Fundamentals of Computer Graphics and Image Processing

Animations, Dynamics (08)

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Outline

- Principles of animation
- Keyframe animation
- Articulated figures
- Kinematics
- Dynamics

How the lectures should look like #1

- Ask questions, please!!!
- Be communicative
- More active you are, the better for you!

Manual animation

- Stop-motion animation
- e.g. Coraline, Wallace & Gromit, etc.

Computer Animation

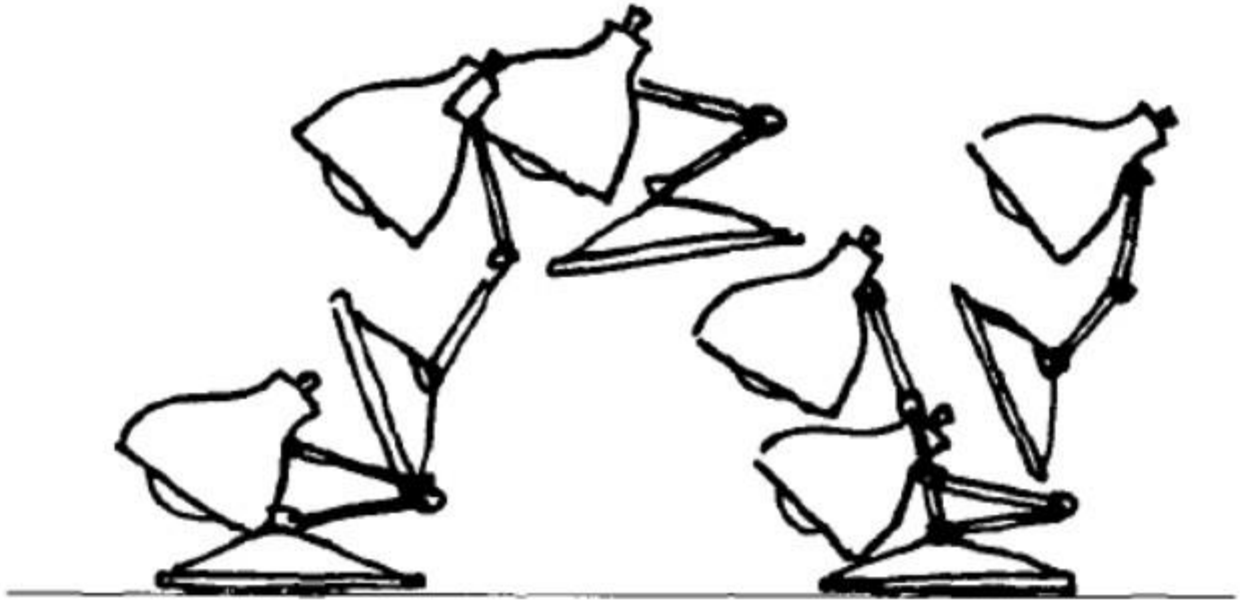
- What is animation?
  - Make objects change over time according to scripted actions
- What is simulation?
  - Predict how object change over time according to physical laws

Computer Animation

- Animation pipeline
  - 3D Modeling
  - Articulation
  - Motion specification
  - Motion simulation
  - Shading
  - Lighting
  - Rendering
  - Postprocessing

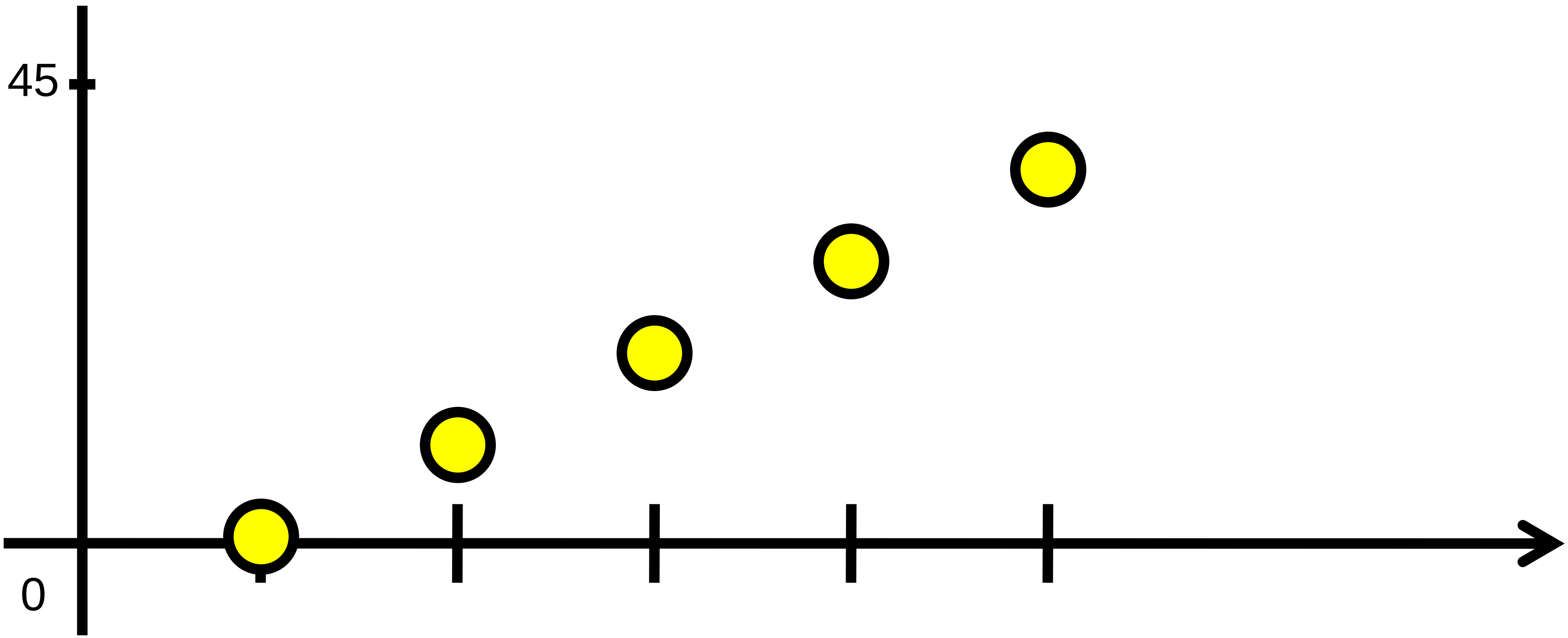
Keyframe Animation

- Define character poses at specific time steps called "keyframes"



Inbetweening ("tweening")

- Computing missing values based on existing surrounding values



Inbetweening ("tweening")

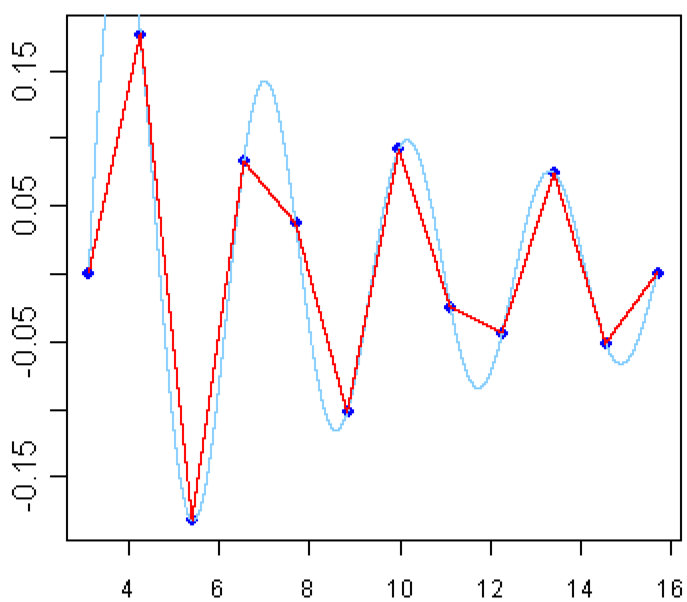
- Linear (constant)

- Ease-in, ease-out

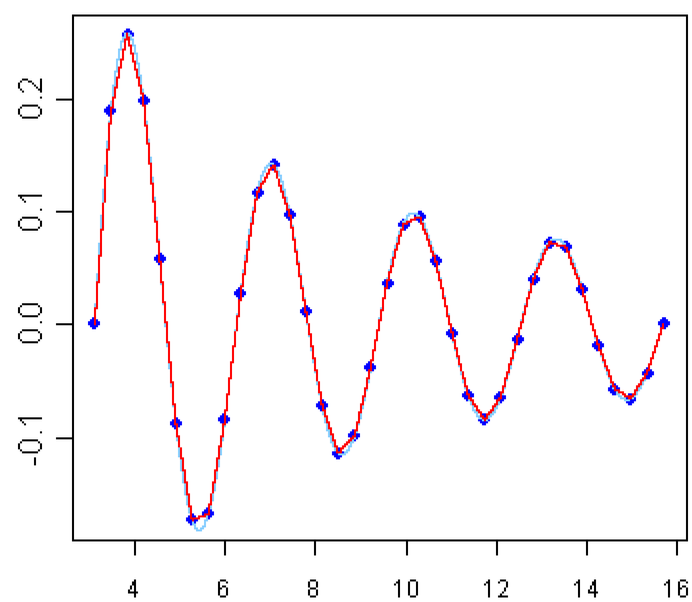
Keyframe Animation

- Inbetweening:
  - Linear interpolation – usually not enough continuity

12 Points



36 Points



Spline Continuity

- How to ensure curves are "smooth"
- Generally, we have three levels of continuity
- C0 - The curves meet
- C0 & C1 - The tangents are shared
- C0 & C1 & C2 - The "speed" is the same

