Animation

CSU44052 Computer Graphics

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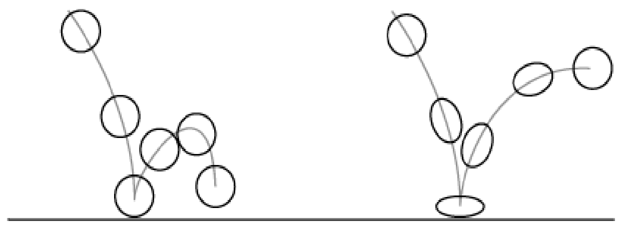
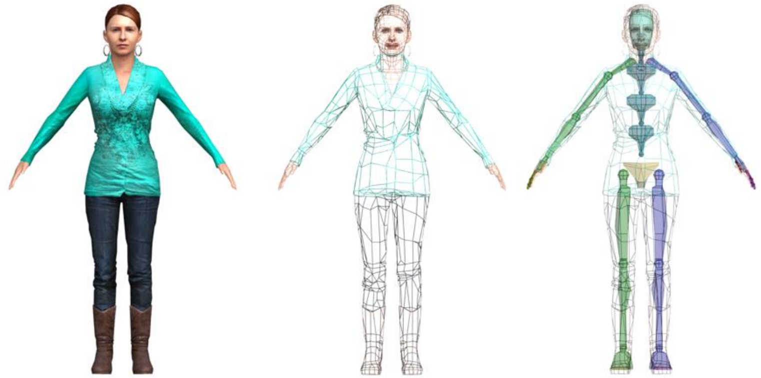
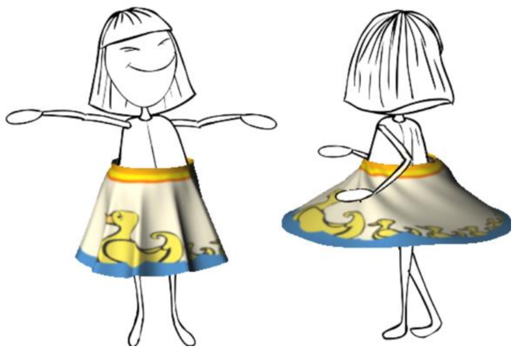
Slides derived from Prof. Jeff Chastine and Prof. Rachel McDonnell

Overview

- Animating Objects
  - Interpolating
  - Splines
- Character Animation
  - Mocap
  - Kinematics
- Physically based animation
  - Cloth, Hair, Fur, Water, etc.





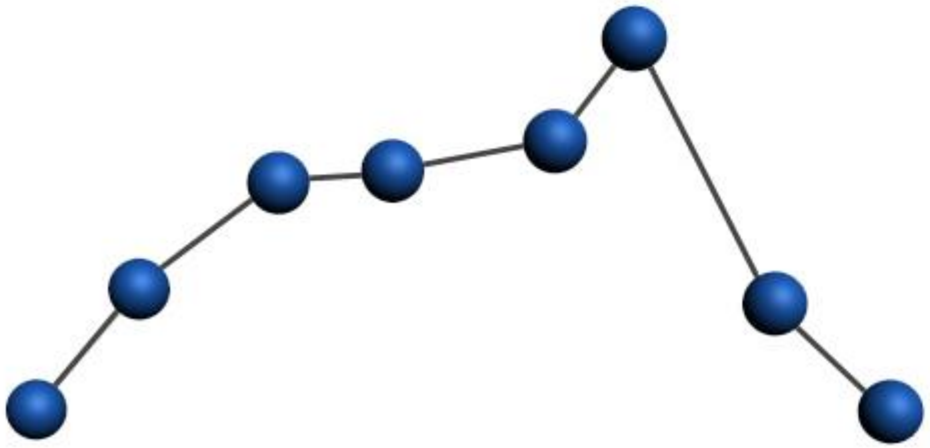


Interpolating Values

- Animator has a list of values associated with a given parameter at key frames
- How best to generate the values of the parameter for frame between keyframes?

