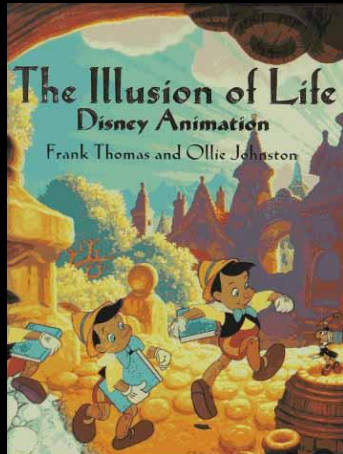


Introduction to Computer Animation

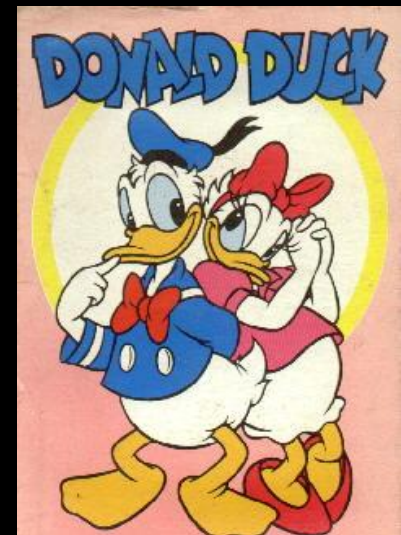
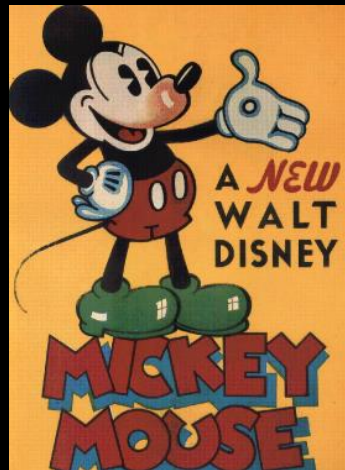
Wen-Chieh (Steve) Lin

*Department of Computer Science and
Institute of Multimedia Engineering*



What is animation?

- Making things move
- Bring things to life
- An expressive art form
 - young but well evolved (approximately 100 years)
- Traditionally “films” or “cartoons”



Brief History of Animation

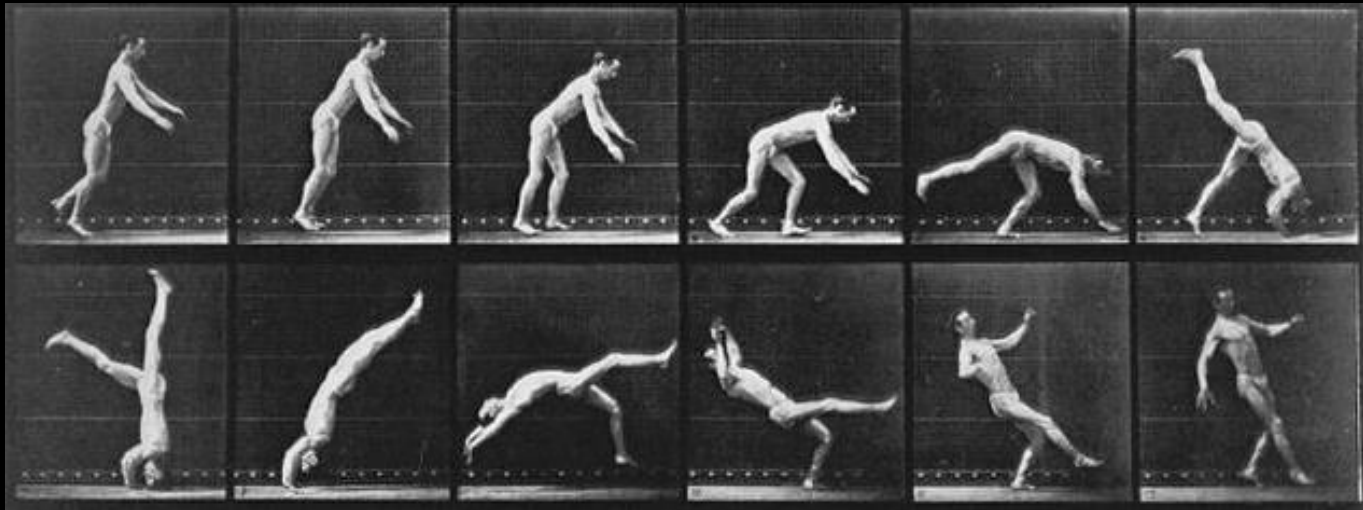
Animation Heritage—Early Devices

- Persistence of vision
 - Shadow puppets
 - Flipbook
 - Thaumotrope (1800s)
 - Phenakistiscope (1830)
 - Zoetrope (1834)



Animation Heritage—Early Devices

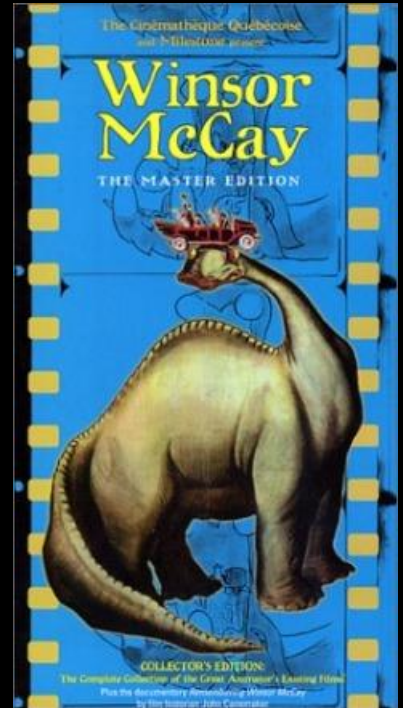
- Photograph
 - Muybridge (1885)



- Film projector (Edison, 1891)

Early “Traditional” Animation

- First animation using a camera
 - 1896, Georges Melies, moving tables
 - 1900, J. Stuart Blackton, added smoke
- First celebrated cartoonist
 - Winsor McCay
 - Little Nemo (1911)
 - Gertie the Dinosaur (1914)

