions separated in configuration space**



Inverse Kinematics

Why is the problem hard?

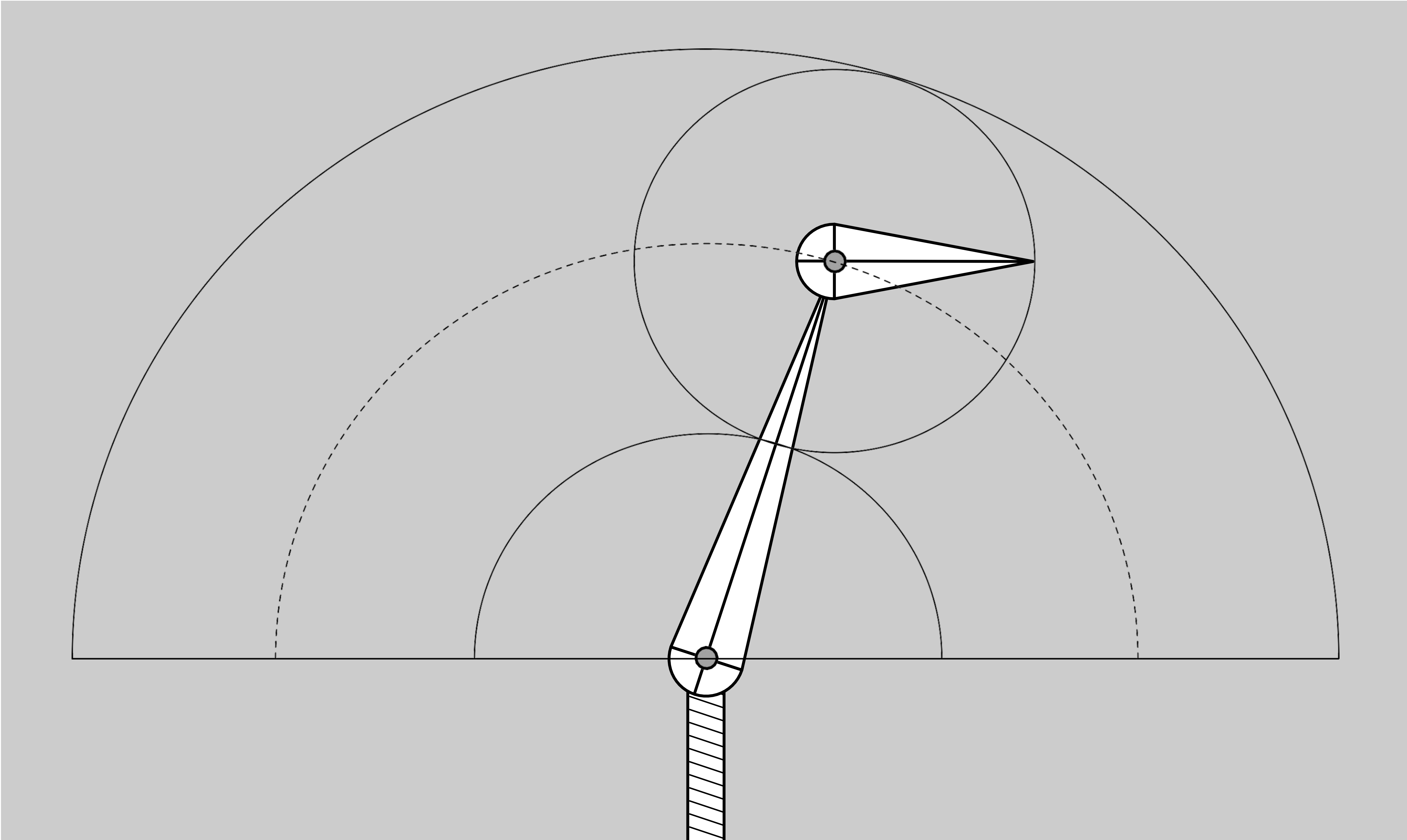
- Multiple solutions connected in configuration space



Inverse Kinematics

Why is the problem hard?