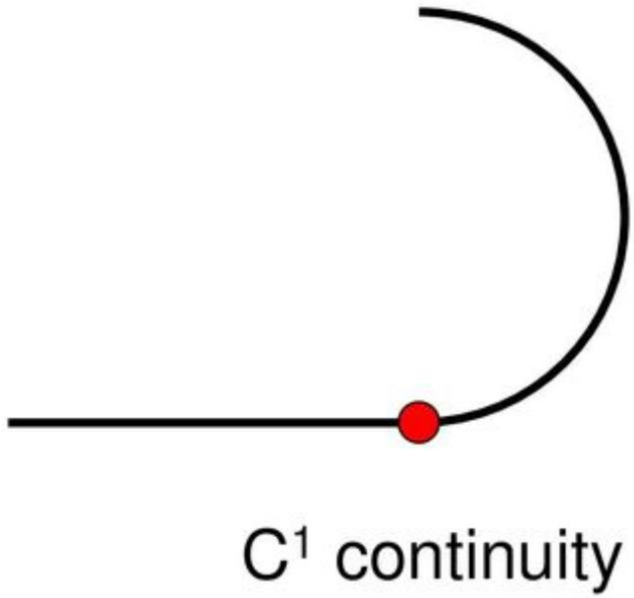
C0 Continuity

- Zero order parametric continuity

C^0 continuity

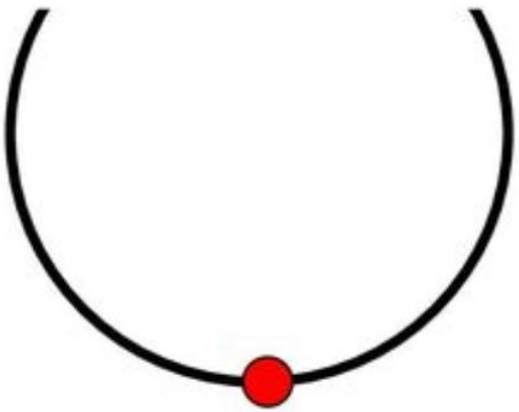
C0 & C1 Continuity

- First order parametric continuity



C0 & C1 & C2 Continuity

- Second order parametric continuity

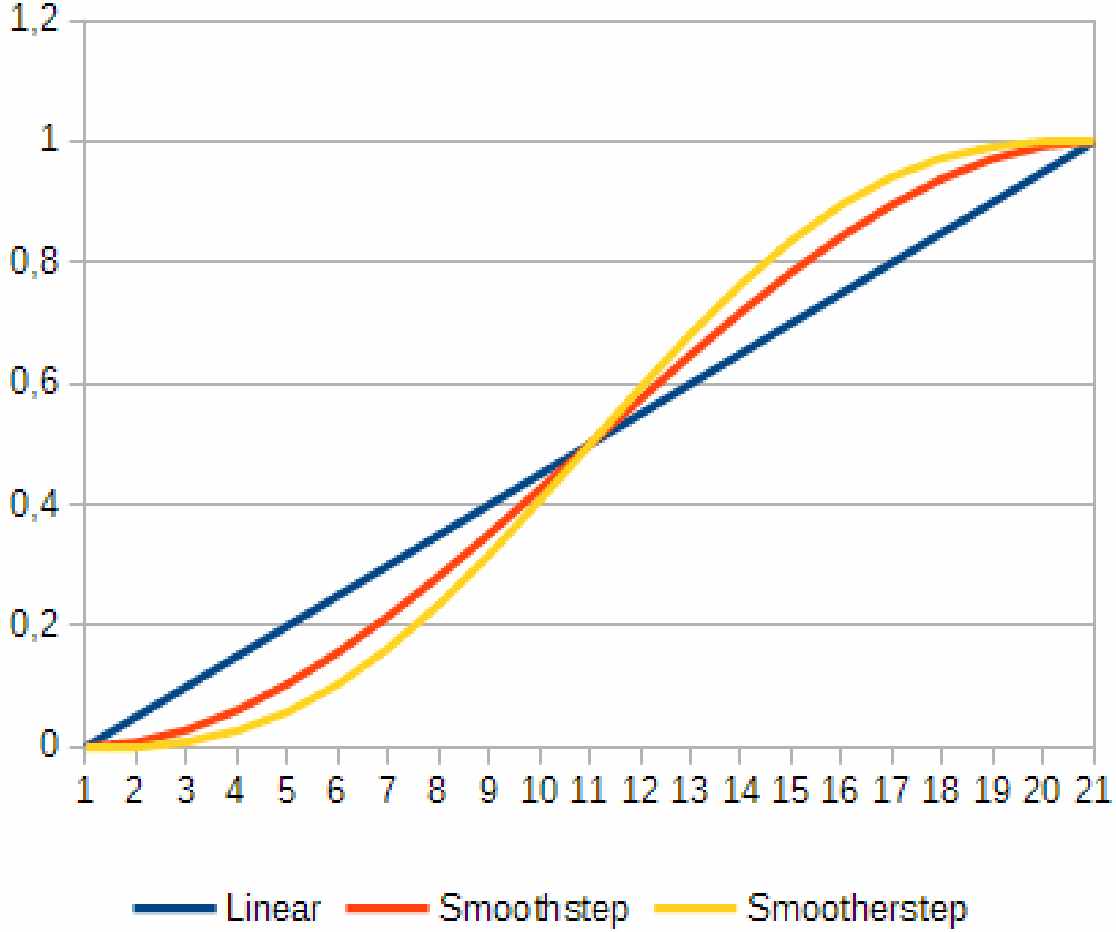


C^2 continuity

Implications for animation

- Linear interpolation is only C0
  - Movement changes instantly at keyframes
  - Very unnatural looking
- We need at least C0 & C1 continuity
  - Hermite interpolation
  - Spline interpolation
  - “Smoothstep” function

Smoothstep



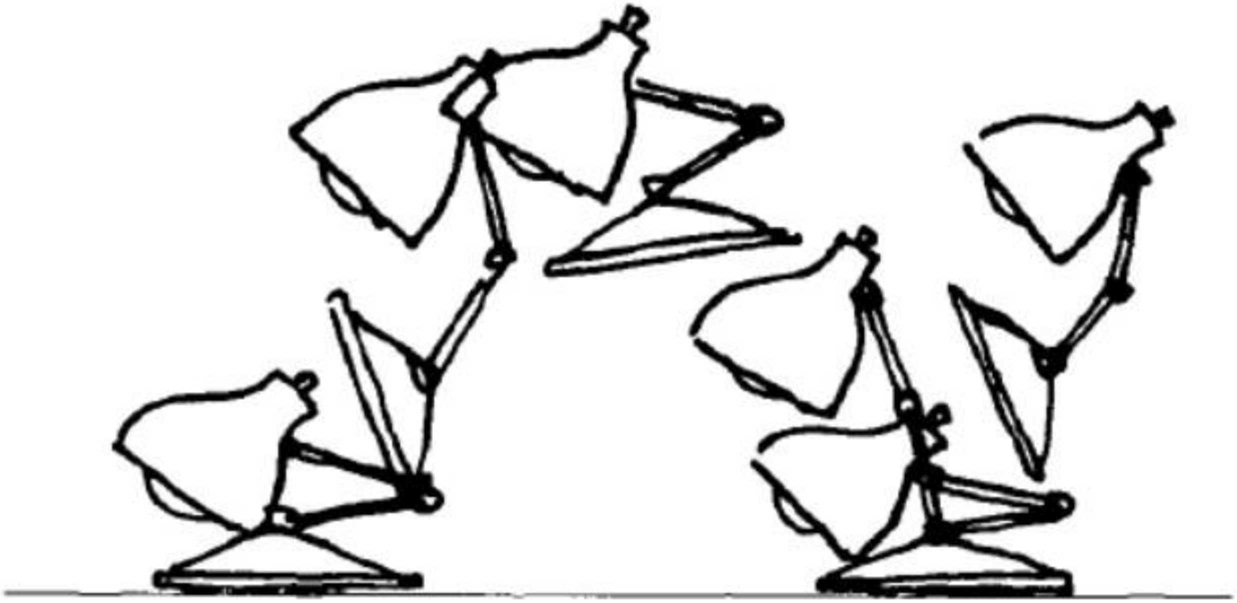
1,2
1
0,8
0,6
0,4
0,2
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Linear
Smoothstep
Smootherstep

Smoothstep

```
float smootherstep(float edge0, float edge1, float x)
{
  // Scale, and clamp x to 0..1 range
  x = clamp((x - edge0)/(edge1 - edge0), 0.0, 1.0);
  // Evaluate polynomial
  return x*x*x*(x*(x*6 - 15) + 10);
}
```

Keyframe Animation

- Inbetweening:
  - Spline interpolation – may be visually good enough
  - May not follow physical laws

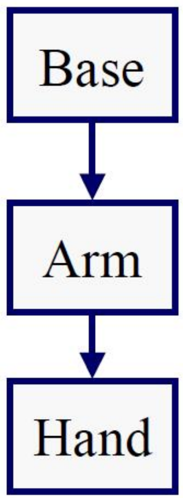


Keyframe Animation

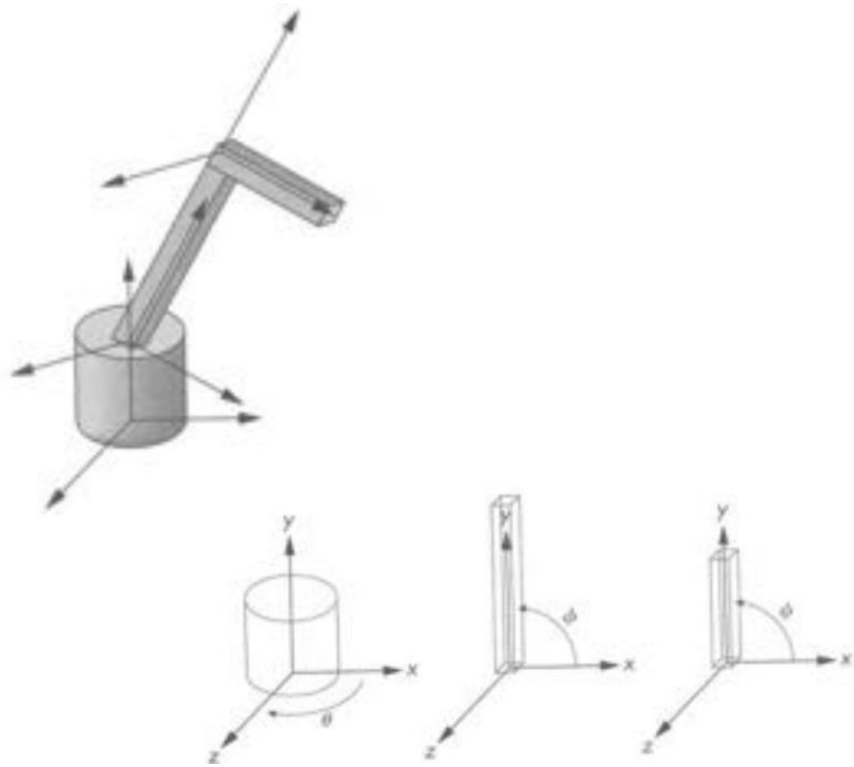
- Inbetweening:
  - Inverse kinematics or dynamics