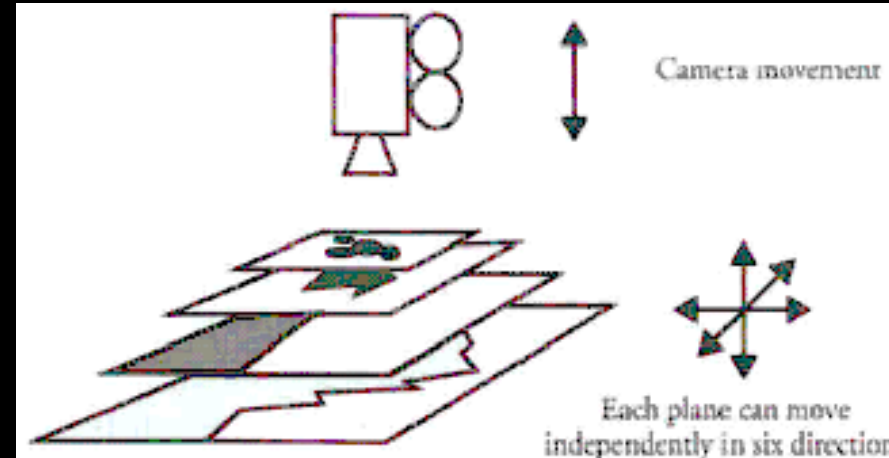


Early Technical Developments

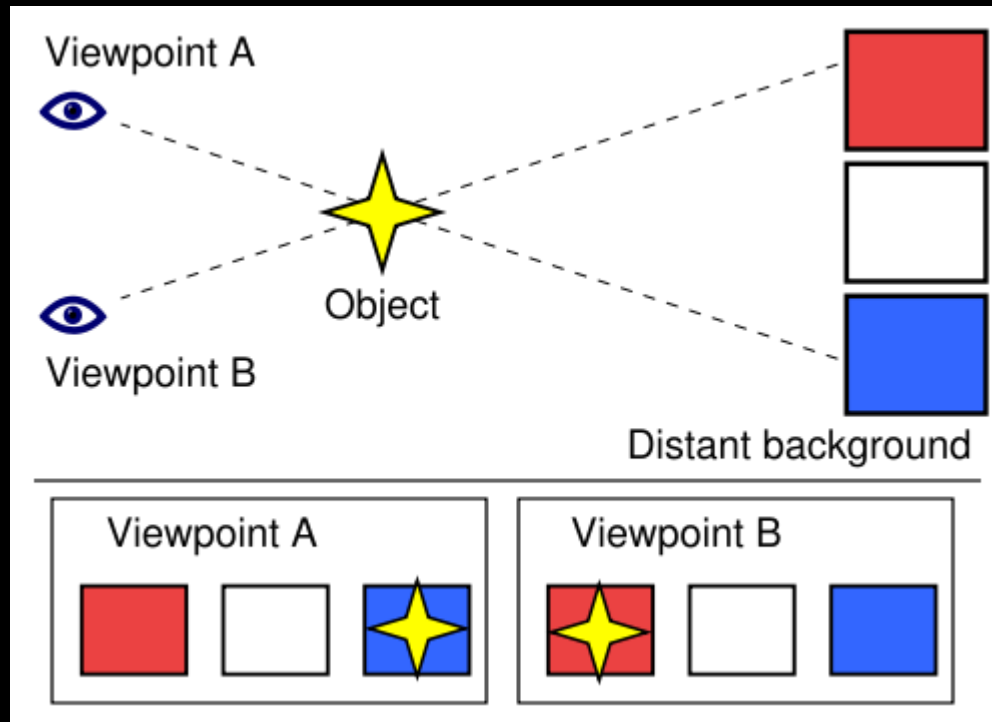
- 1910, Bray and Hurd
 - Patented translucent *ce/s* (formerly celluloid was used, but acetate is used now) used in layers for **compositing**
 - Patented gray-scale drawings
 - Patented using pegs for **registration** (alignment) of overlays
 - Patented the use of large background drawings and panning camera

Disney

- Advanced animation more than anyone else
- First to have sound in 1928, Steamboat Willie
- First to use storyboards
- First to attempt realism
- Invented multiplane camera
 - Creating illusion of depth
 - Zooming
 - Parallax
 - Motion blur



Side note: Parallax





ANIMATION IN THE 1930's

Pure Hardwork

Disney's Multiplane Camera



Computer Animation Techniques

Computer Animation

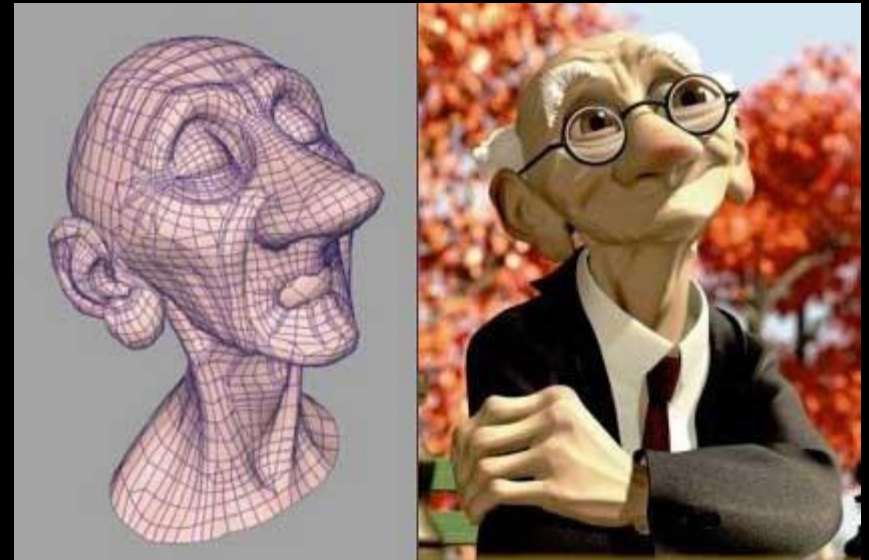
- Uses computer algorithms and techniques to produce animation
- Brings new meaning to animation
 - Interactive (games, virtual reality, education tools)
 - Mix into live action (digital special effects)
 - Part of digital production



Luxo Jr. (Pixar, 1986)

Digital Production Pipeline

- Story
- Storyboards [CoCo](#)
- Visual development
- Character design
- Scene layout
- Modeling
- Animation
- Shading and texturing
- Lighting
- Rendering
- Post production



Toy Story

- First full-length CG film



How Pixar's 'Toy Story 4' Was Animated



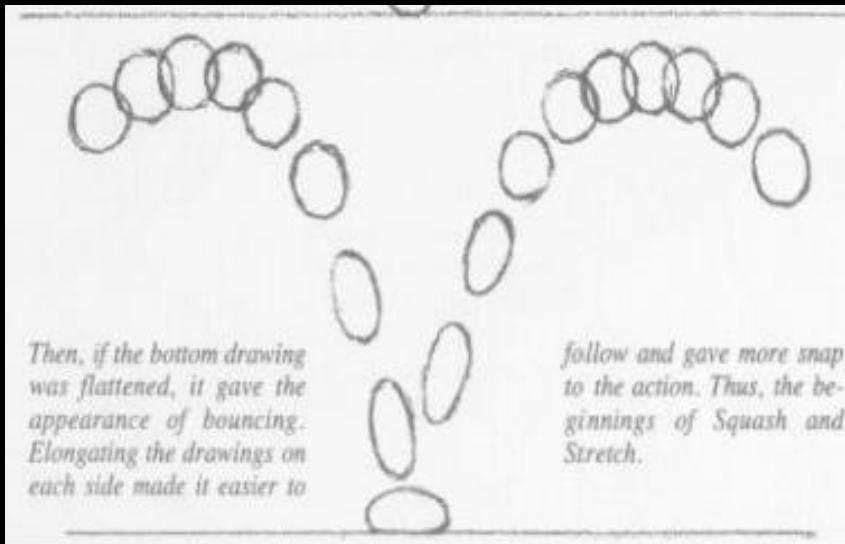
Computer Animation Techniques

- Keyframing
- Skeletal Animation
 - Kinematics
 - Motion capture
 - Motion editing
- Dynamics and Simulation
- Behavior Animation

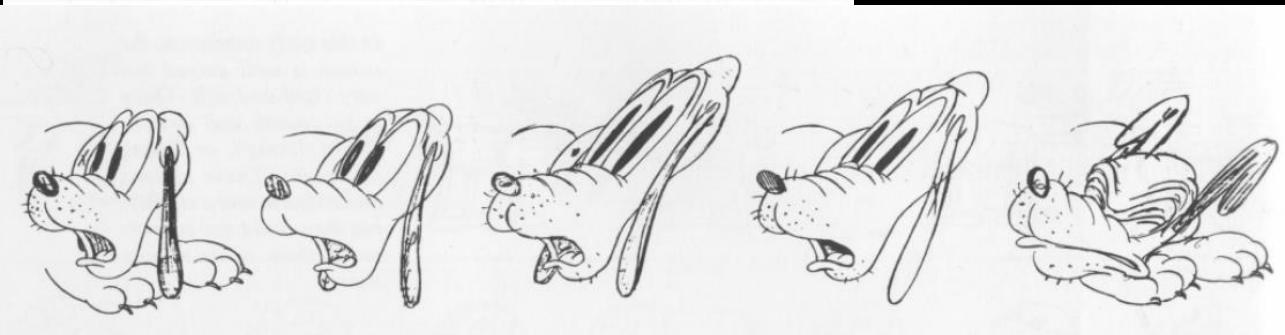
Keyframing

Keyframing

Specify only the important frames,
interpolate the frames in-between



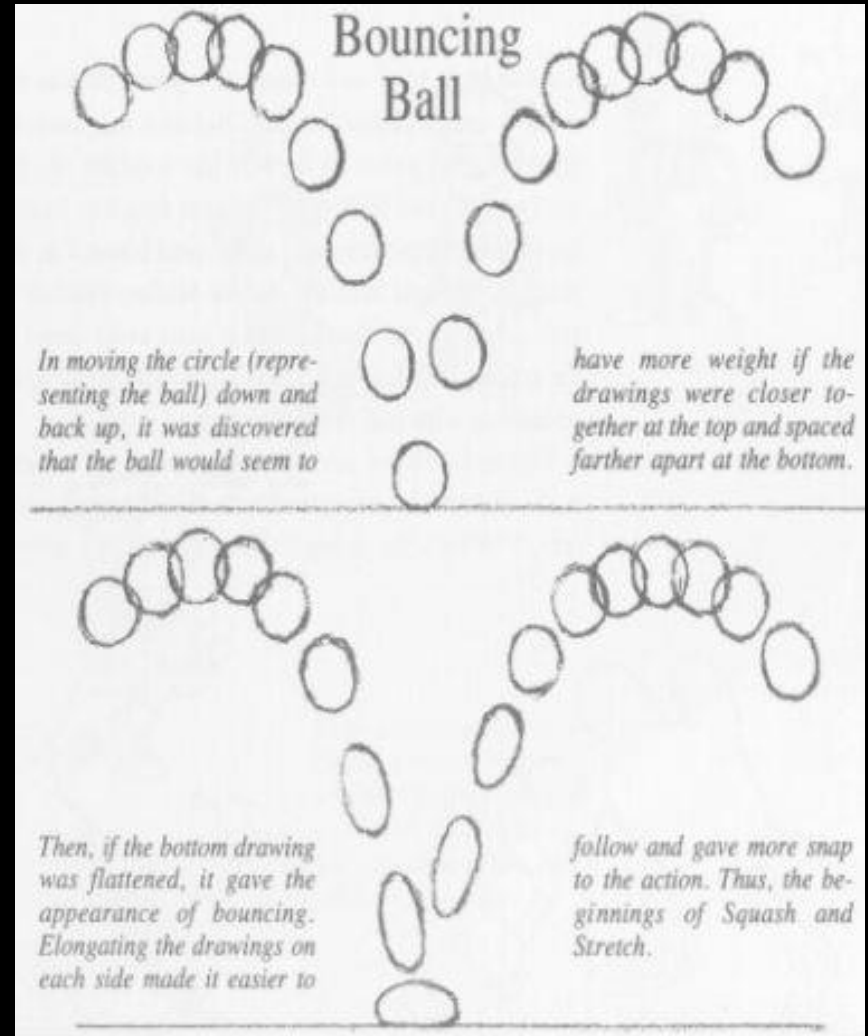
What and how to
interpolate is important