- Solutions may not always exist

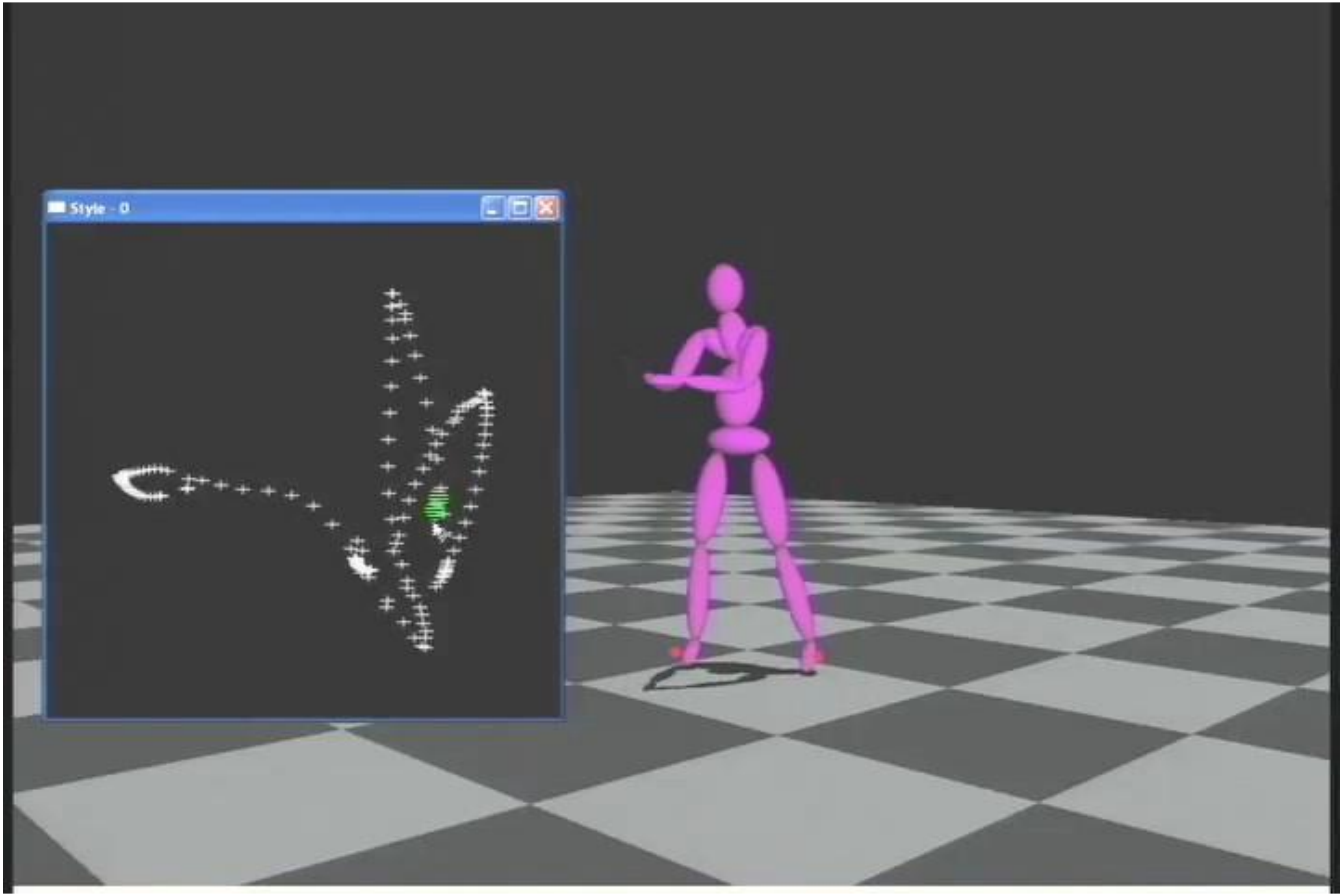


Inverse Kinematics

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

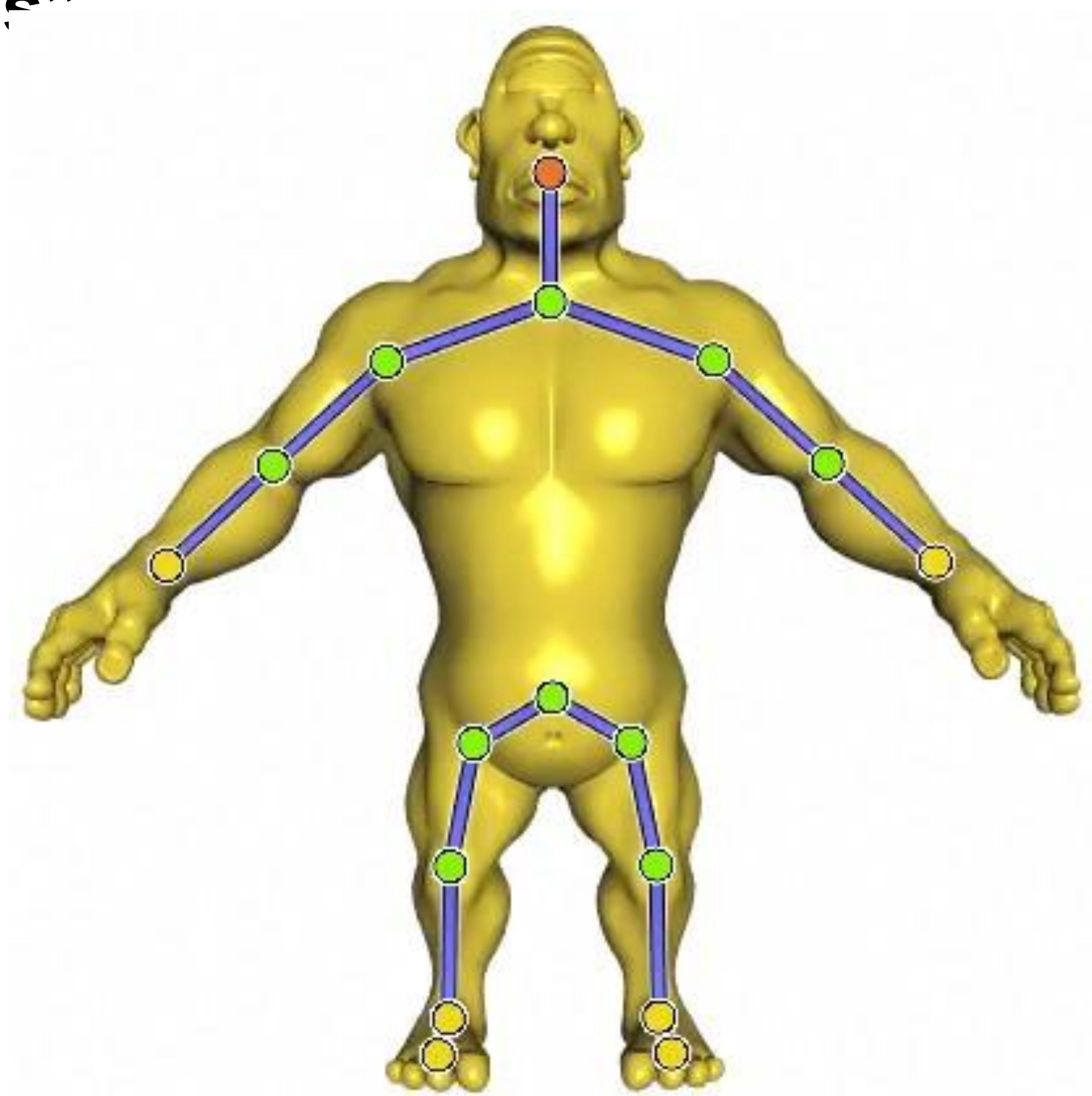
  straightforward Weaknesses

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

Skinning

Skinning

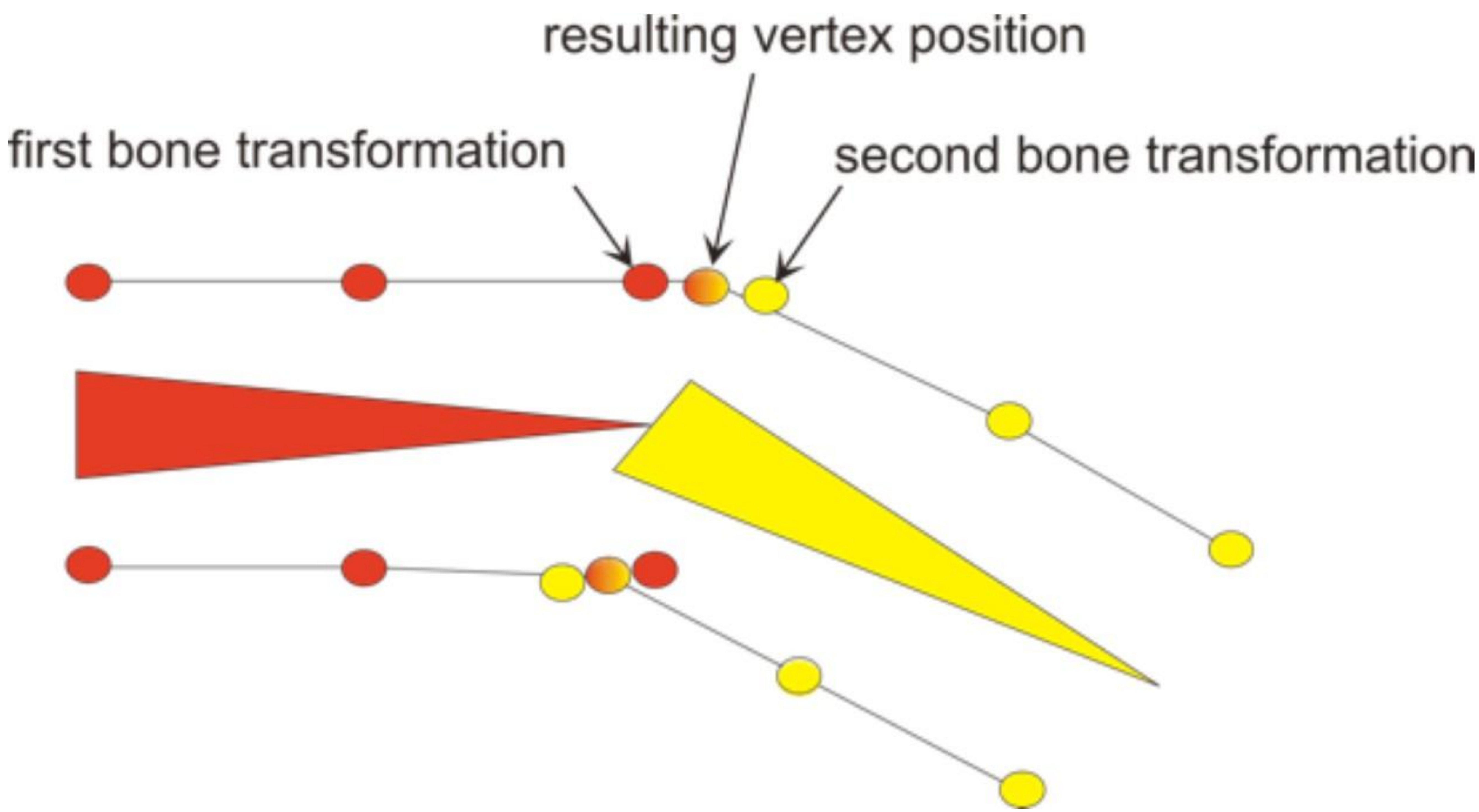
Goal: move the surface along with assigned bones or "handles"



Courtesy of Alec Jacobson

Basic Idea

1. **Transform each vertex with each bone rigidly**
2. **Blend the results using weights, or assignments**



Common Approach: Linear Blend Skinning (LBS)

Blend contribution linearly.

Super simple to implement. Great for real time.

How much influence this bone has on v (often sparse)