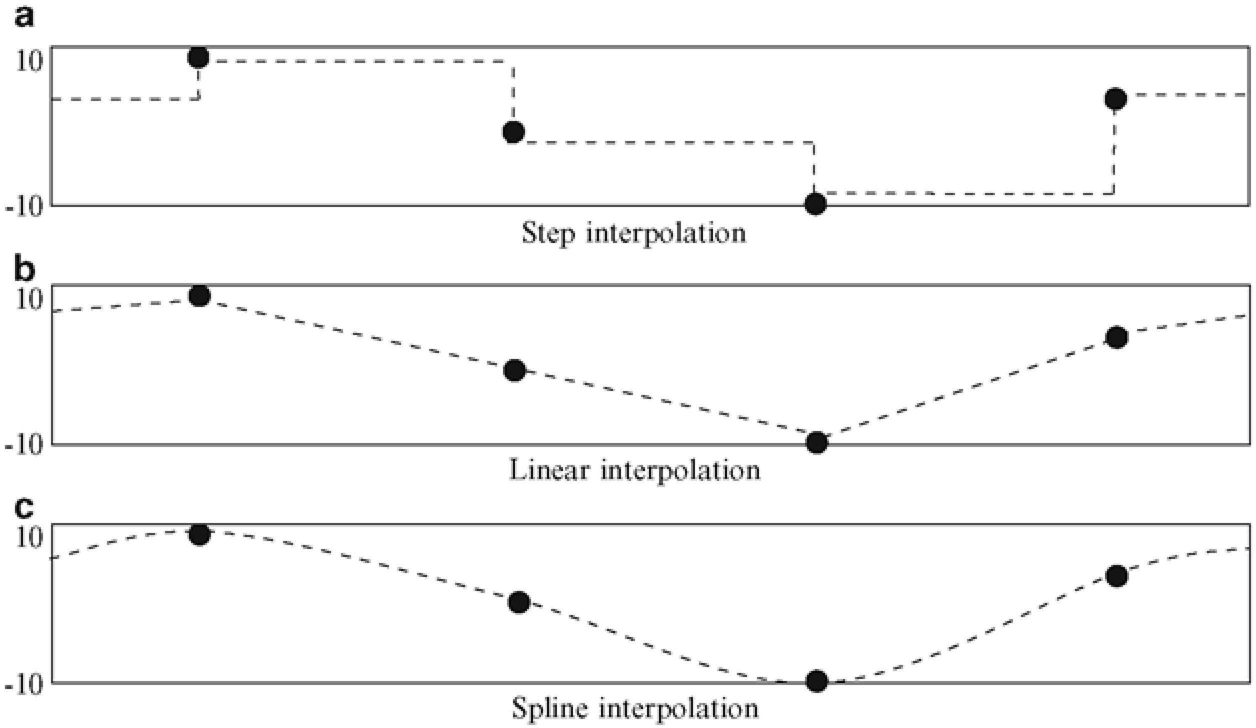
Keyframing in 3D

- Animator specifies the important keyframes
- Computer generates the in-betweens automatically using **interpolation methods**



Uses - Keyframe animation

Keyframe animation

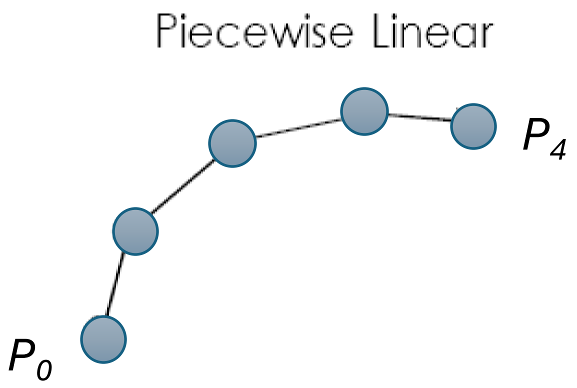


Linear interpolation

- Connect straight lines between data-points
- Given $P_0 \ldots P_N$, define segment:

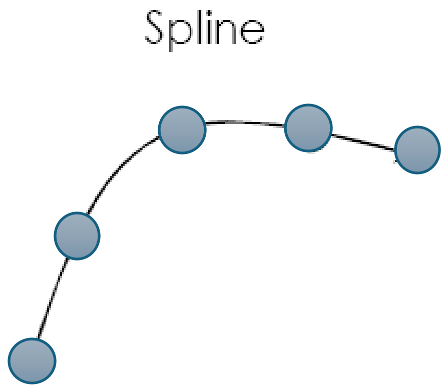
$$L_i(t) = (1 - t)P_i + t\, P_{i+1}$$

for t in [0,1], i in [0, N]



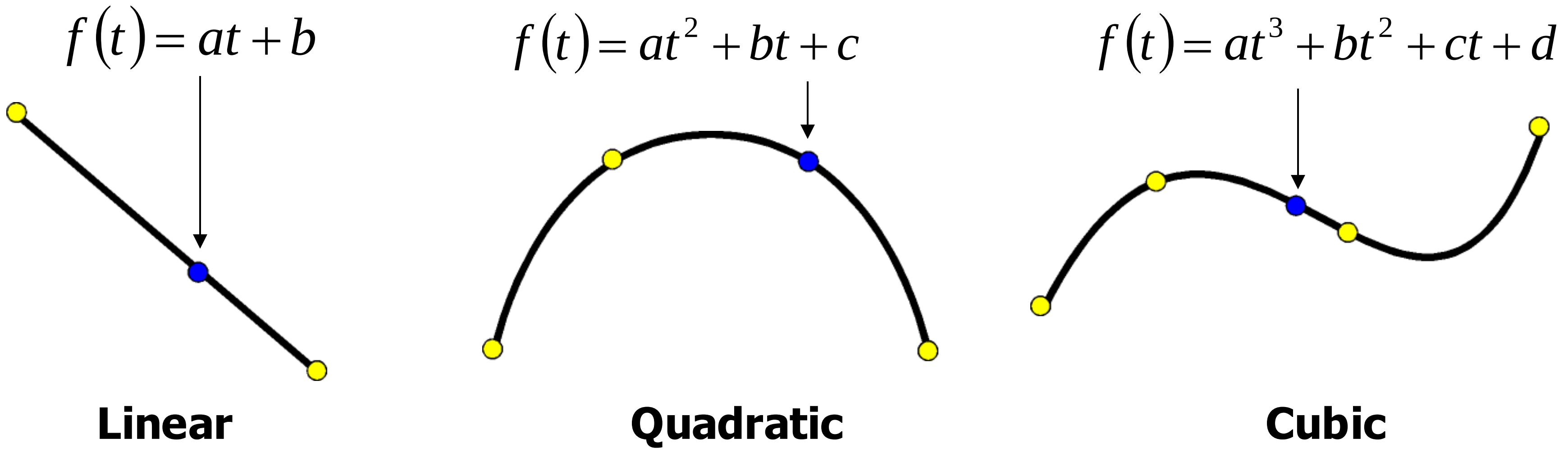
Smooth Interpolation

- To make smooth curves from data points
- There are many different methods of representing general curves
- Many types of splines for interpolating, approximating, etc.
- Here we use piecewise polynomials.
    - Cubic splines
    - Bezier curves
    - B-splines



Splines

- With n points we fit a polynomial of degree n-1 (order n polynomial).
- Let f(t) be the parameterised polynomial where $0 \le t \le 1$