“The Illusion of Life”

What is a key?

- For a bouncing ball
 - 3D Positions
 - Orientation?
 - Squishedness?



What is a key?

- For characters?
 - 3D Position and orientation
 - Joint angles of the skeleton
 - Facial features
 - Hair/fur?
 - Clothing?
- Scene components?
 - Camera
 - Lights
 - Snow



Frozen (Pixar, 2013)

Example: Keys in Pixar Characters

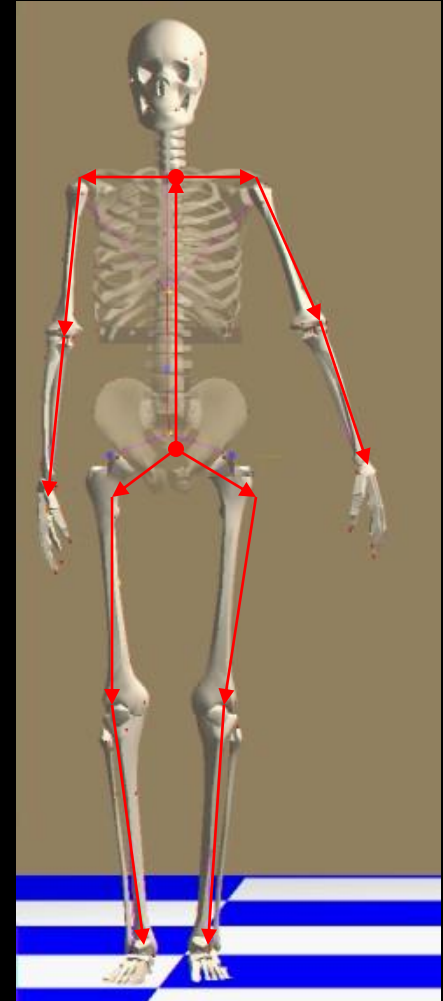


Skeletal Animation

Kinematics

The study or specification of motion, independent of the underlying physics that created the motion

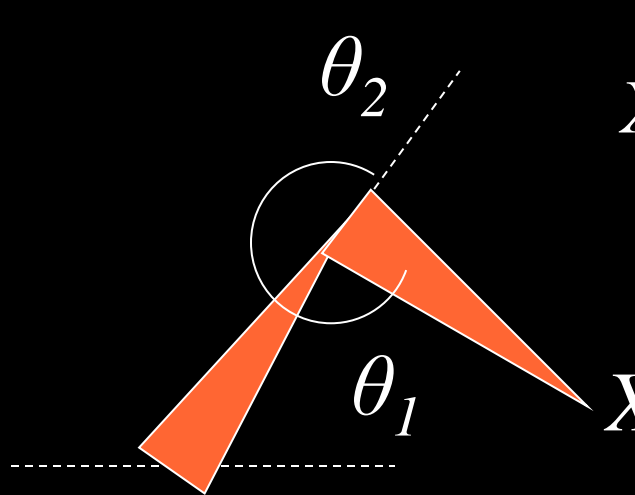
Articulated Figure:
A figure made up of a series of links (bones) connected at joints



Forward Kinematics

Given the character's state,
calculate its pose

$$X = f(\theta)$$



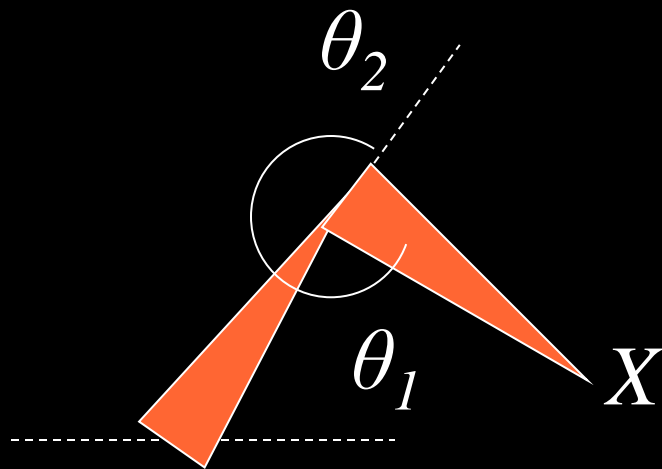
The diagram illustrates a 2-link planar arm. The first link is a red triangle with its base at the origin (0,0) and its tip at the first joint. The angle between the first link and the horizontal dashed line is θ_1 . The second link is another red triangle attached to the first joint, with its tip at the end-effector point X . The angle between the second link and the extension of the first link is θ_2 . The end-effector point X is labeled at the tip of the second link.

$$X = \begin{bmatrix} l_1 \cos \theta_1 + l_2 \cos(\theta_1 + \theta_2) \\ l_1 \sin \theta_1 + l_2 \sin(\theta_1 + \theta_2) \end{bmatrix}$$