Articulated Figures

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

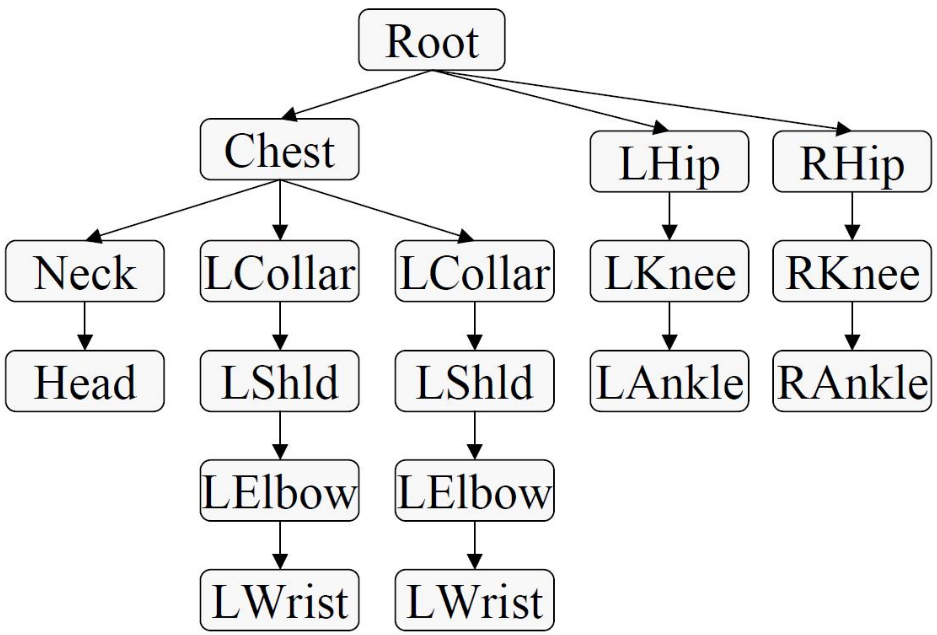


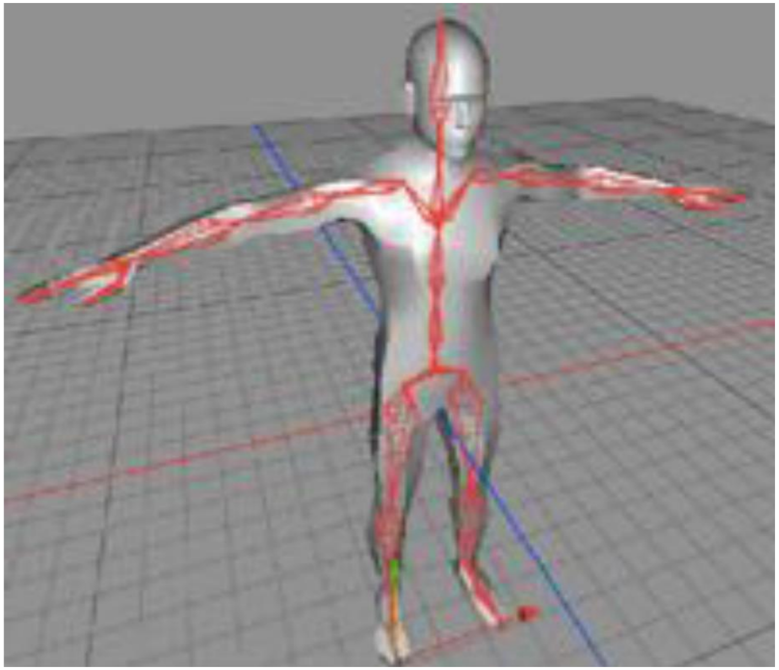
Scene Graph



Articulated Figures

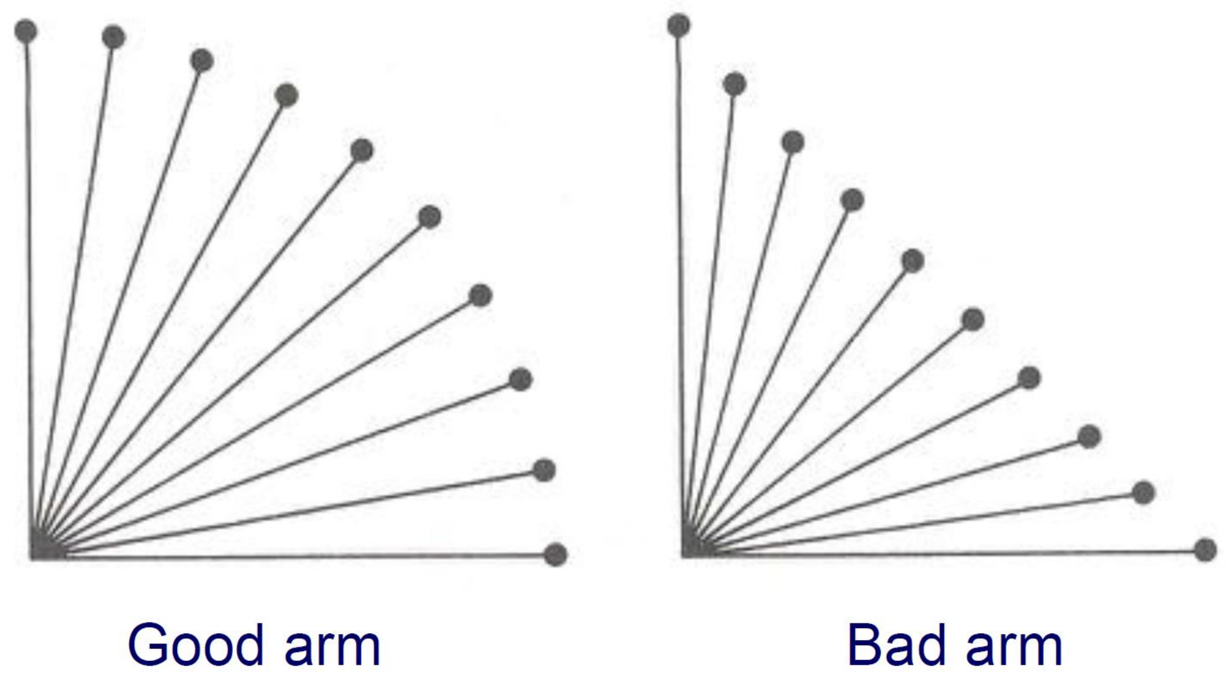
- Well suited for humanoid characters





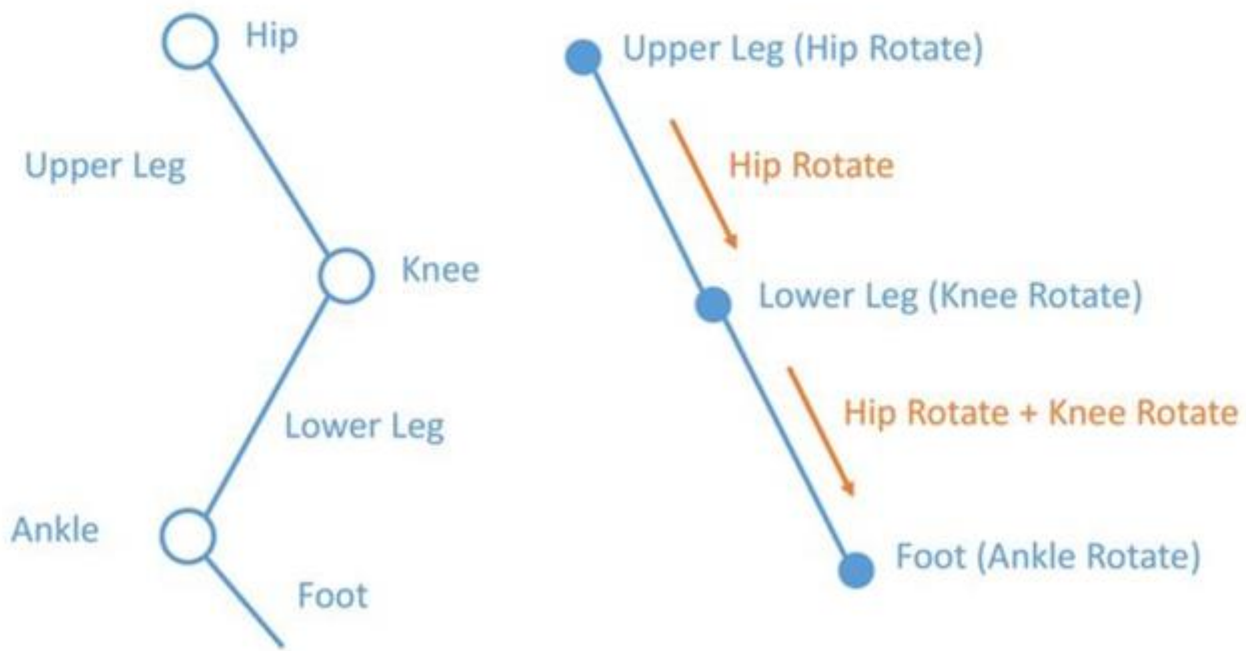
Keyframe Animation

- Inbetweening:
  - Compute angles between keyframes



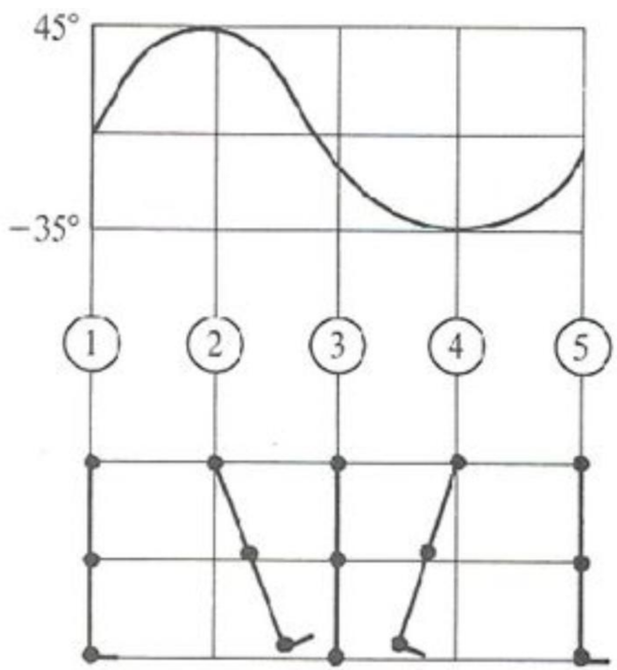
Example: Walk Cycle

- Inbetweening:
  - Compute angles between keyframes



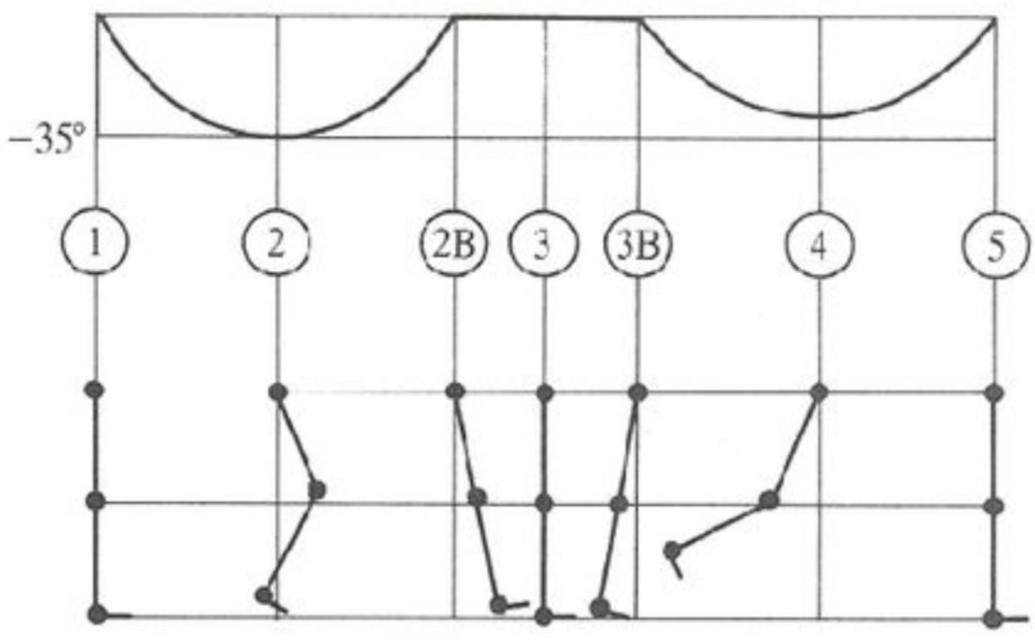
Example: Walk Cycle

- Hip joint orientation



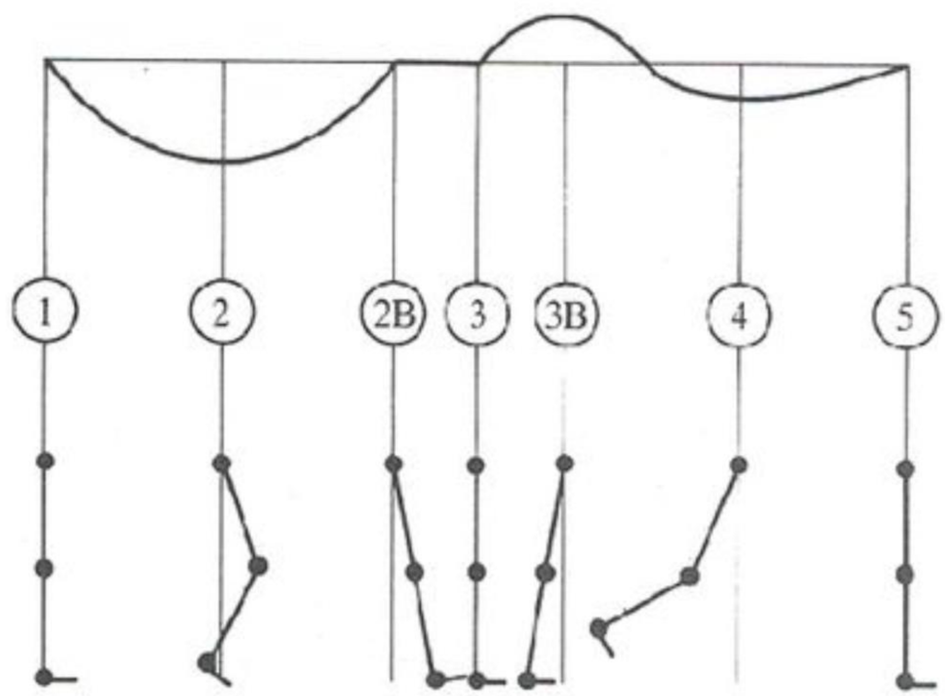
Example: Walk Cycle

- Knee joint orientation



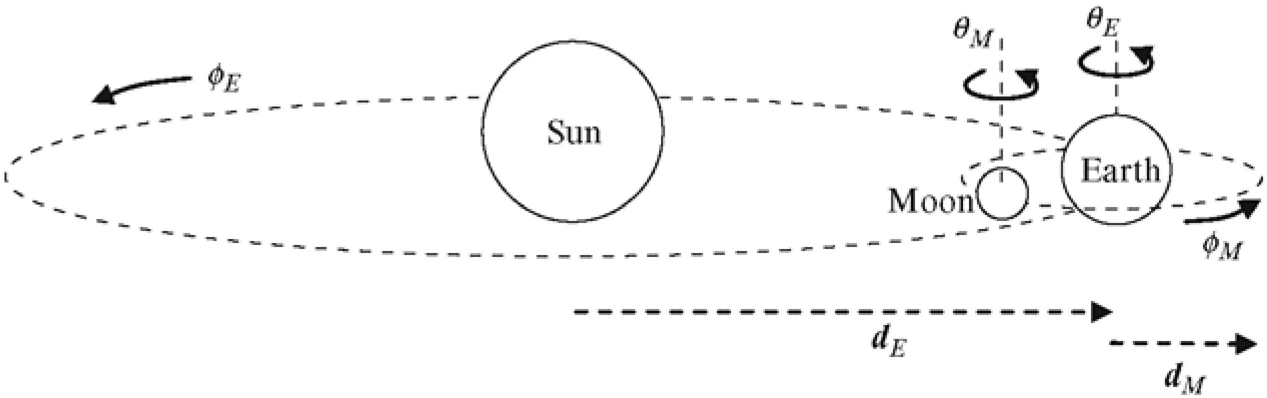