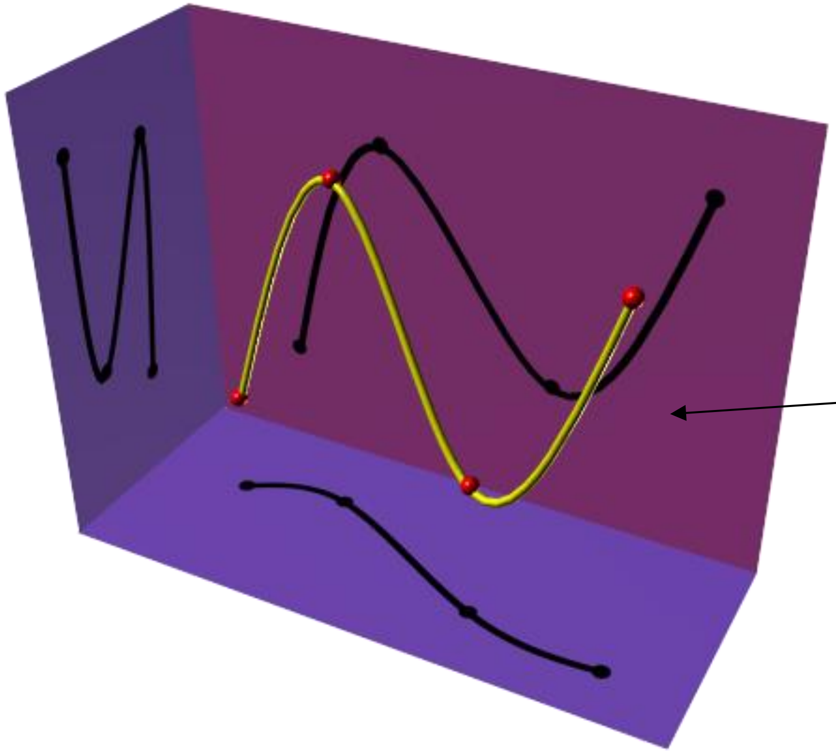


3D Splines

12 unknowns
∴ 4 3D points required

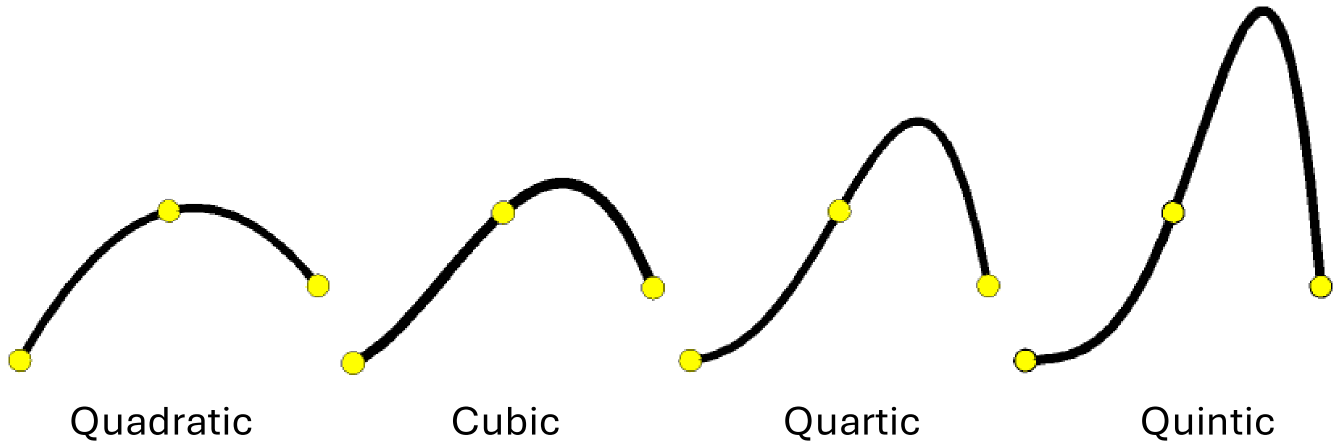
$$\left.\begin{aligned} x(t) &= a_x t^3 + b_x t^2 + c_x t + d_x \\ y(t) &= a_y t^3 + b_y t^2 + c_y t + d_y \\ z(t) &= a_z t^3 + b_z t^2 + c_z t + d_z \end{aligned}\right\} \rightarrow \begin{bmatrix} x(t) & y(t) & z(t) \end{bmatrix} = \begin{bmatrix} t^3 & t^2 & t & 1 \end{bmatrix} \begin{bmatrix} a_x & a_y & a_z \\ b_x & b_y & b_z \\ c_x & c_y & c_z \\ d_x & d_y & d_z \end{bmatrix}$$