Inverse Kinematics

Given the character's pose,
calculate its state

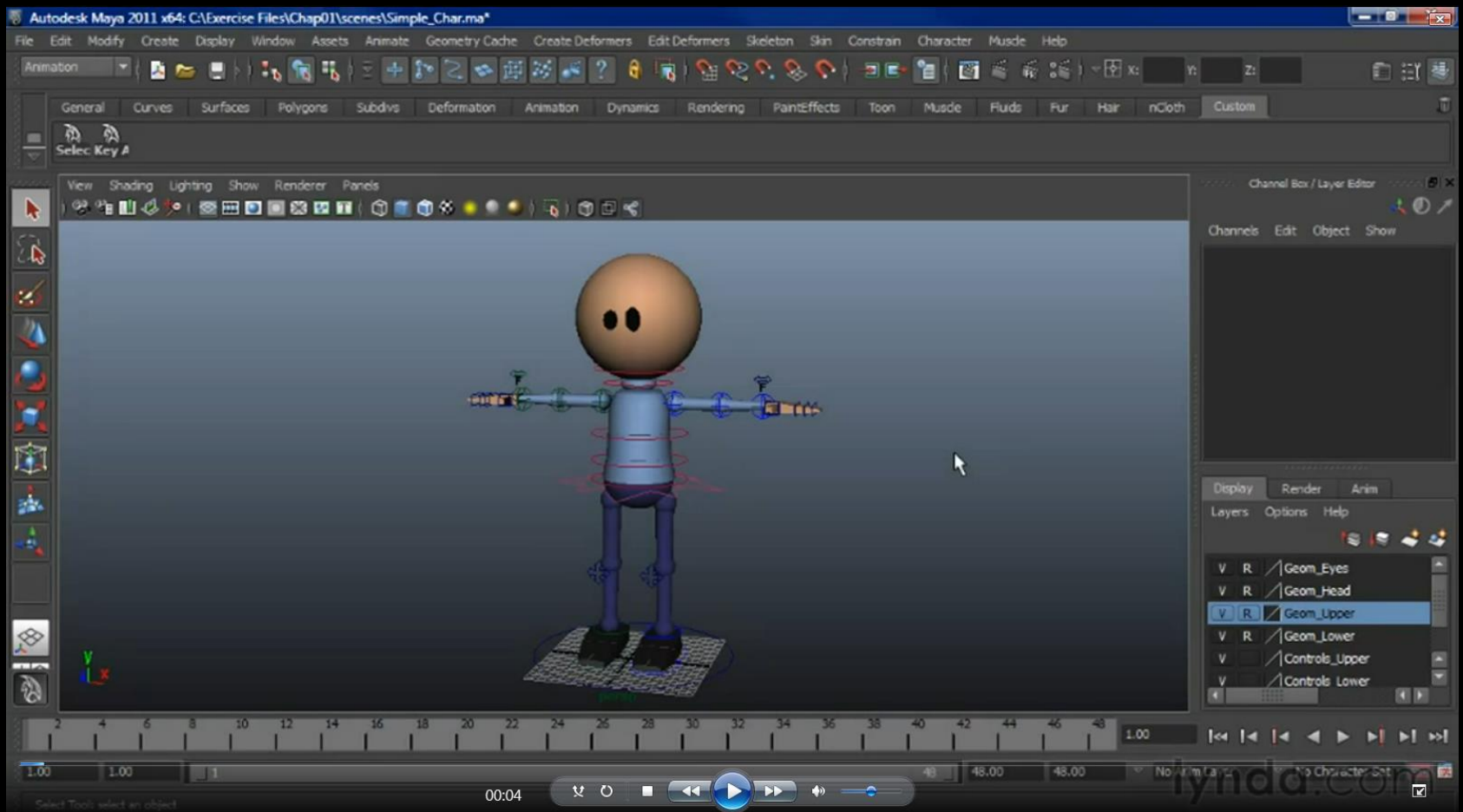
$$\theta = f^{-1}(X)$$



$$\theta = \begin{bmatrix} \frac{-(l_2 \sin \theta_2)x + (l_1 + l_2 \cos \theta_2)y}{(l_2 \sin \theta_2)y + (l_1 + l_2 \cos \theta_2)x} \\ \cos^{-1} \frac{(x^2 + y^2 - l_1^2 - l_2^2)}{2l_1l_2} \end{bmatrix}$$

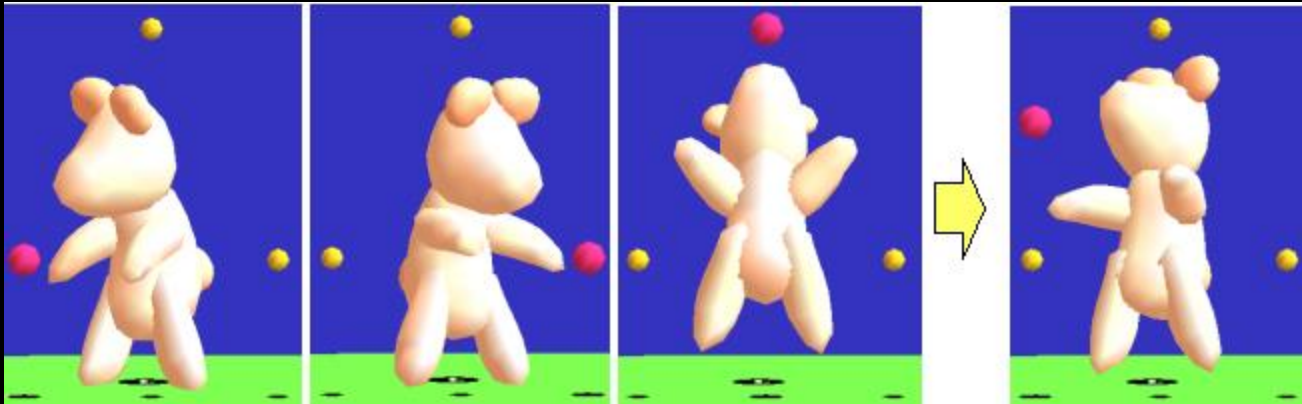
Example: Forward Kinematics

- Maya tutorial



Example: Inverse Kinematics & Keyframing

- Takeo Igarashi, Tomer Moscovich, John F. Hughes, “Spatial Keyframing for Performance-driven Animation,” SCA 2005



- Associate a key pose with a 3D position
- Interpolate in pose space
- Video

Motion Capture

- Live action recording
 - track motion of reference points
 - convert to joint angles to drive an articulated 3D model
 - drive a deformable surface



Xsens, inertia sensors



Motion Capture in Films



I, Robot

Avatar by Weta Digital



Facial Motion Capture: FACET by Weta Digital

- Facial Mocap in King Kong
- Dawn of The Planet of The Apes (猩球崛起)
- War for The Planet of The Apes
 - SIGGRAPH 2017 talk (14:21)
- Academy® Scientific and Technical Award – Technical Achievement, 2017



Motion Capture in Games

- NBA2K24

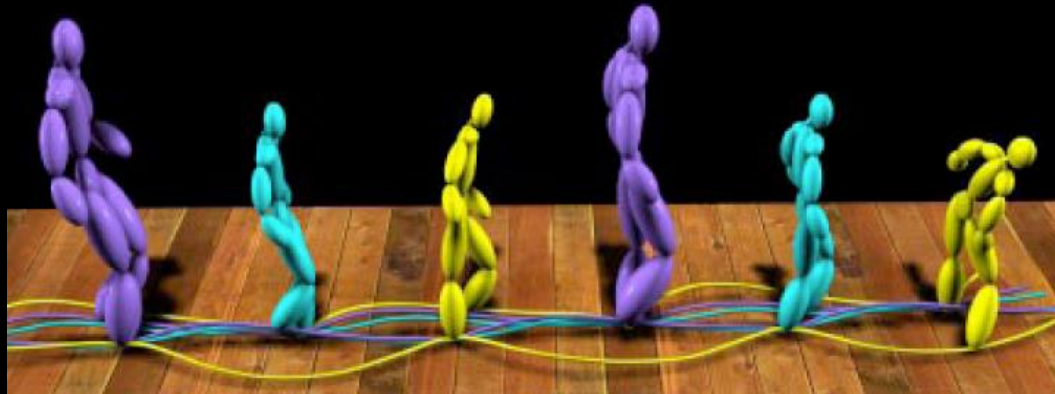




Quantic Dream—*Beyond Two Souls* (2013)

Motion Editing

- Get a specific motion
 - from capture, keyframes
 - specific character, action, style
- Want something else while preserving original
 - which part to preserve is case dependent
 - cannot characterize/distinguish motions well enough