Example: Walk Cycle

- Ankle joint orientation



Animation Hierarchies

- Animate objects in relation to their parent
  - Sun matrix is Ms
  - Earth matrix is MsMe
  - Moon matrix is MsMeMm

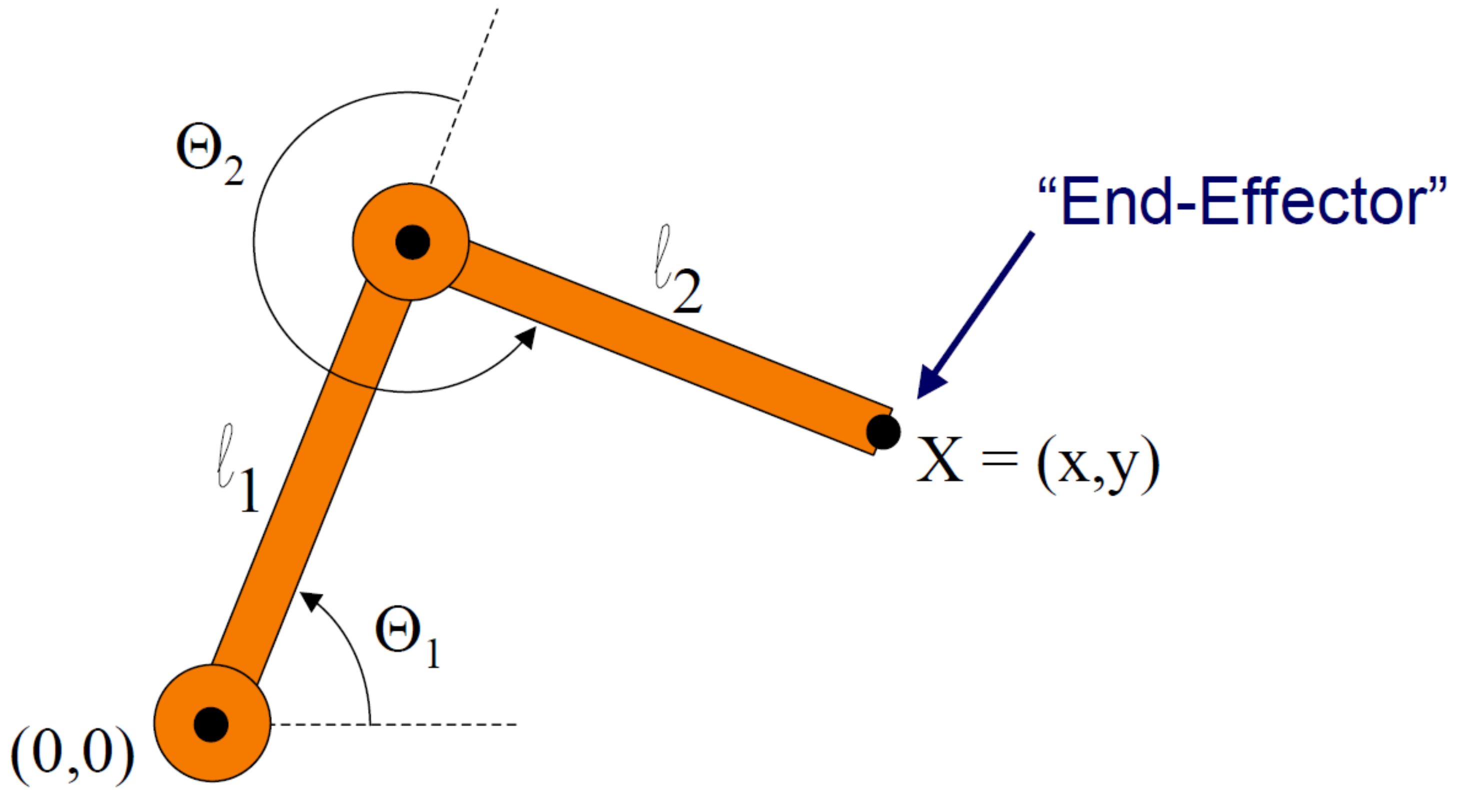


Kinematics and Dynamics

- Kinematics
  - Considers only motion
  - Determined by positions, velocities, accelerations
- Dynamics
  - Considers underlaying forces
  - Capture motion from initial positions and physics

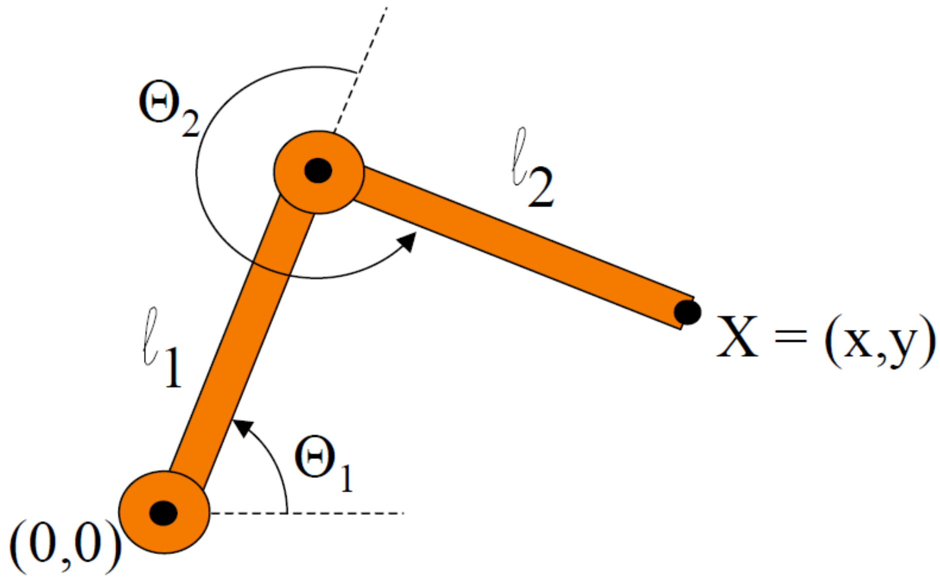
Example: 2-Link Structure

- Two links connected by rotational joints



Forward Kinematics

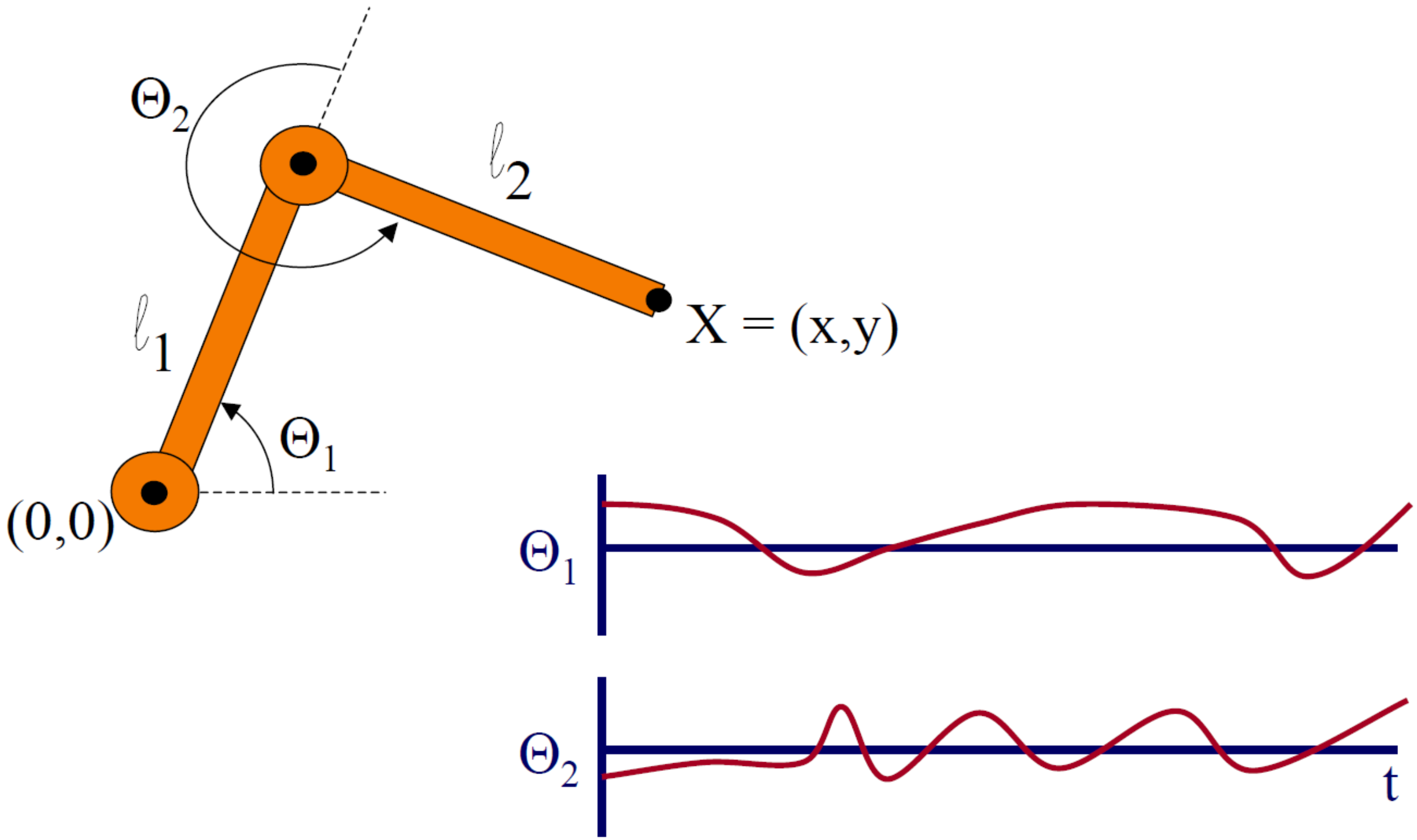
- Animators specifies angles Θ1 and Θ2
- Computer finds position of end effector: X