- We use 3 polynomials, one for each axis to define the variation in x, y, z with distance t along the curve, respectively



$p(t)$

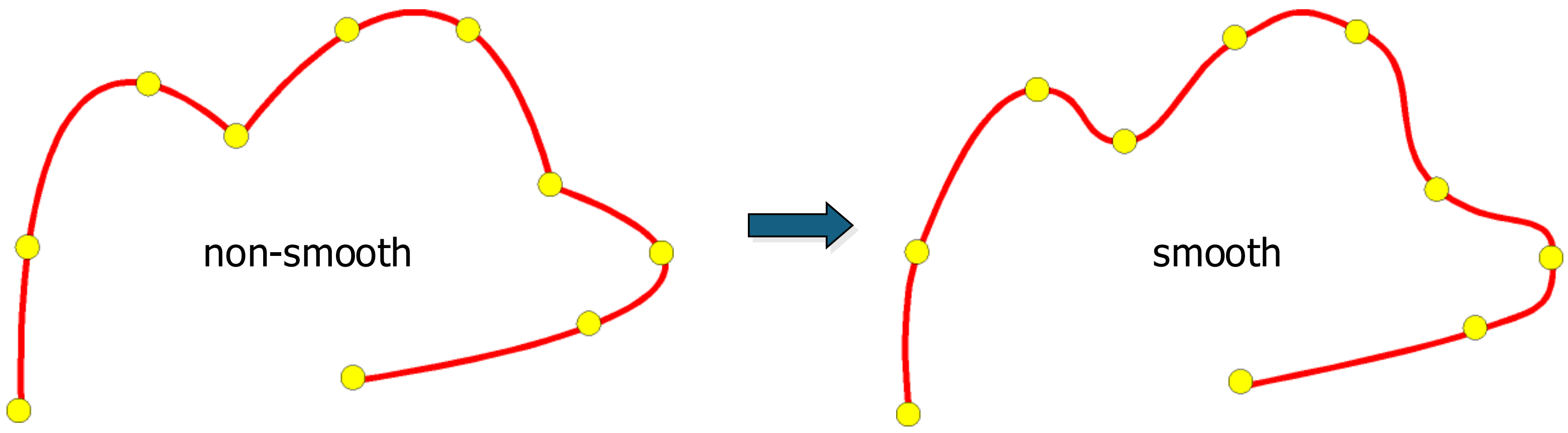
Splines



- If we have more than 4 points we require a polynomial of higher degree
  - higher degree polynomials are more difficult to control
  - they exhibit unwanted wiggles (oscillations)
- In general we use **cubic polynomials** for curves in computer graphics
  - minimal wiggles and faster to compute than high degree polynomials
  - lowest degree which allows *non-planar curves* (quadratics require 3 points, 3 points always lie in the same plane)

Curve Continuity

- Normally we supply 4 points we wish the spline to pass through.
- If we have more than 4 points we must employ more than 1 spline $\Rightarrow$ use a piecewise cubic polynomial
- For n points, we have (n-1)/3 individual cubic segments
  - without further constraints these will not join smoothly

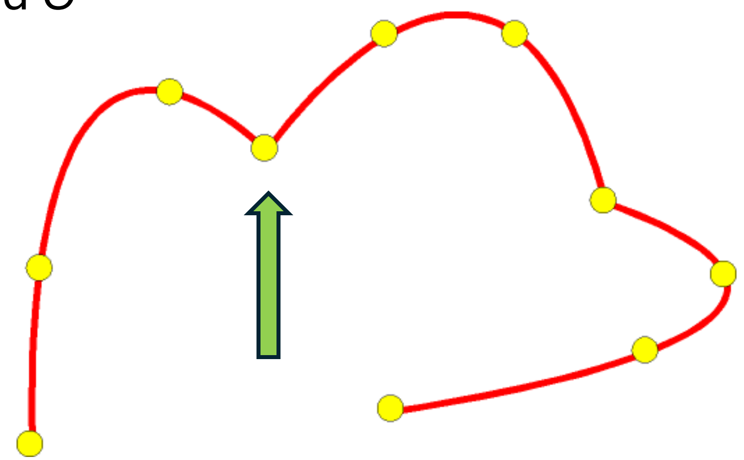


Curve Continuity

- To ensure a smooth connection between curve segments we enforce further *continuity* constraints
- 2 types of continuity:
  - *parametric continuity*, denoted C^n where n = degree of continuity
  - *geometric continuity*, denoted G^n