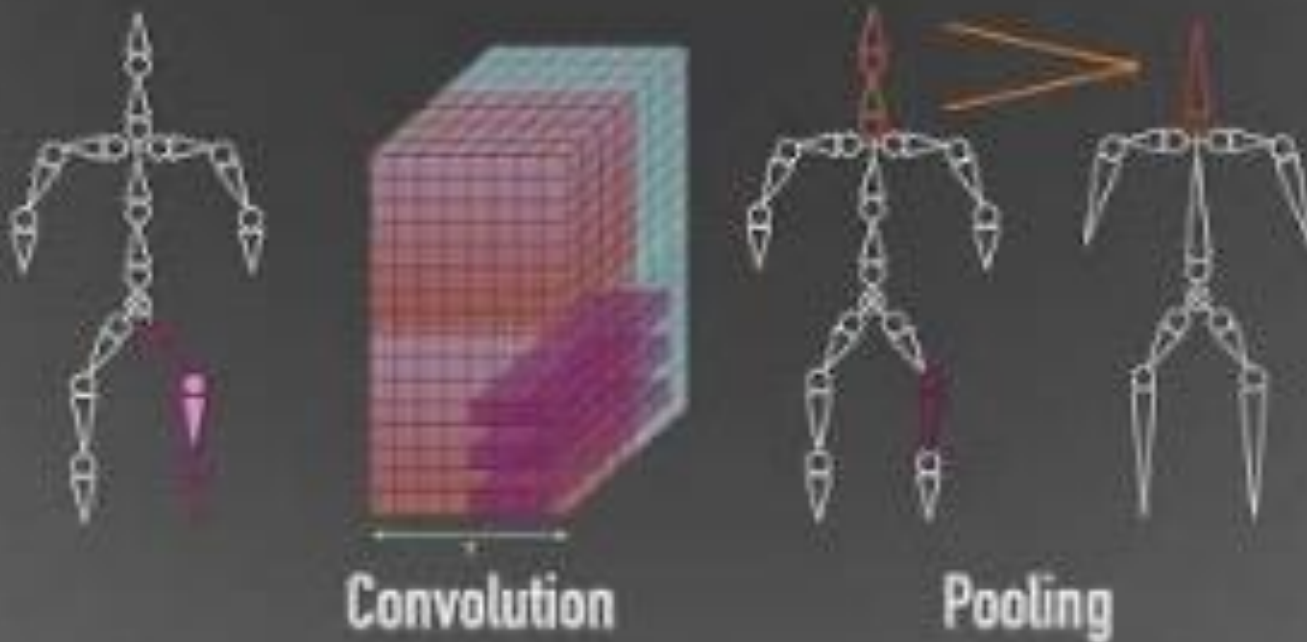


Motion Retargeting Video



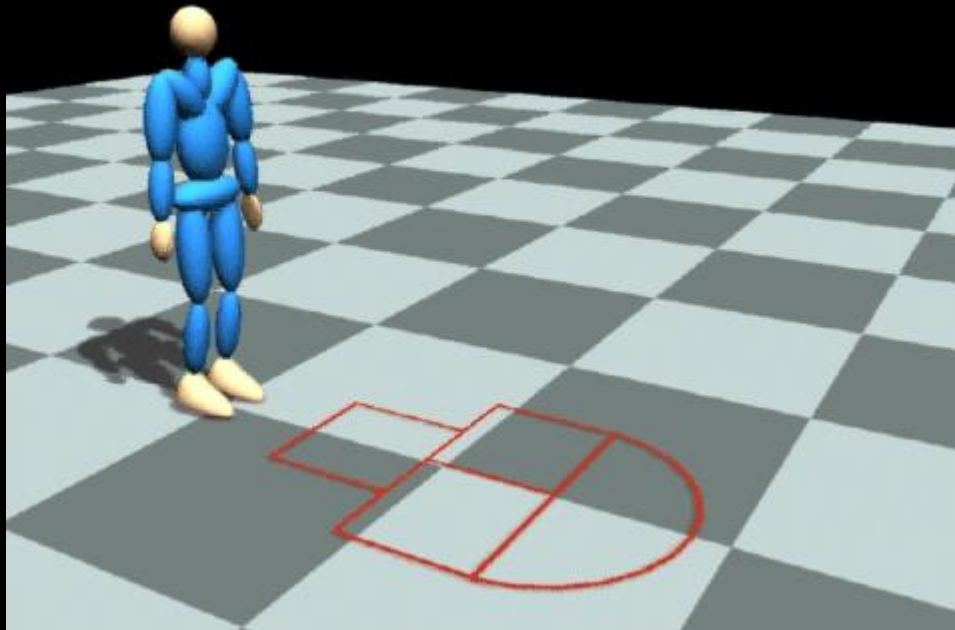
Skeleton-Aware Networks for Deep Motion Retargeting

Skeleton-Aware Networks



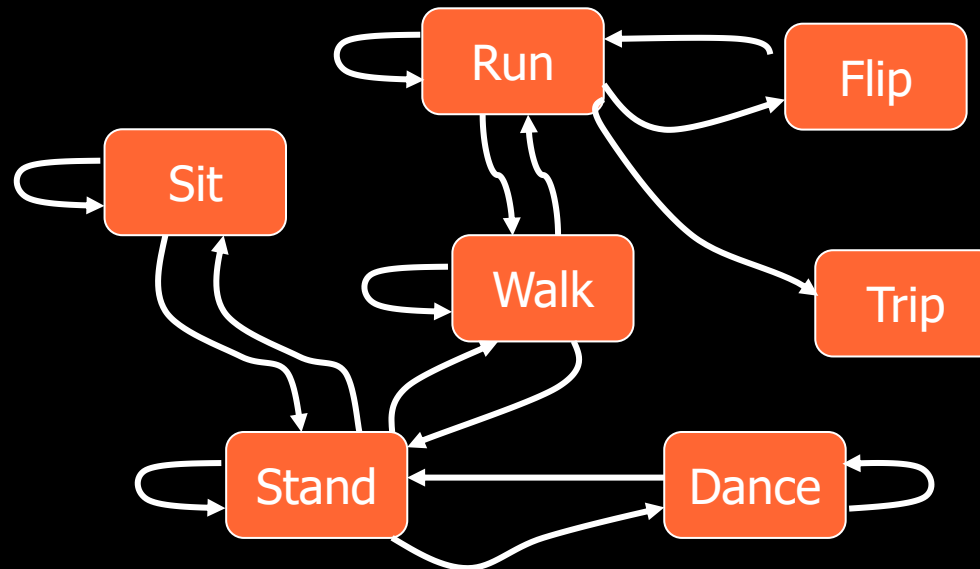
Optimization-based Motion Synthesis

- Video



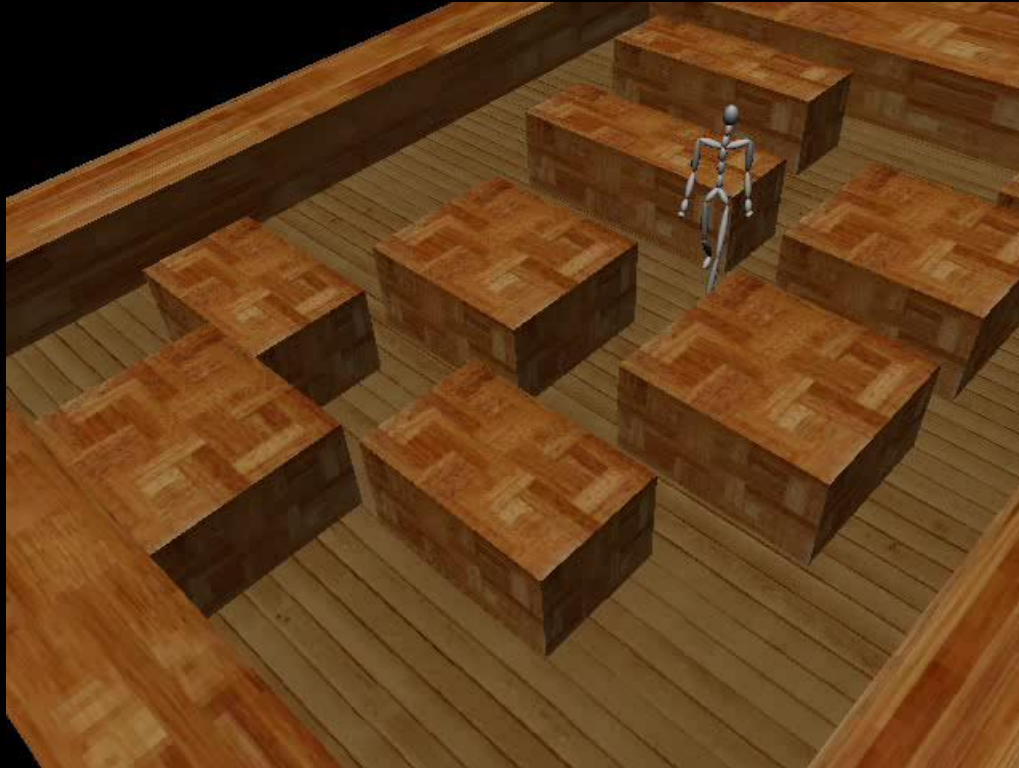
Motion Synthesis Using Motion Graph

- Build motion graph that connects multiple short motion clips
- Synthesizing motion by traversing the graph



Motion Graph Example

- [video](#)