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

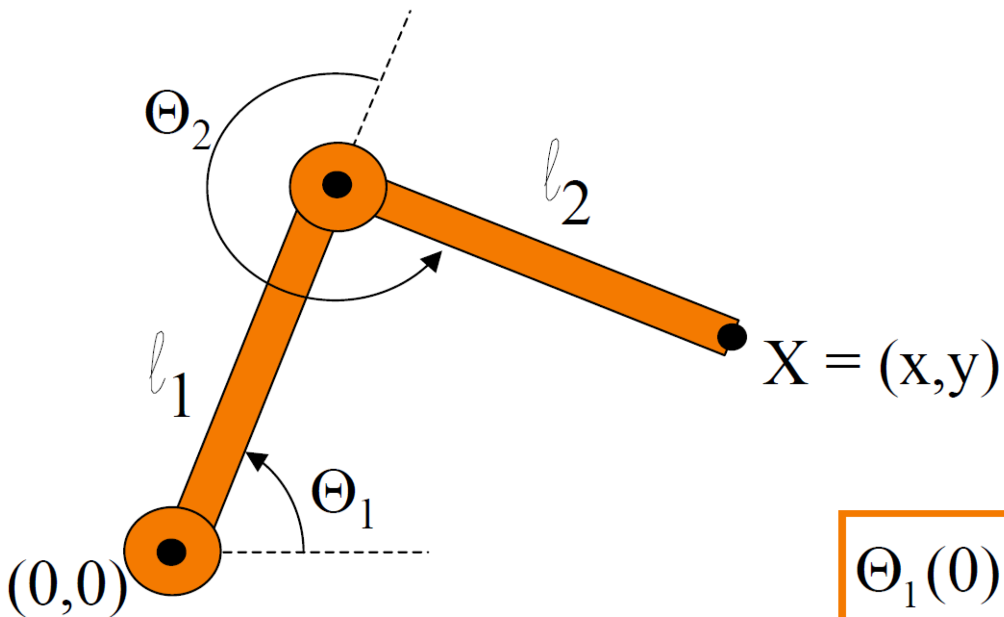
Forward Kinematics

- Joint motion can be specified by spline curves



Forward Kinematics

- Joint motions can be specified by initial conditions

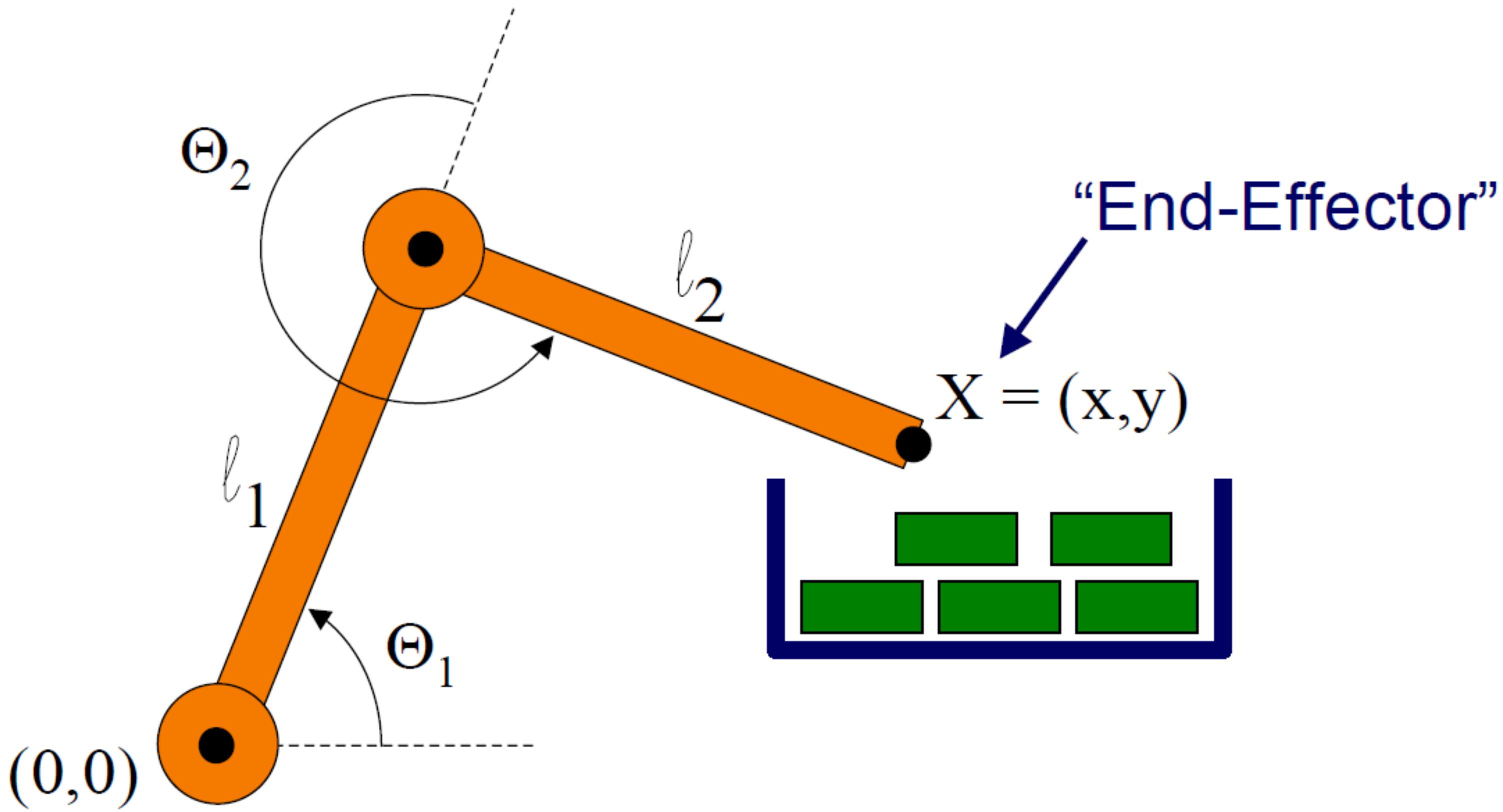


$$\Theta_1(0) = 60^\circ \qquad \Theta_2(0) = 250^\circ$$

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

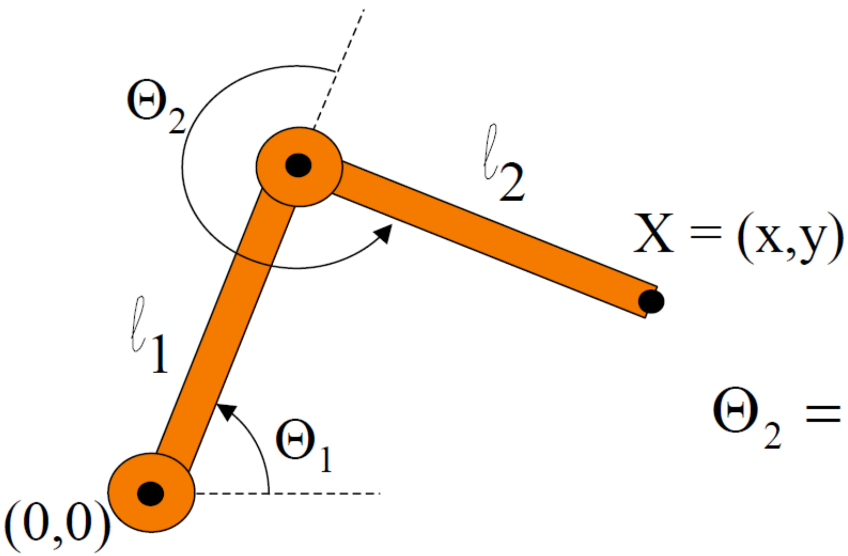
Example: 2-Link Structure

- What if animator knows position of "end effector"



Inverse Kinematics

- Animator specifies end effector positions: X
- Computer finds joint angles Θ1 and Θ2

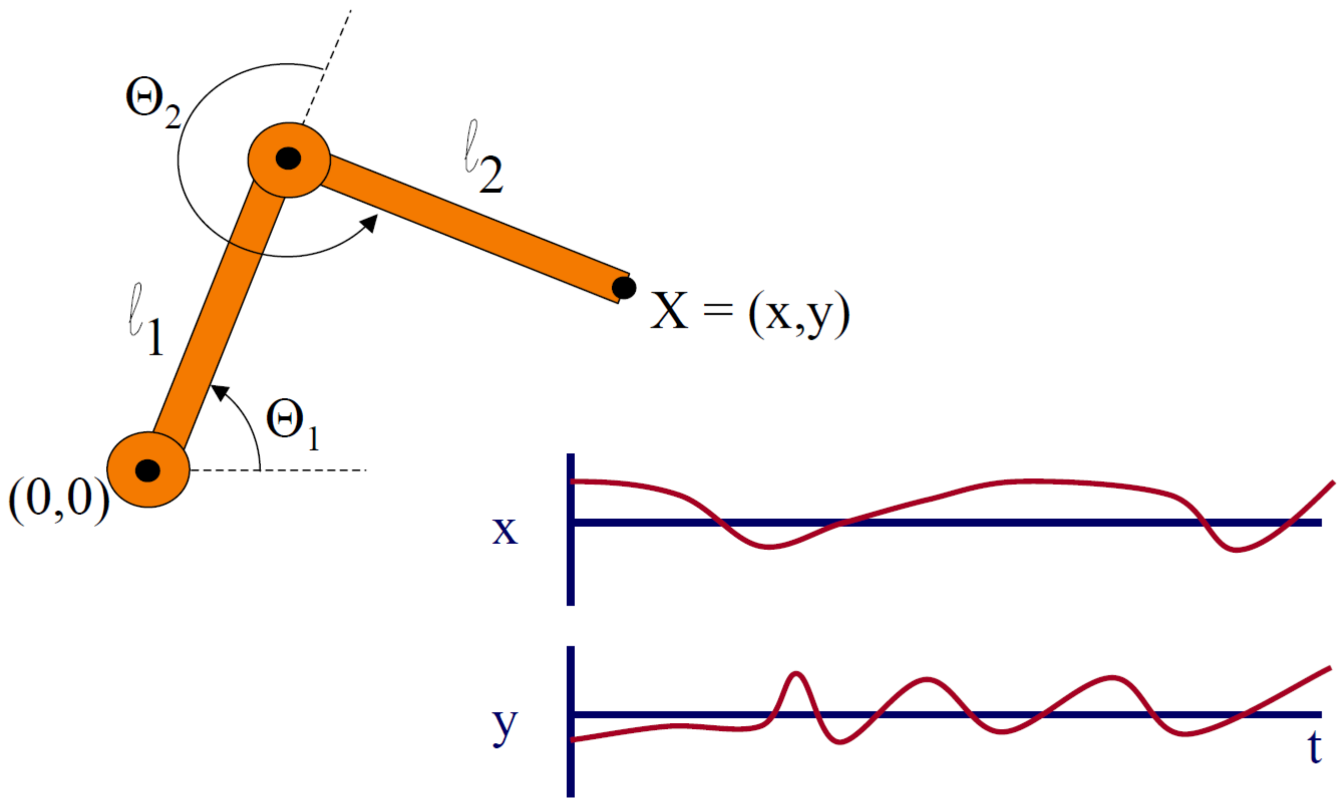


$$\Theta_2 = \cos^{-1}\left(\frac{x^2 + x^2 - l_1{}^2 - l_2{}^2}{2l_1 l_2}\right)$$