$$C^n \Rightarrow \left.\frac{d^n c_i(u)}{du^n}\right|_{u=1} = \left.\frac{d^n c_{i+1}(u)}{du^n}\right|_{u=0}$$

differentials are equal



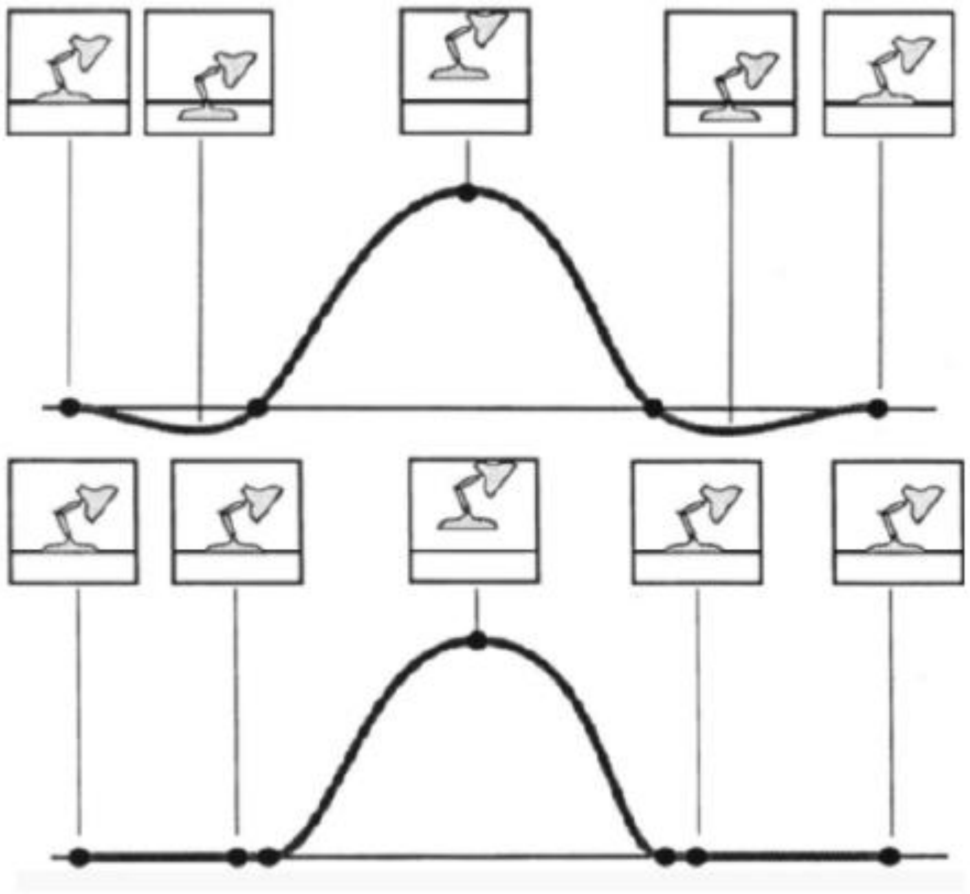
$$G^n \Rightarrow \left.\frac{d^n c_i(u)}{du^n}\right|_{u=1} = \alpha \left.\frac{d^n c_{i+1}(u)}{du^n}\right|_{u=0}$$

differentials are proportional

- In general, two curves which are parametric continuous to a certain degree are also geometric continuous to that same degree, but the reverse is not so.

Interpolation

- Not fool-proof
- May not follow the laws of physics
- Splines may undershoot & cause interpenetration
- Animator must also keep an eye out for these types of side-effects.