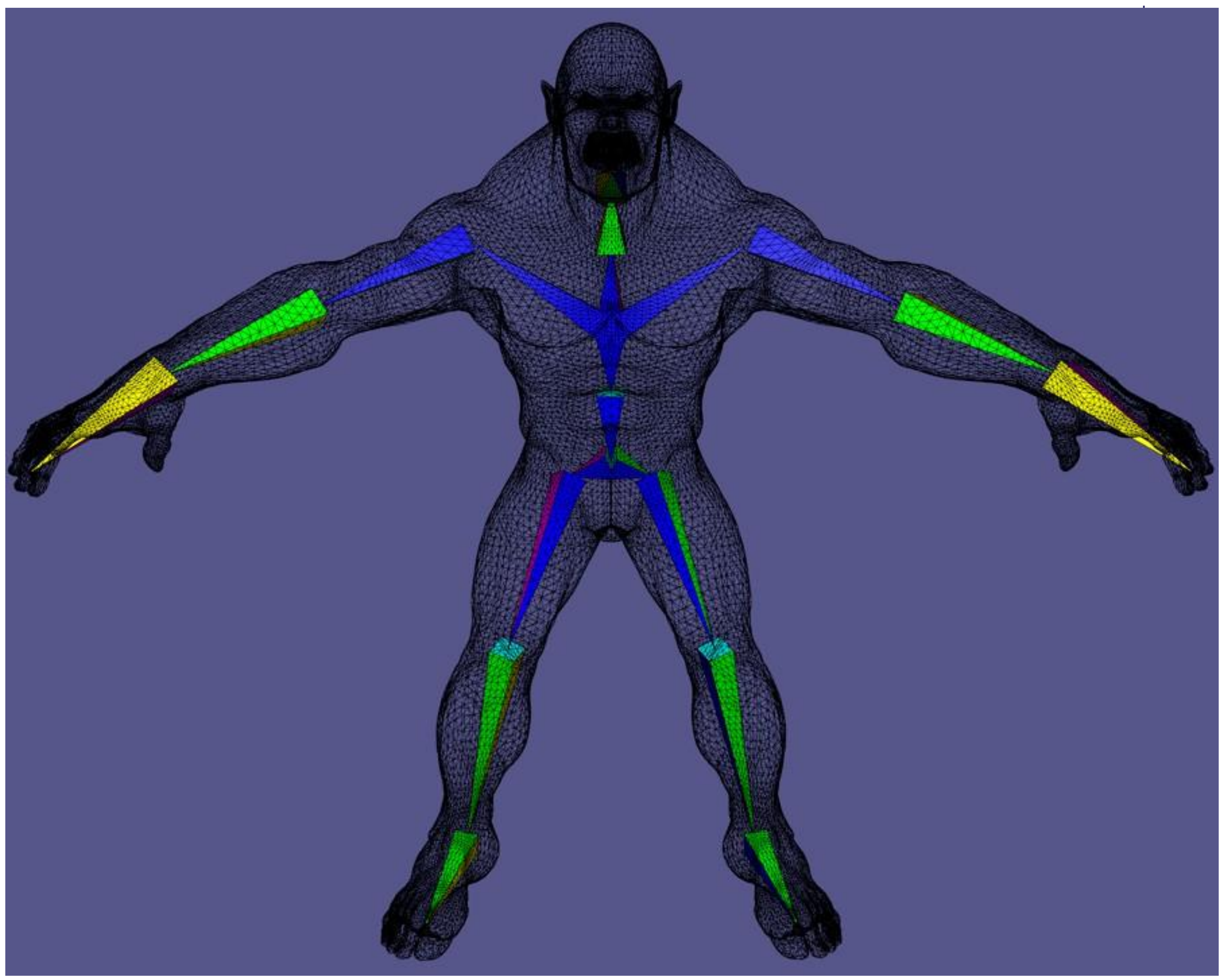
Bone j transformation

$$\mathbf{v}' = \sum_{j \in H} w_j(\mathbf{v}) \mathbf{T}_j \begin{pmatrix} \mathbf{v} \\ 1 \end{pmatrix}$$