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

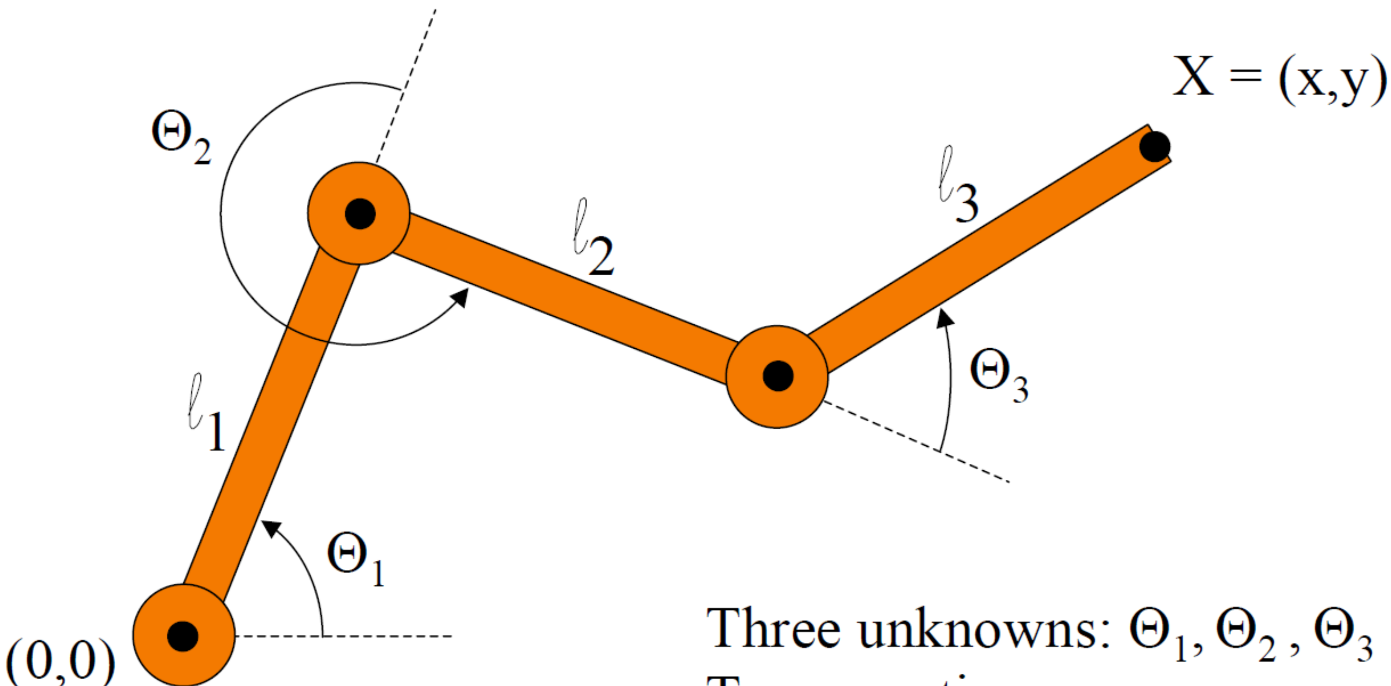
Inverse Kinematics

- End-effector positions can be specified by splines



Inverse Kinematics

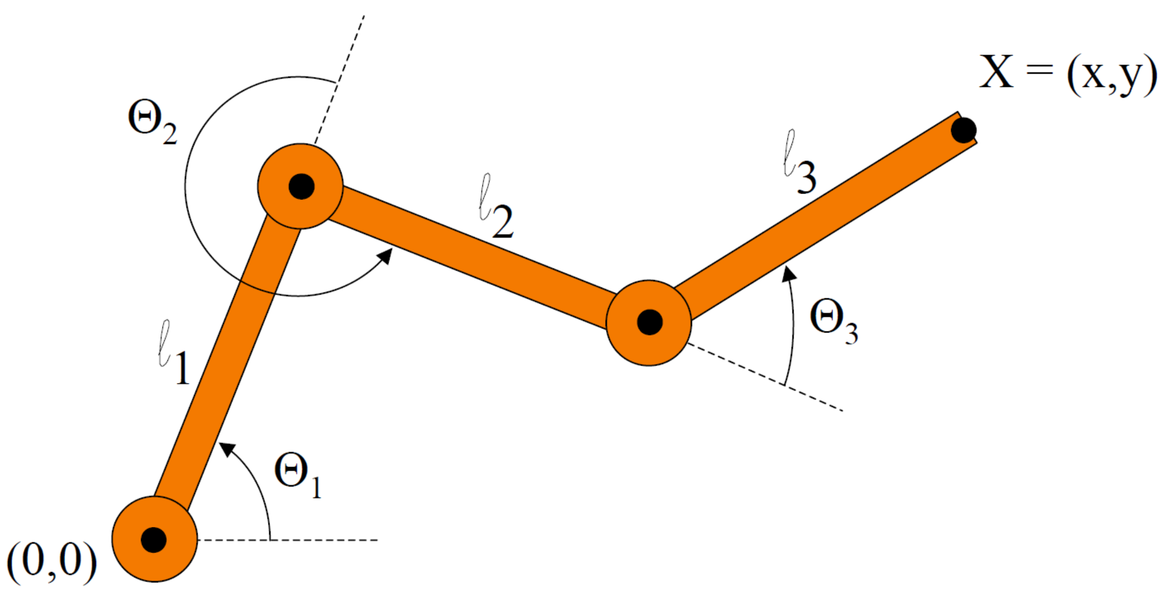
- Problem with more complex structures
  - System with equation is usually under-defined
  - Multiple solutions



Three unknowns: $\Theta_1, \Theta_2, \Theta_3$
Two equations: x, y

Inverse Kinematics

- Solution for more complex structures
  - Find best solution (eg. minimize energy in motion)
  - Non-linear optimization



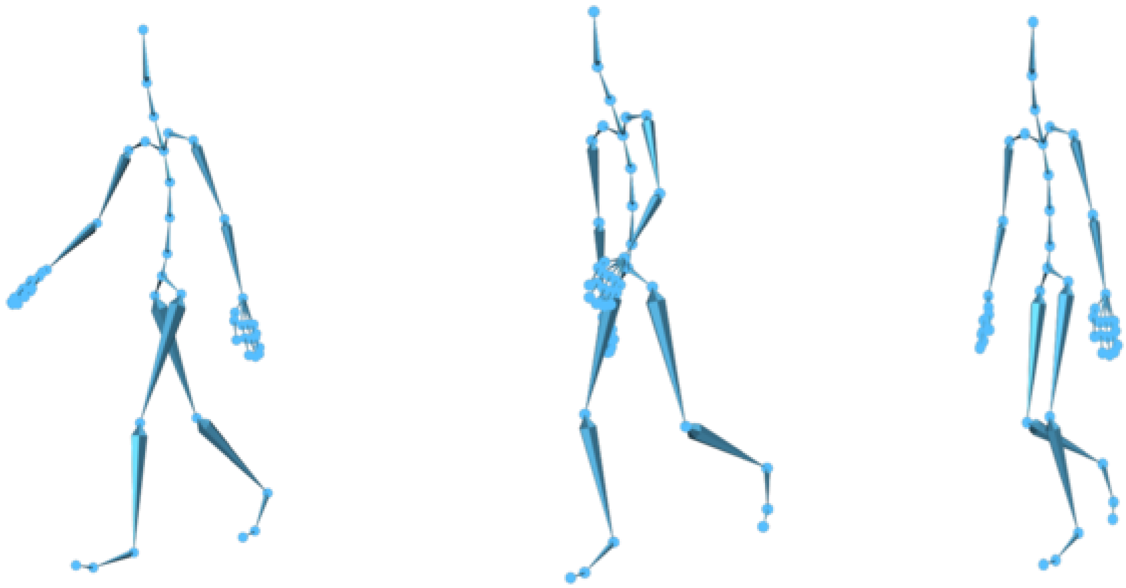
Inverse Kinematics

- Forward Kinematics
  - Specify conditions (joint angles)
  - Compute conditions of end effectors
- Inverse Kinematics
  - “Goal-directed” motion
  - Specify goal positions of end effectors
  - Compute conditions required to achieve goal

Character Animation
(Linear Blend Skinning)
(Skeletal Animation)

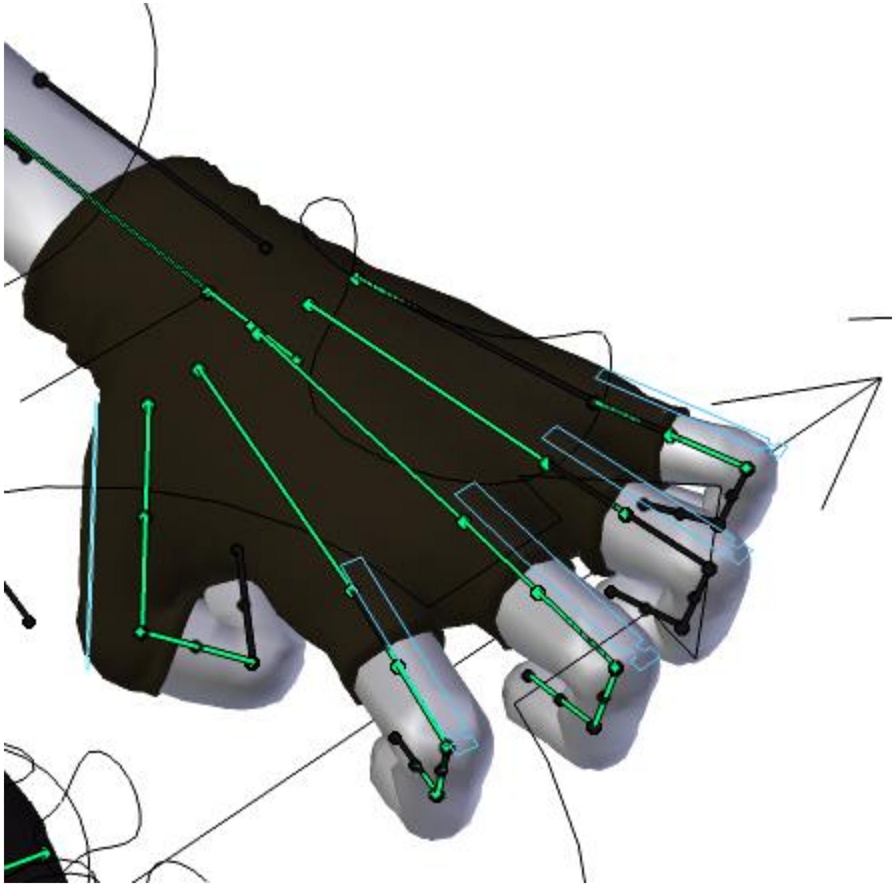
Skeletal Animation

- Hierarchical graph structure called Skeleton
  - Nodes and edges (bones)