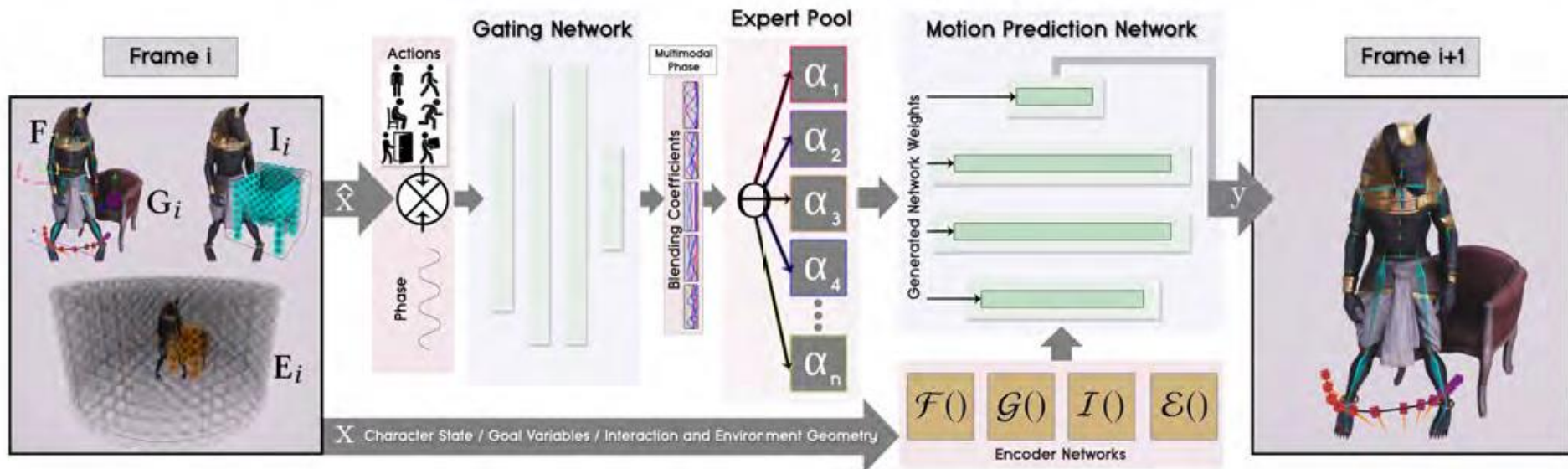


Interactive Avatar Control

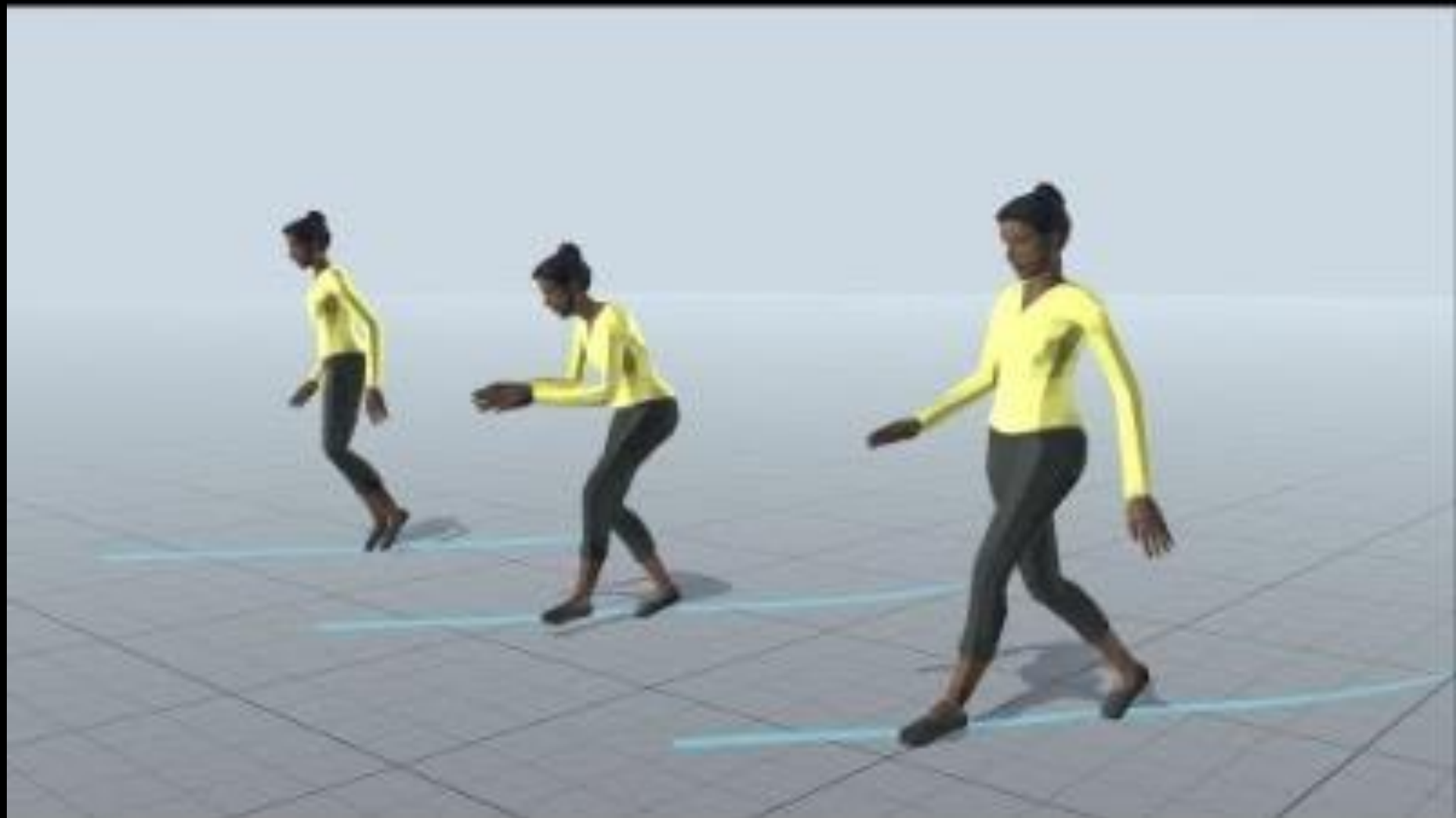
Lee, Chai, Reitsma, Hodgins, Pollard, SIGGRAPH'02

Deep Learning for Motion Control and Synthesis

- “Neural State Machine for Character-Scene Interactions,” SIGGRAPH Asia 2019
- <https://youtu.be/7c6oQP1u2eQ>



MoGlow: Probabilistic and controllable Motion Synthesis, SIGGRAPH Asia 2020



Dynamics and Simulation

Dynamics and Simulation

- Generate motion based on physical laws (e.g., Newton's laws, Fluid dynamics)
- Simulated physical phenomena
 - gravity
 - momentum
 - collision
 - friction
 - fluid flow (liquid, gas, turbulence)
 - flexibility, elasticity, fracture

Dynamics – Particle Systems

Particle Systems [Reeves83]

Represent “fuzzy” objects
(such as fire, smoke) as
a collection of particles

Particles contain local state

- Position
- Velocity
- Age
- Lifespan
- Rendering properties



Dynamics – Simulated Flames



Duc Quang Nguyen, Ronald Fedkiw and Henrik Wann Jensen,
SIGGRAPH 2002

Realflow: Commercial fluid simulation software



Simulated Snow in Animation

Simulated Snow in Animation

[trailer](#)