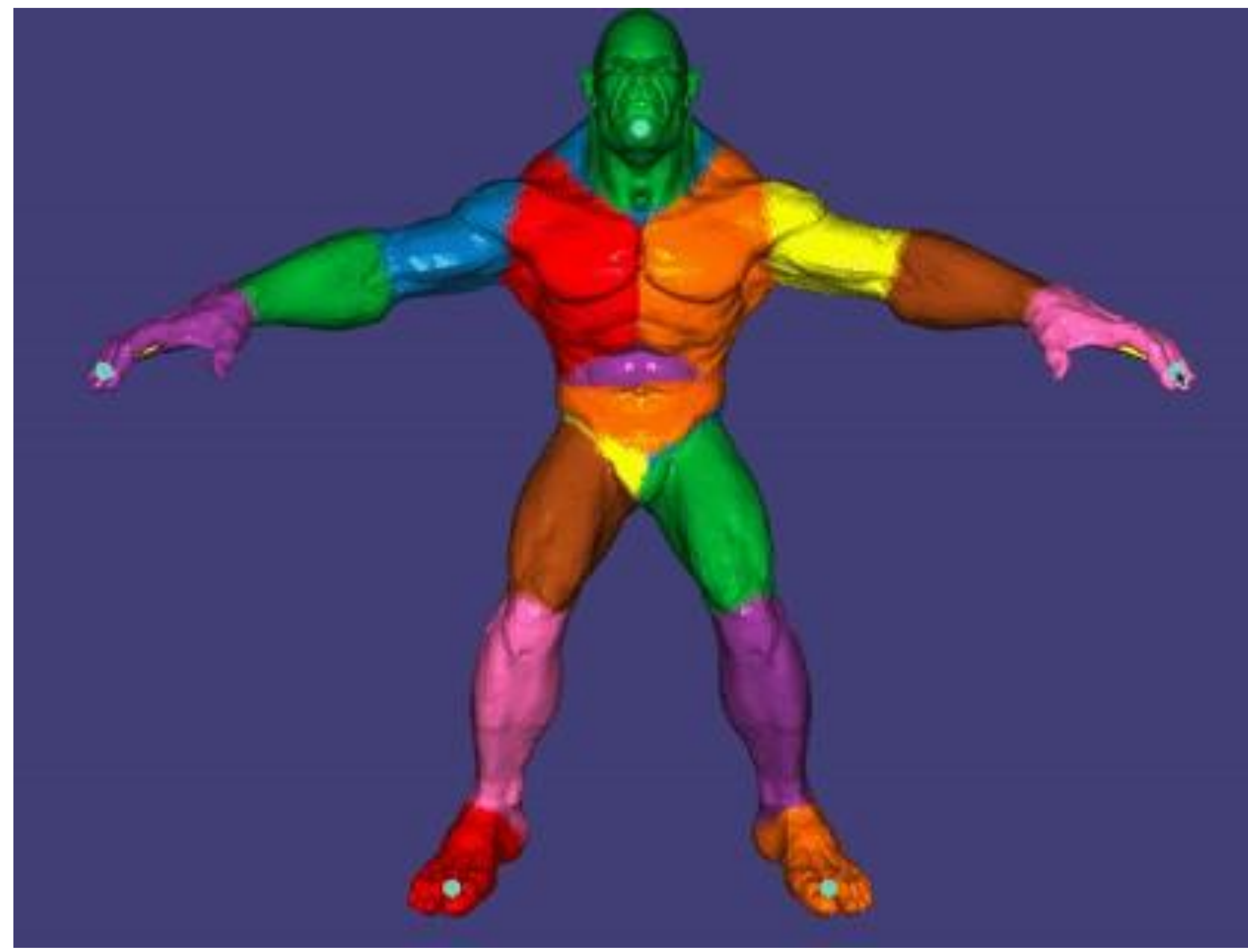
New vertex

Original vertex

Illustration of Rig & Skinning Weights



Bone transformations



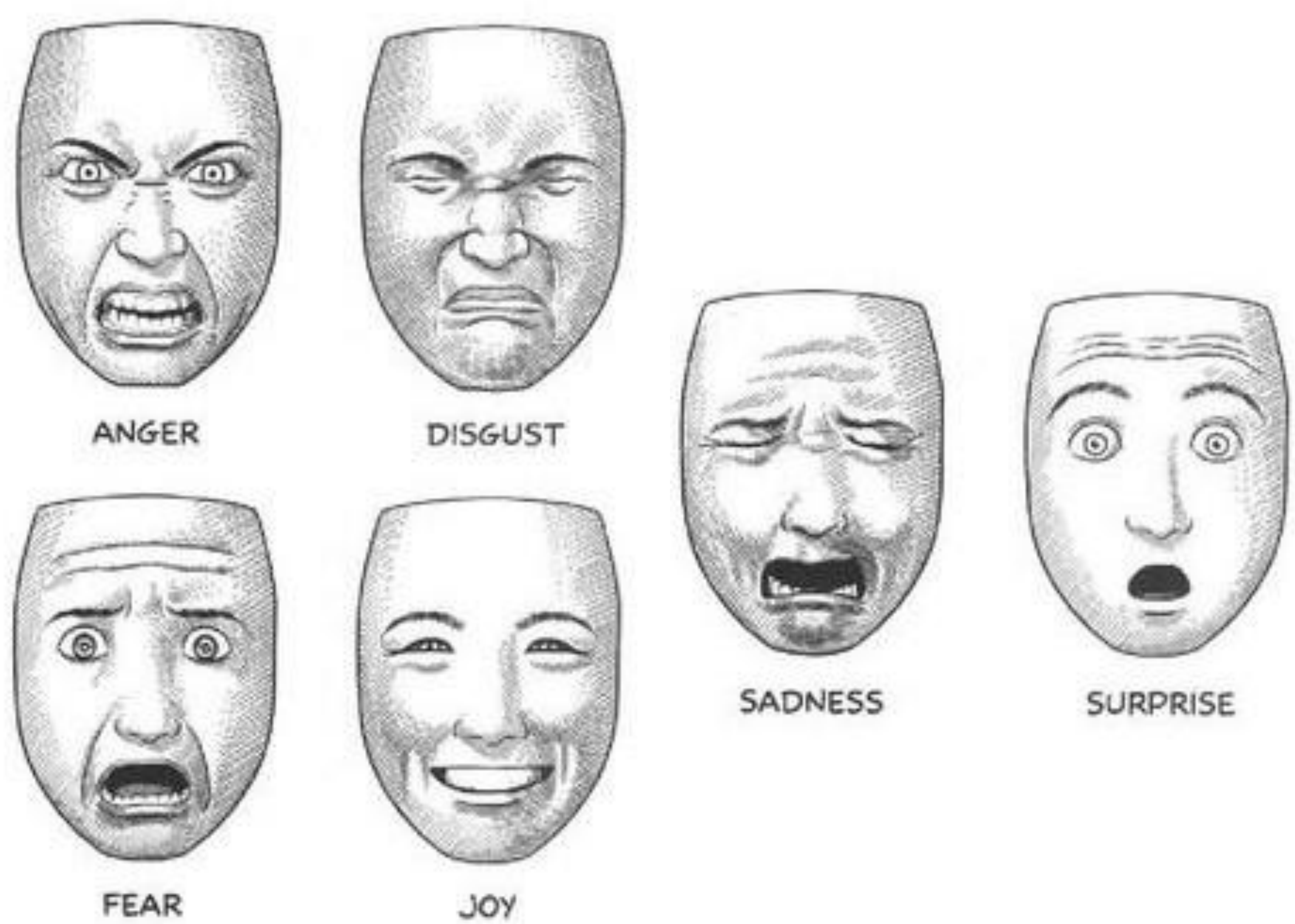
Skinning Weights

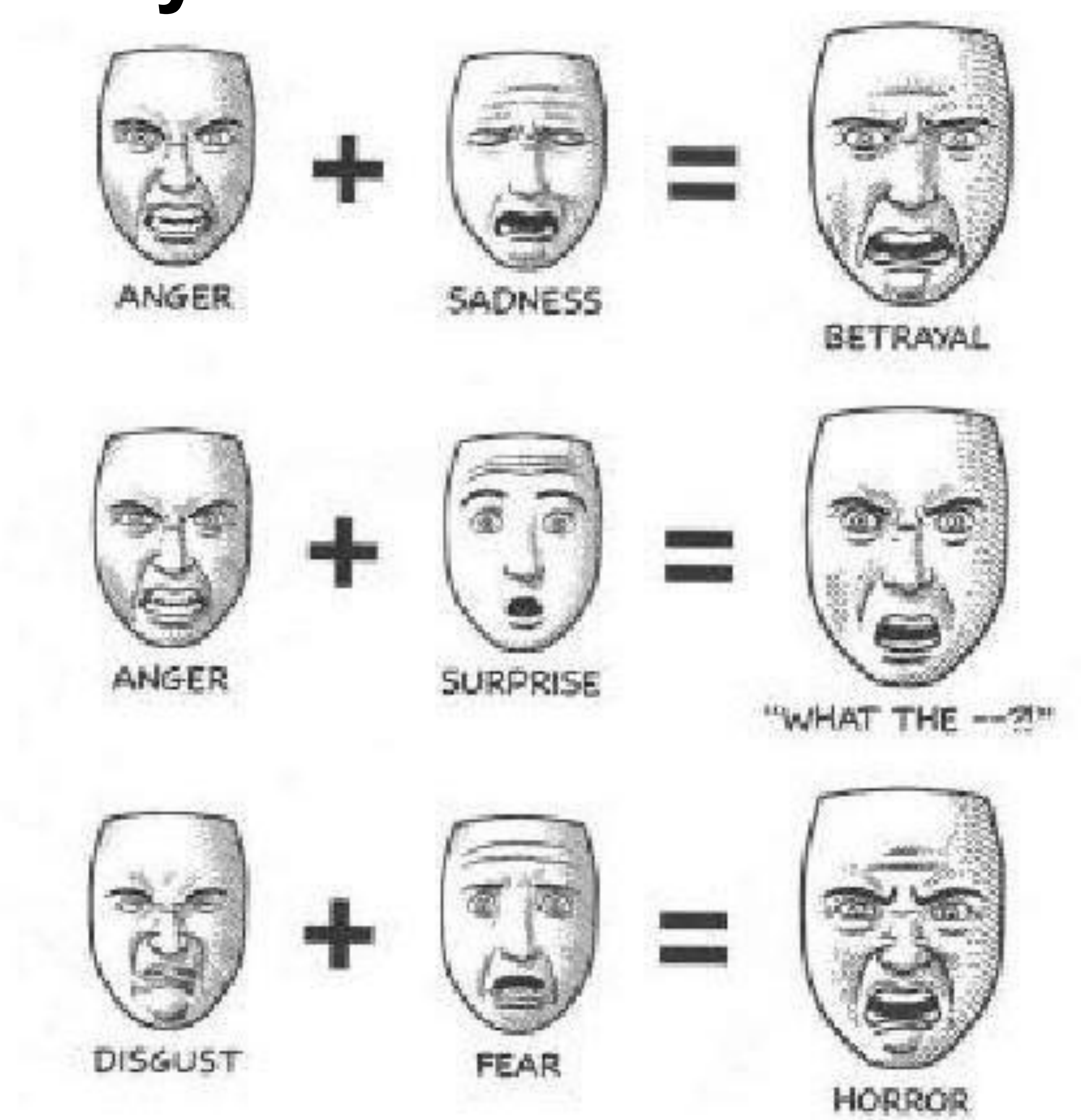
Blend Shapes

Blend Shapes

Not all deformation is from bones.

Interpolate surfaces between key shapes





Making Comics: Storytelling Secrets Of Comics, Manga, and Graphics Novels by Scott McCloud

Blend Shapes

- A set of vertex offsets to neutral shape
- Linearly interpolate these key blend shapes for control
- Often used for expressions
- Works for deformations that are linear,
  i.e. the average of two shapes is a valid shape

$$B = \mathrm{vec}\left(\begin{bmatrix} \Delta x_1 & \Delta y_1 & \Delta z_1 \\ & \vdots & \\ & \vdots & \\ \Delta x_N & \Delta y_N & \Delta z_N \end{bmatrix}\right)$$

$$V = \sum_i \beta_i B_i$$

Blend Shapes

Courtesy Félix Ferrand

Riggin
g

Rigging

Augment character with controls to
easily change its pose, create facial expressions,
bulge muscles, etc.

Rigging is like the strings on a marionette.

Capture space of meaningful deformations. Varies from character to character.