Skeletal Animation

- Graph structure can be disconnected in space



Real-time skeletal skinning

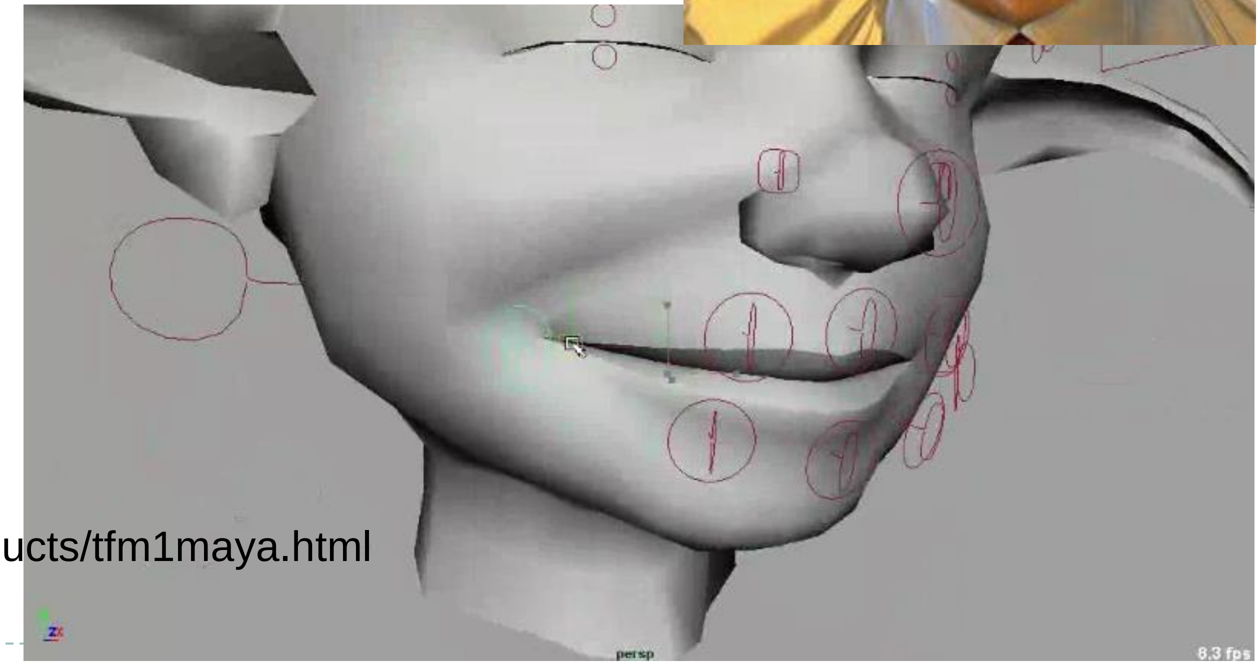
Real-time Skeletal Skinning with Optimized Centers of Rotation

Binh Huy Le
Jessica K. Hodgins

https://www.youtube.com/watch?v=DflfcQiC2oA

Facial animation

- Facial expressions
- Lips to speech synchronization
- Controllers
- Skinning
- Morphing



http://www.anzovin.com/products/tfm1maya.html

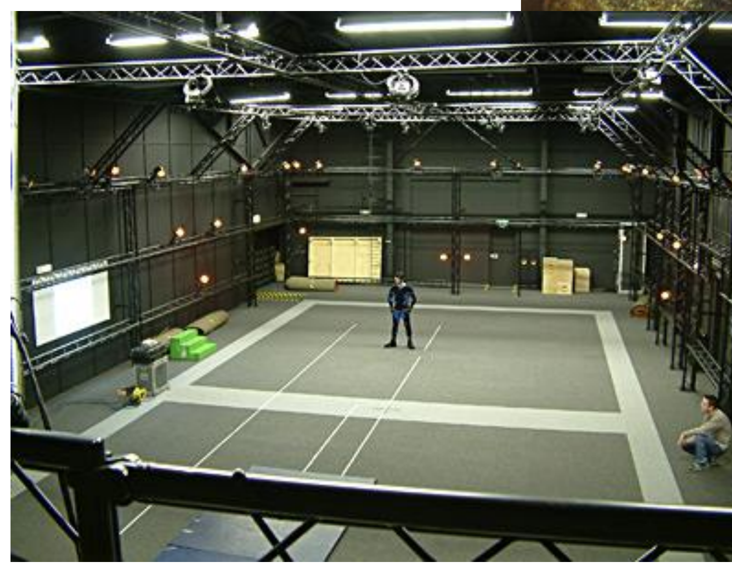
Reusable animation

- One skeleton – different models

http://www.studiopendulum.com/alterego/

Motion capture

- Markers on actor's body
- Optical / magnetic sensors
- 3D reconstruction of markers' position
- Motion mapping
  to virtual character



Outline

- Principles of animation
- Keyframe animation
- Articulated figures
- Animation Hierarchies
- Kinematics
- **Dynamics**

Dynamics

- Dynamics
  - Considers underlaying forces
  - Capture motion from initial positions and physics
  - Simulation of Physics insures realism of motion

Procedural animation

- Programmed rules for changing parameters of the animated objects
- E.g. according to music, physics, psychology

Physically based animation

- Rigid bodies
  - No geometry deformation
  - Collision response

- Soft bodies
  - Allow for deformation
  - Energy damping

Animation construction

- Set body properties
  - Mass, elasticity, friction, …
- Set physical rules
  - Gravity, collisions, wind, …
- Set initial state
  - Position, velocity, direction, …
- Set constraints

- Run simulation / animation

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 in 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: Simulate objects using 2nd Newtons law
- F = ma
- Ordinary differential equation (ODE)
- Numerically solved using Euler's method
- Use discrete time steps

Euler Integration

- Euler Integration

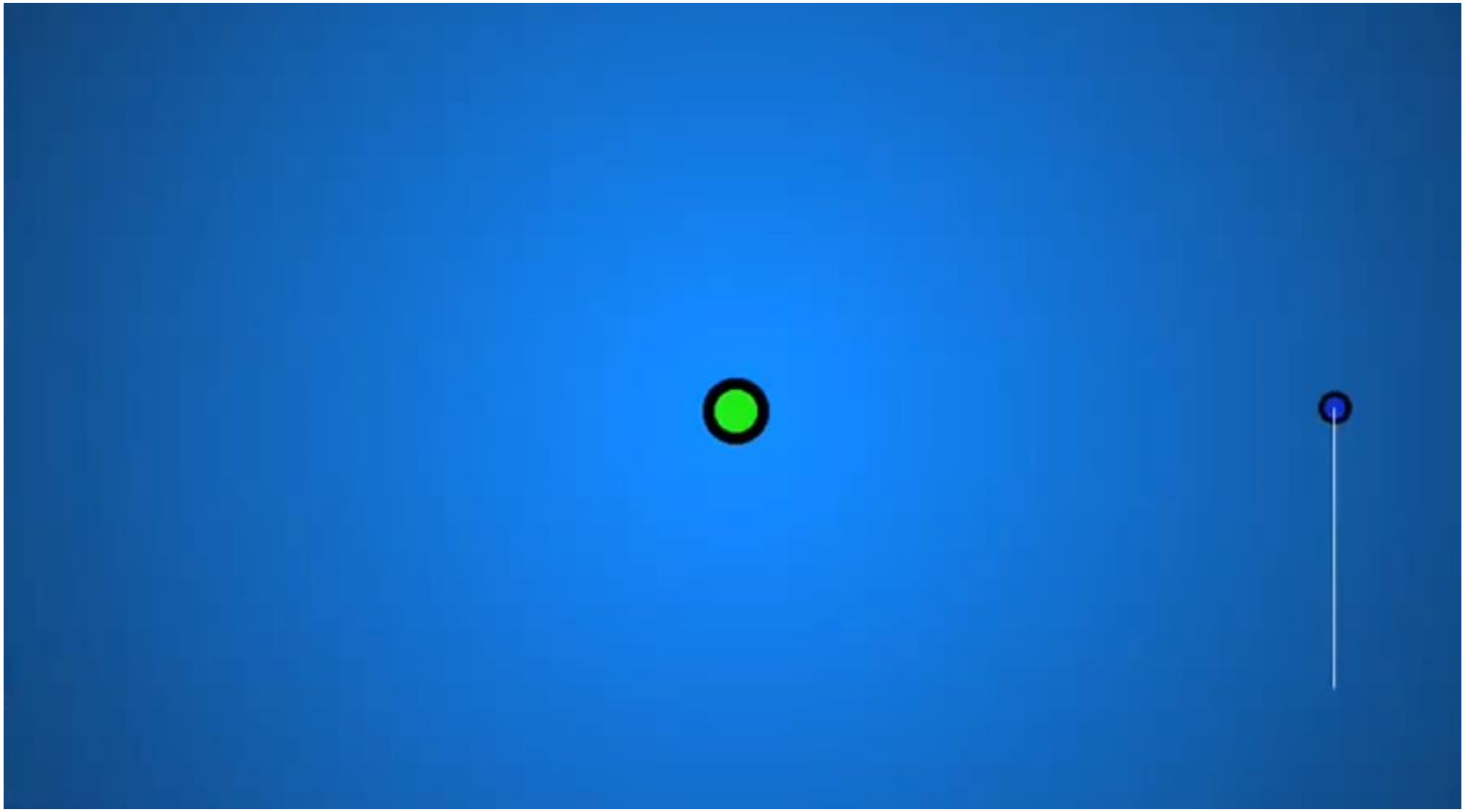
```
Object::Update(float dt){
  /* Constant acceleration: gravity */
  a = vec3(0, 0, -9.81);
  /* New, velocity */
  v = v + a * dt;
  /* New, position */
  p = p + v * dt;
}
```

Euler Integration

- External forces can influence motion

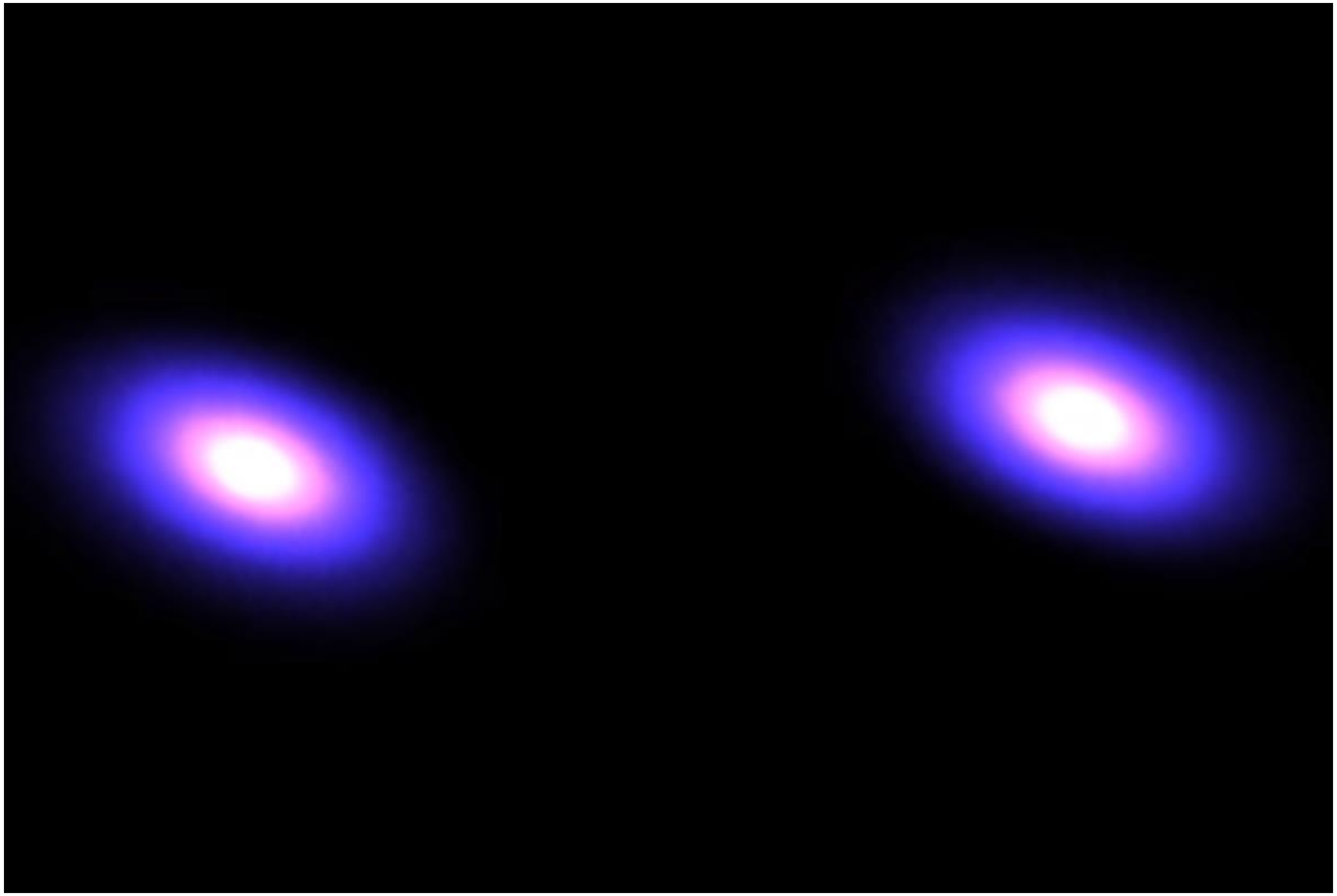
```
Object::Update(float dt)
{
  /* Use mass and external forces */
  float m = this->Mass();
  F = sumExternalForces(this);
  /* Compute acceleration */
  a = F/m;
  /* New, velocity */
  v = v + a * dt;
  /* New, position */
  p = p + v * dt;
}
```