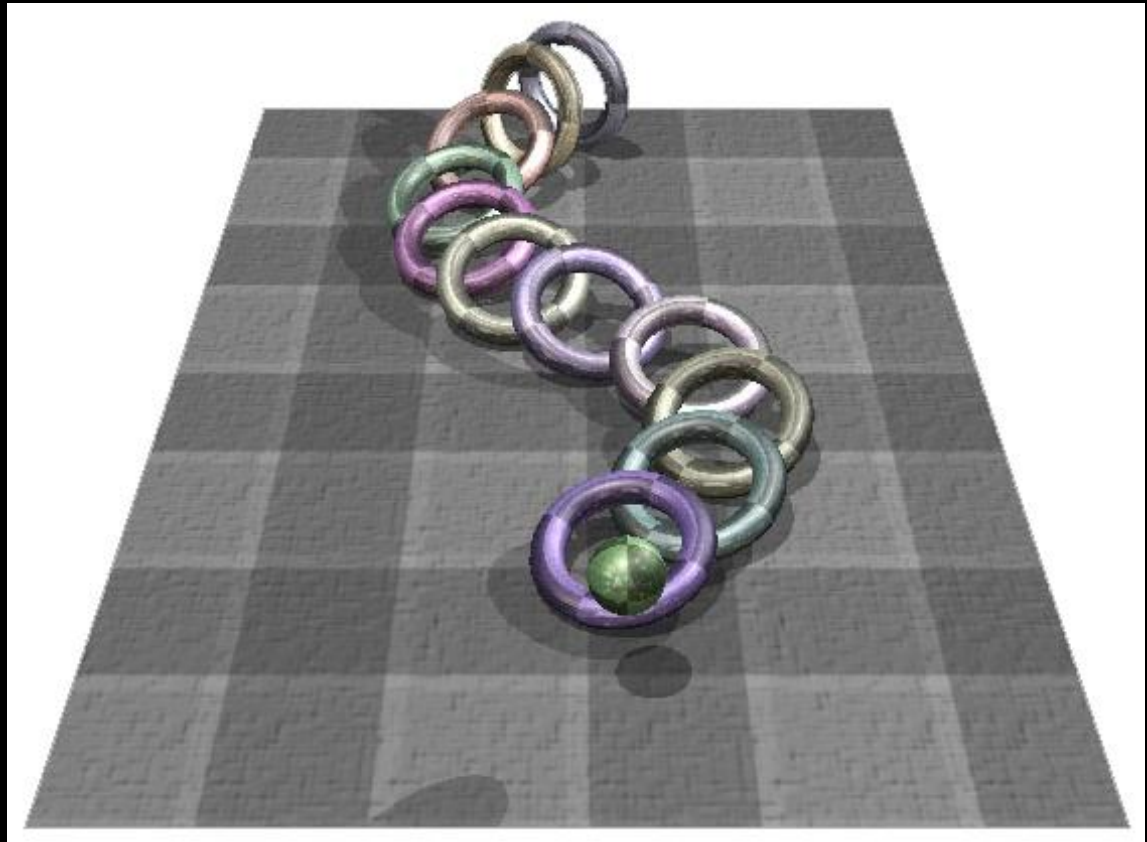
SIGGRAPH

©Disney

Dynamics – Rigid Bodies

Rigid Bodies

- Integration
- Collisions
- Constraints



Dynamics – Deformable Objects

Deformable Objects

- FFD
- Elastics
- Finite Elements

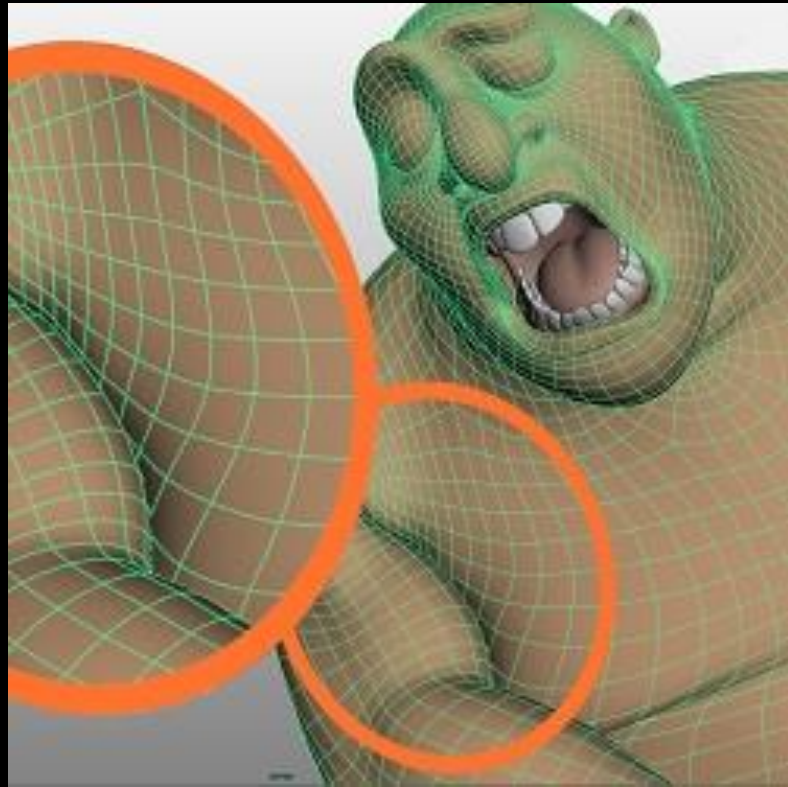


Doug James & Dinesh Pai, SIGGRAPH 2002

Dynamics – Deformable Objects

Skinning

- Skeleton-driven deformation



McAdams, SIGGRAPH 2011

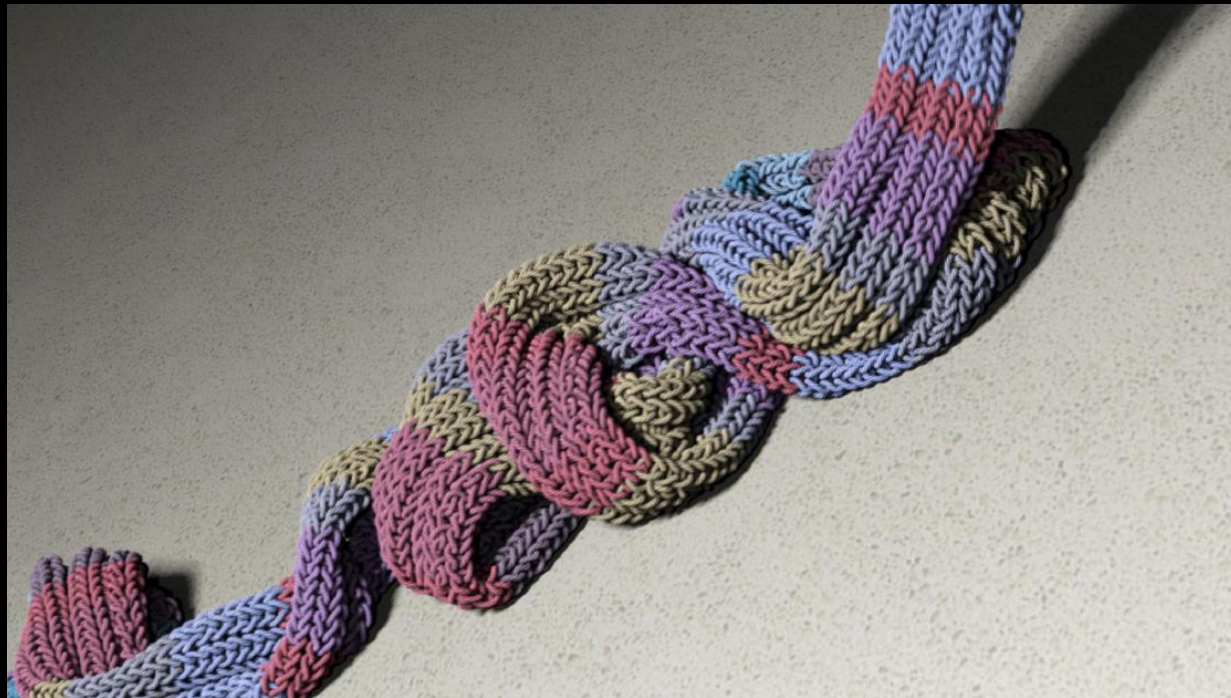
Thin Skin Elastodynamics

- Duo Li, Shinjiro Sueda, Debanga R. Neog, Dinesh K. Pai
- [Siggraph 2013](#)