Skeleton is ONE type of rigging

Example of A Diverse Set of Sophisticated Rigs

Courtesy of
Matthew Lailler

Motion Capture

Motion Capture

Data-driven approach to creating animation sequences

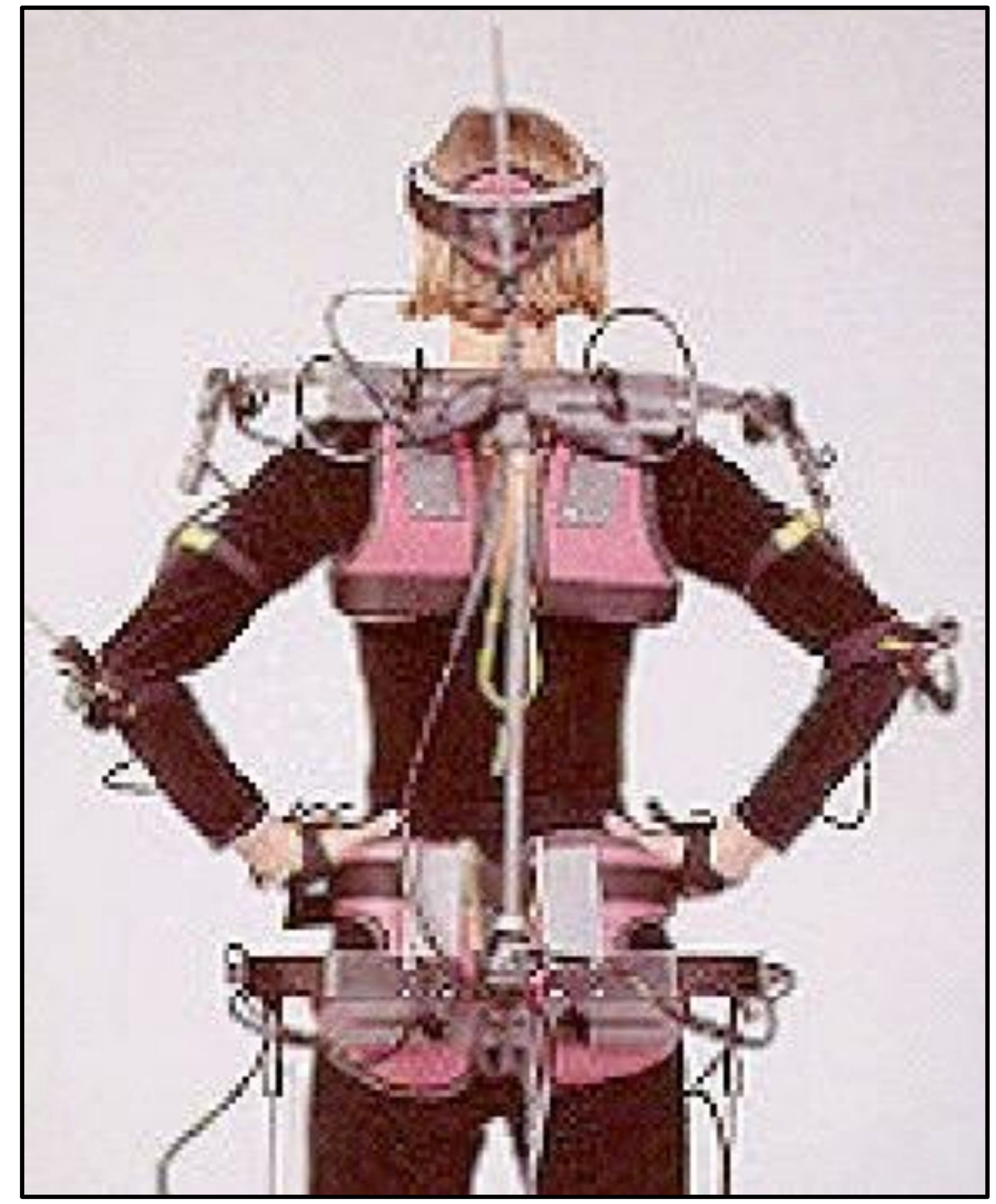
- **Record real-world performances**
- **Extract pose as a function of time from raw data**

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

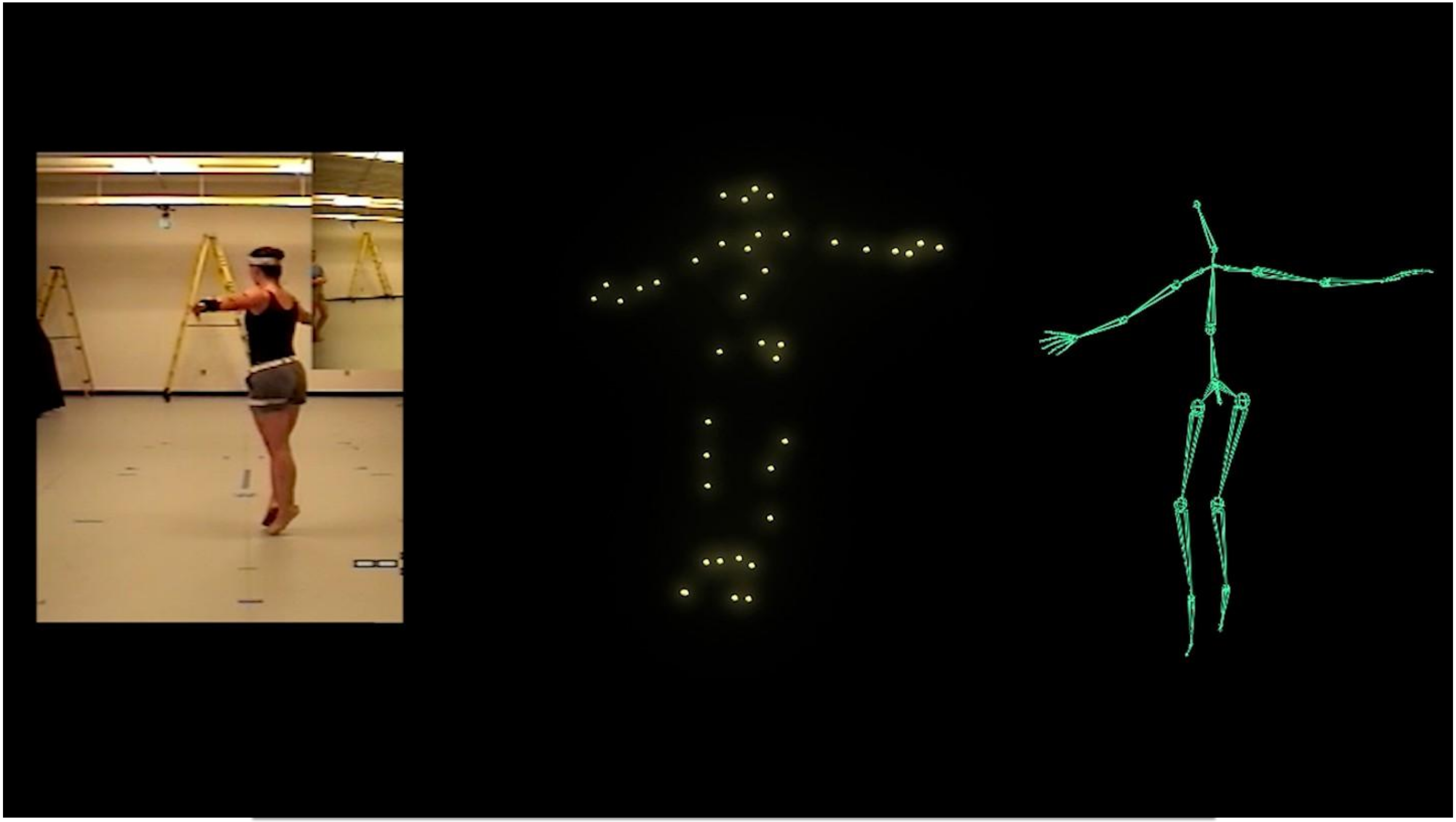
Retroflective markers attached to subject