Gravity simulation



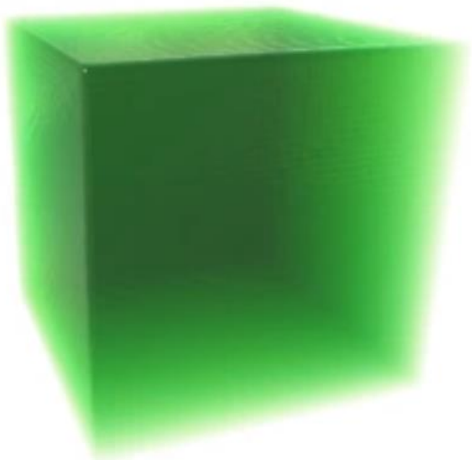
https://www.youtube.com/watch?v=ztwkXq4Hj7Q

N-body simulation



https://www.youtube.com/watch?v=ua7YlN4eL_w

Fluid simulation



https://www.youtube.com/watch?v=r17UOMZJbGs

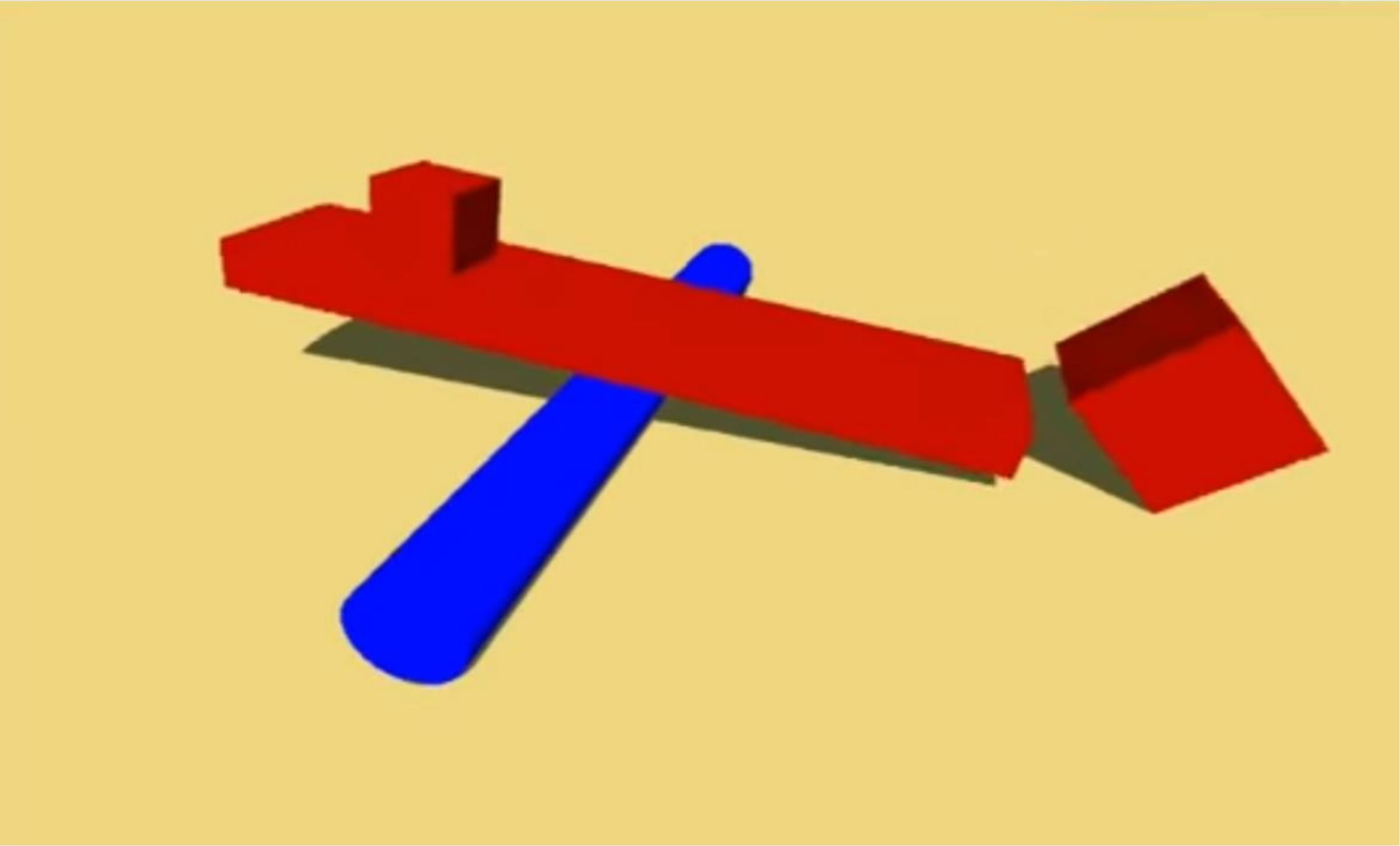
Smoke and Dust

https://www.youtube.com/watch?v=RuZQpWo9Qhs

Rigid-Body Dynamics

- Assume objects are rigid
- Preserve and calculate angular momentum
- Calculate collisions based on geometry
- Define center of mass

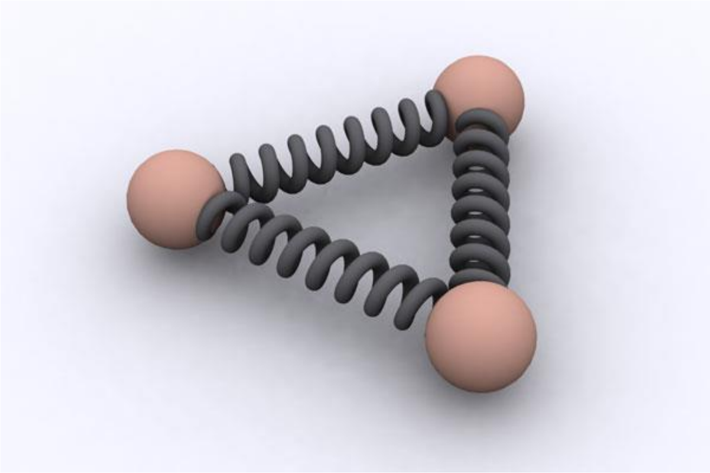
Rigid-Body Dynamics



https://www.youtube.com/watch?v=dvXBstJah5s

Soft-Body Dynamics

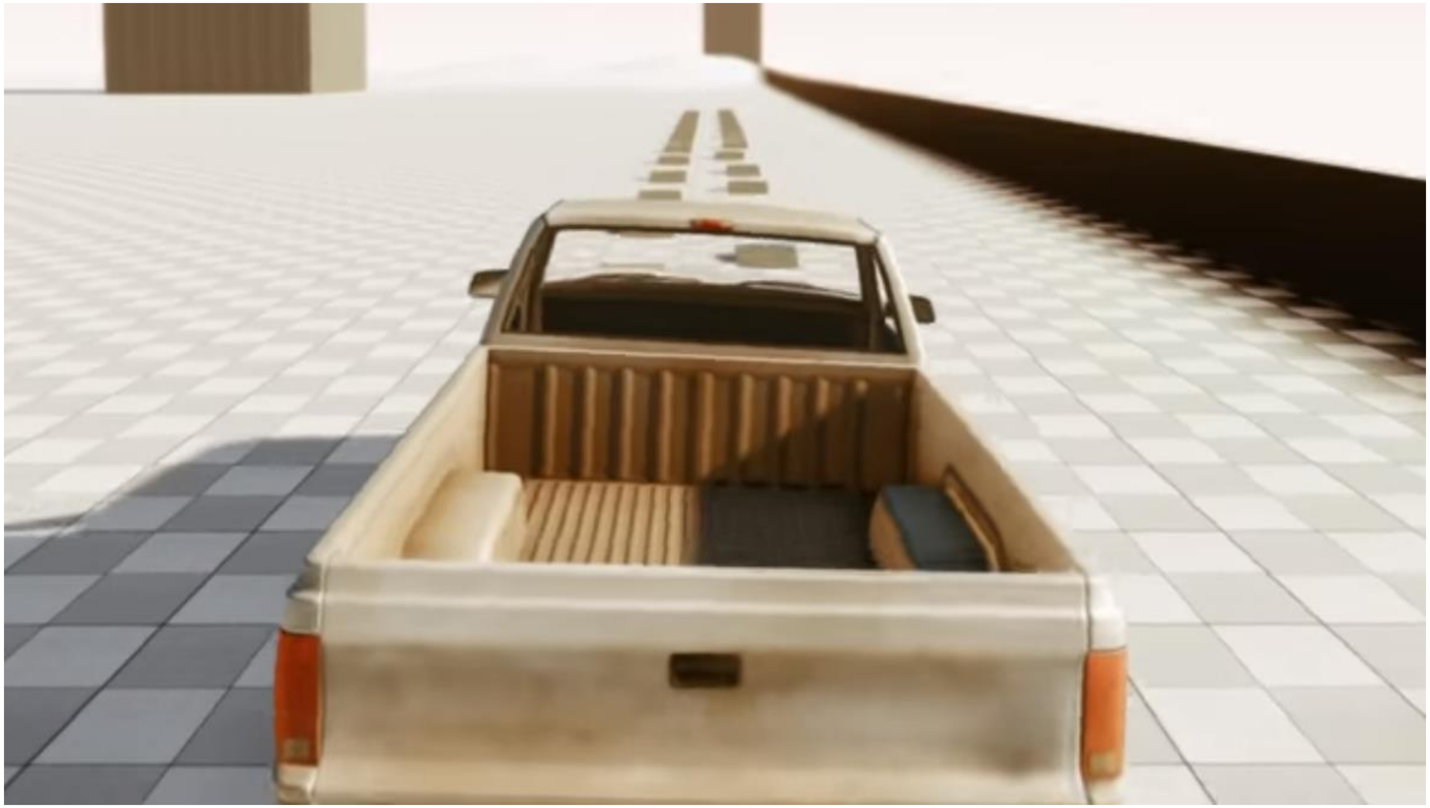
- Model objects using linked particles
- Usually using spring/mass models
- Polygon edges can represent springs
- Vertices are simulated using particles with mass



Cloth simulation

https://www.youtube.com/watch?v=M2XuQSZ-8h4

Soft-Body simulation



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

AI controlled

https://www.youtube.com/watch?v=IQEx56O73b8

Summary

- Advantages
  - Animation is emergent
  - No need to specify animation details
  - Animations can very between runs
- Challenges
  - Accuracy and stability of simulation
  - Specification of constraints

Next Lecture

Raycasting

Acknowledgements

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Output of all the publications and great team work

Very best data from 3D cameras

Questions ?!

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