Dynamics – Cloth

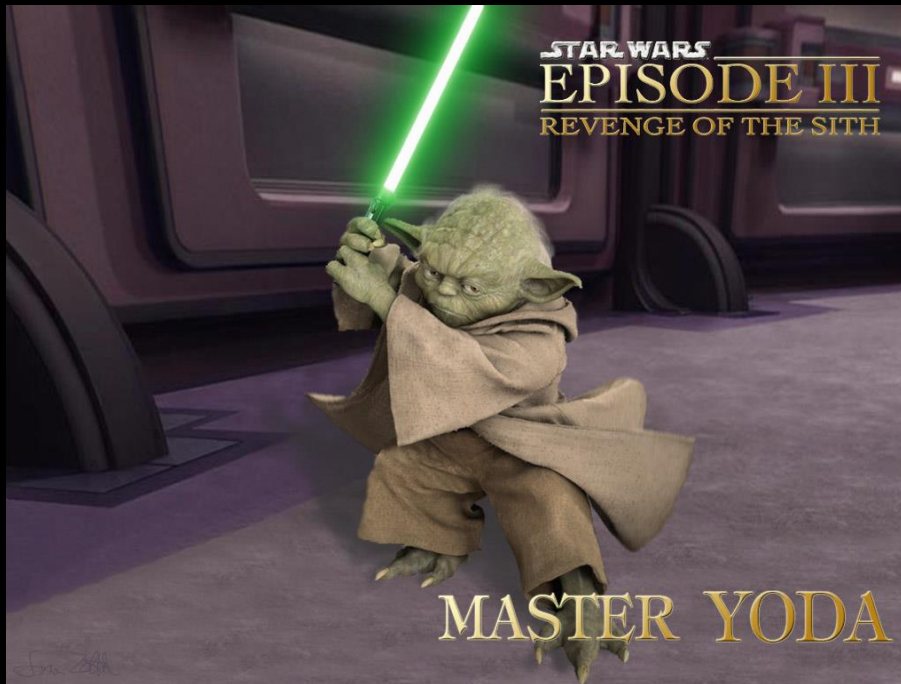
Cloth Simulation

- Stable Integration
- Material Properties

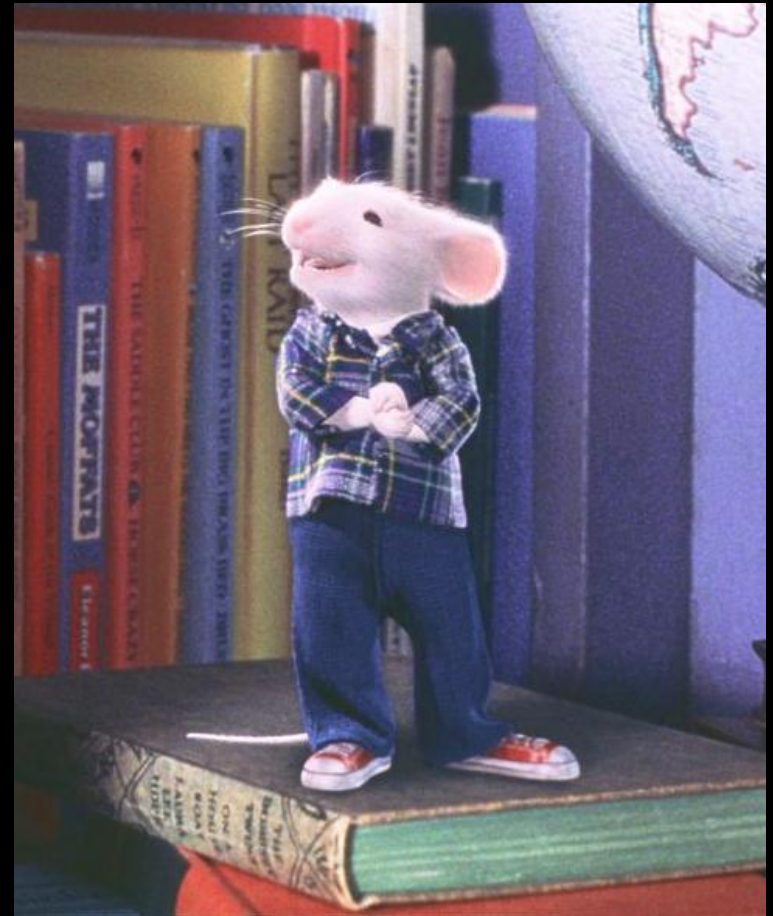


Kaldor, James, and Marschner, SIGGRAPH'08

Simulated Cloth in Films



Star Wars



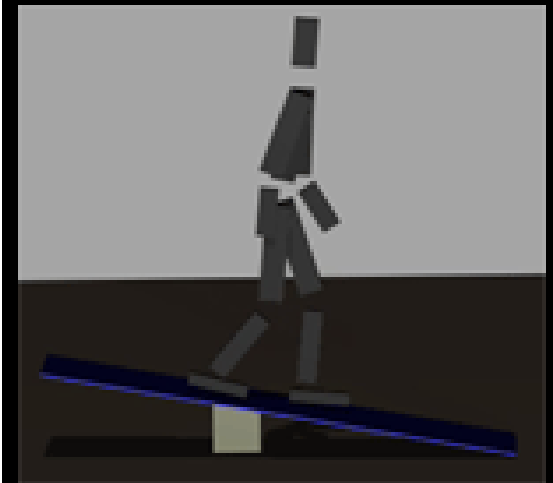
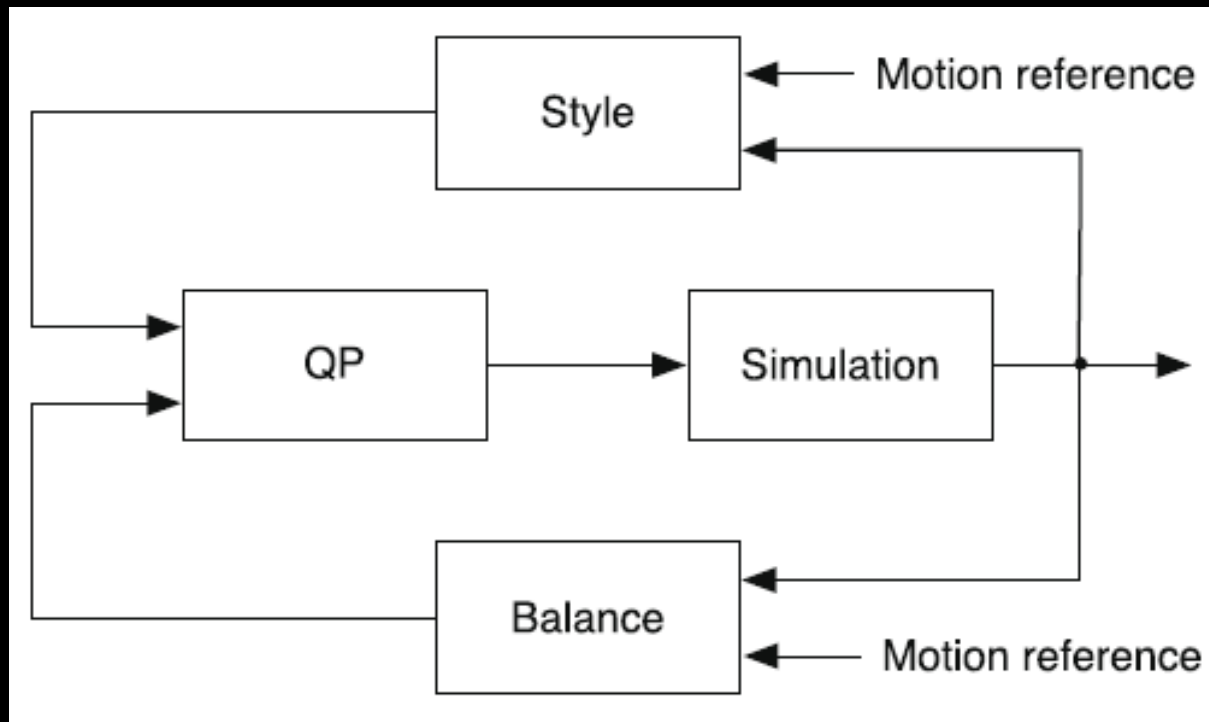
Stuart Little

Cloth Simulation in CoCo



<https://youtu.be/U8U2xyyEhjs>

Dynamics + Control



da Silva, Abe, and Popović, SIGGRAPH 2008

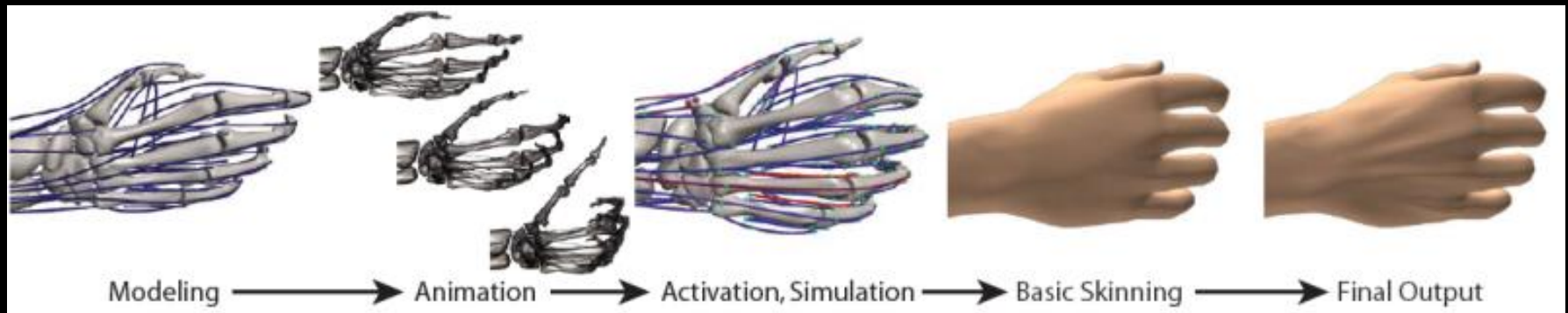
Adversarial Skill Embeddings, SIG 2022

Adversarial Imitation Learning & Unsupervised Reinforcement Learning



Musculotendon Simulation of Hand

- Dynamics simulation + control



Shinjiro Sueda et al., SIGGRAPH 2008

[Movie \(goto 1:15\)](#)

Side-by-Side Reality Check

We compare the simulated tendons of the thumb to several real thumb photographs

Behavioral Animation

- Animating by describing an actor's behavior
- An actor's behavior defines how the actor interacts with other actors and the environment



```
TRex()  
if(player is close)  
    eatPlayer()  
else if(can see player)  
    chasePlayer()  
else  
    wander()
```


PSCrowd Demo: real-time crowd engine for PS3

- Real-time crowd behavior engine for PS3



Behavioral Animation (cont.)

- Useful for crowd animations



The Lion King, Stampede Scene (1994)



The Lion King, Stampede Scene (2019)



The Making of Lion King 2019

- <https://www.youtube.com/watch?v=94e9Y45EIsW>



Summary

- Keyframing: interpolating between keyframes
- Skeletal animation: human and animals
 - Kinematics: representing and posing a character
 - Motion capture
 - Motion editing
 - Motion synthesis
- Dynamics and simulation:
 - passive objects
 - active objects with force/torque control
- Behavior animation: group and crowd