IR illumination and cameras

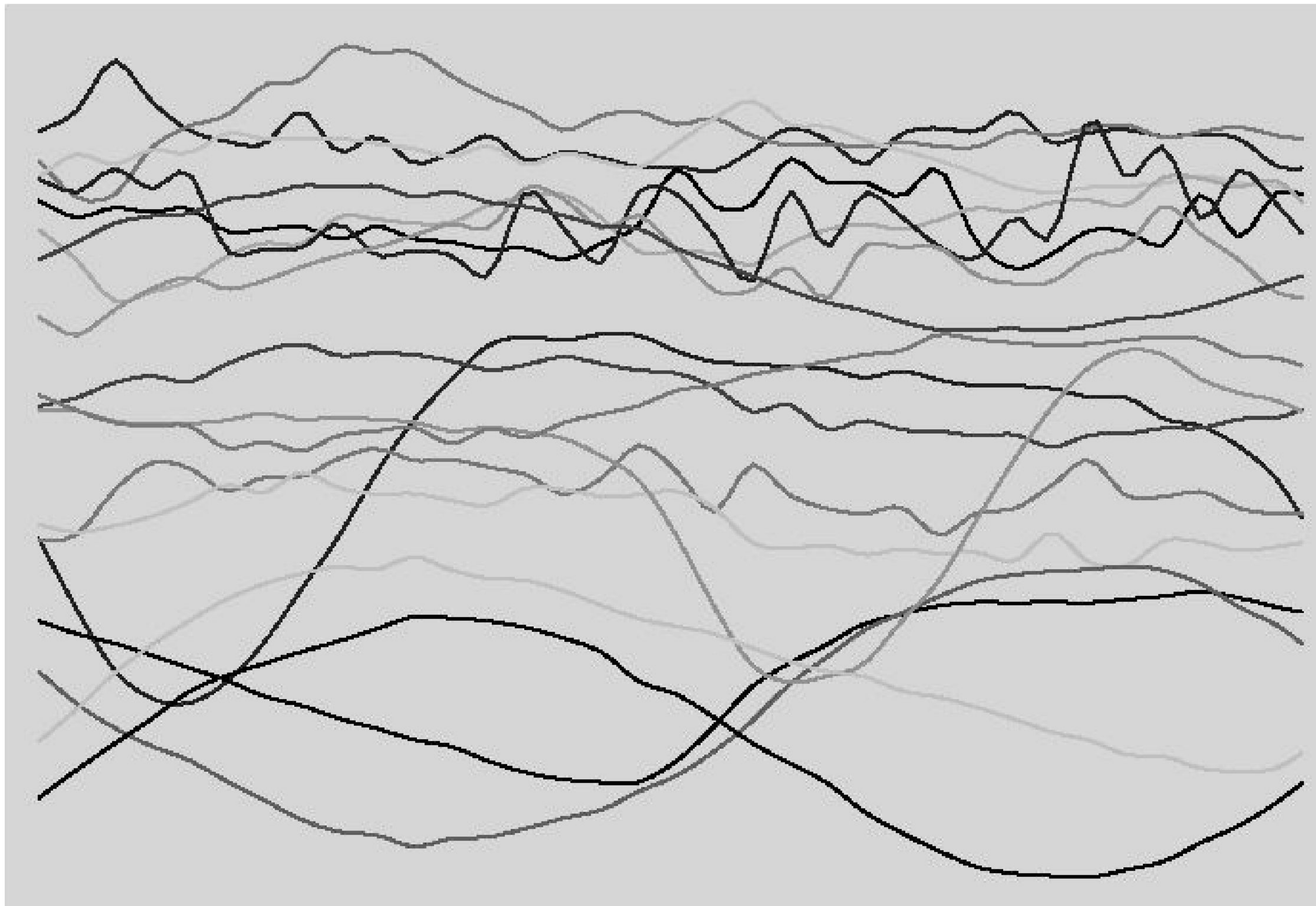
- Markers on subject
- Positions by triangulation from multiple cameras
- 8+ cameras, 240 Hz, occlusions are difficult

Slide credit: Steve Marschner

Motion Capture



Motion Data



Subset of motion curves from captured walking motion.

From Witkin and Popovic, 1995

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

Markerless Motion Capture

Kanazawa et al. 2018

Kanazawa et al. 2019

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