Shape Interpolation

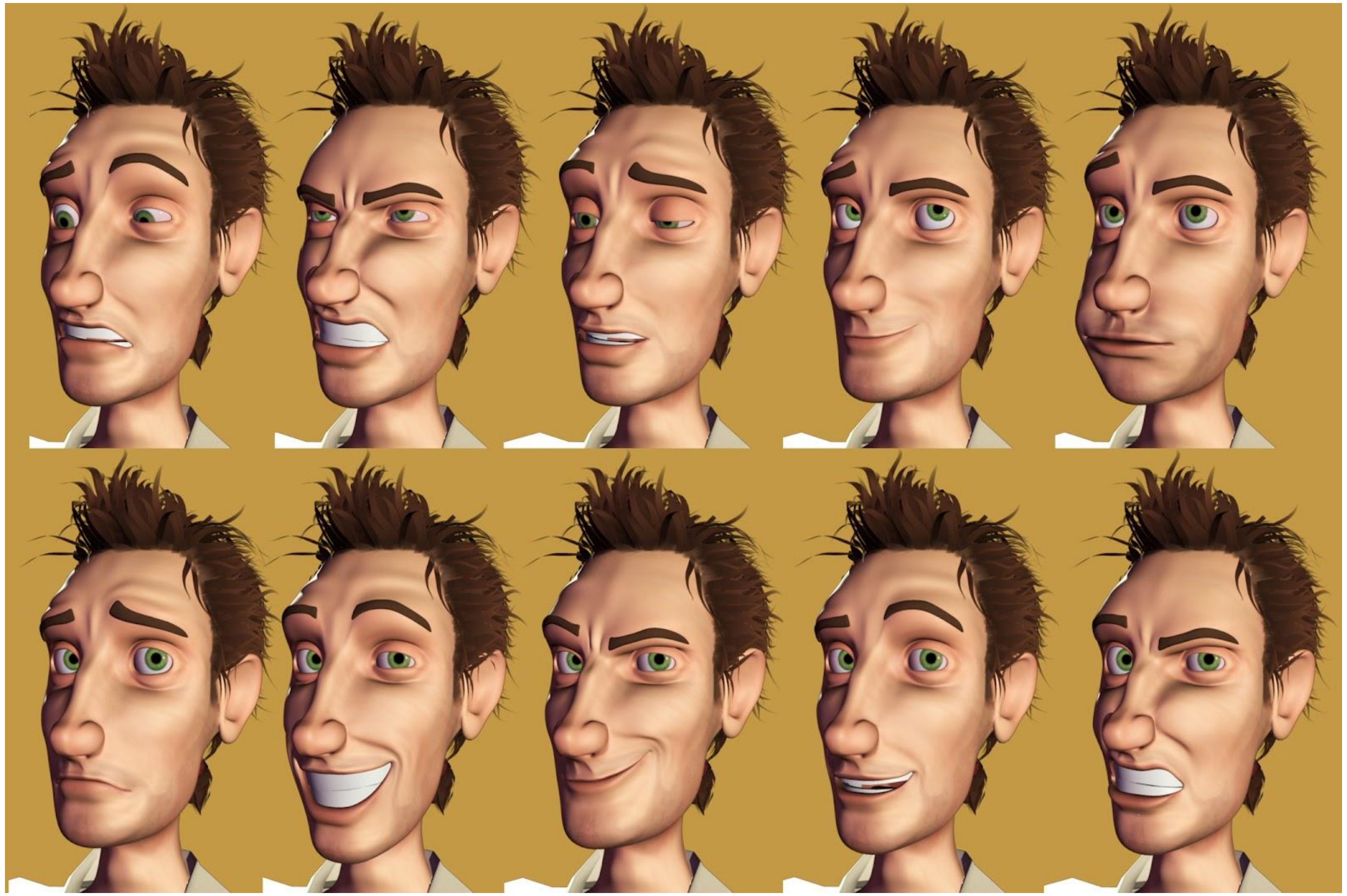
- Sculpt several target shapes

- Use weighted average

- Meshes must have same topology

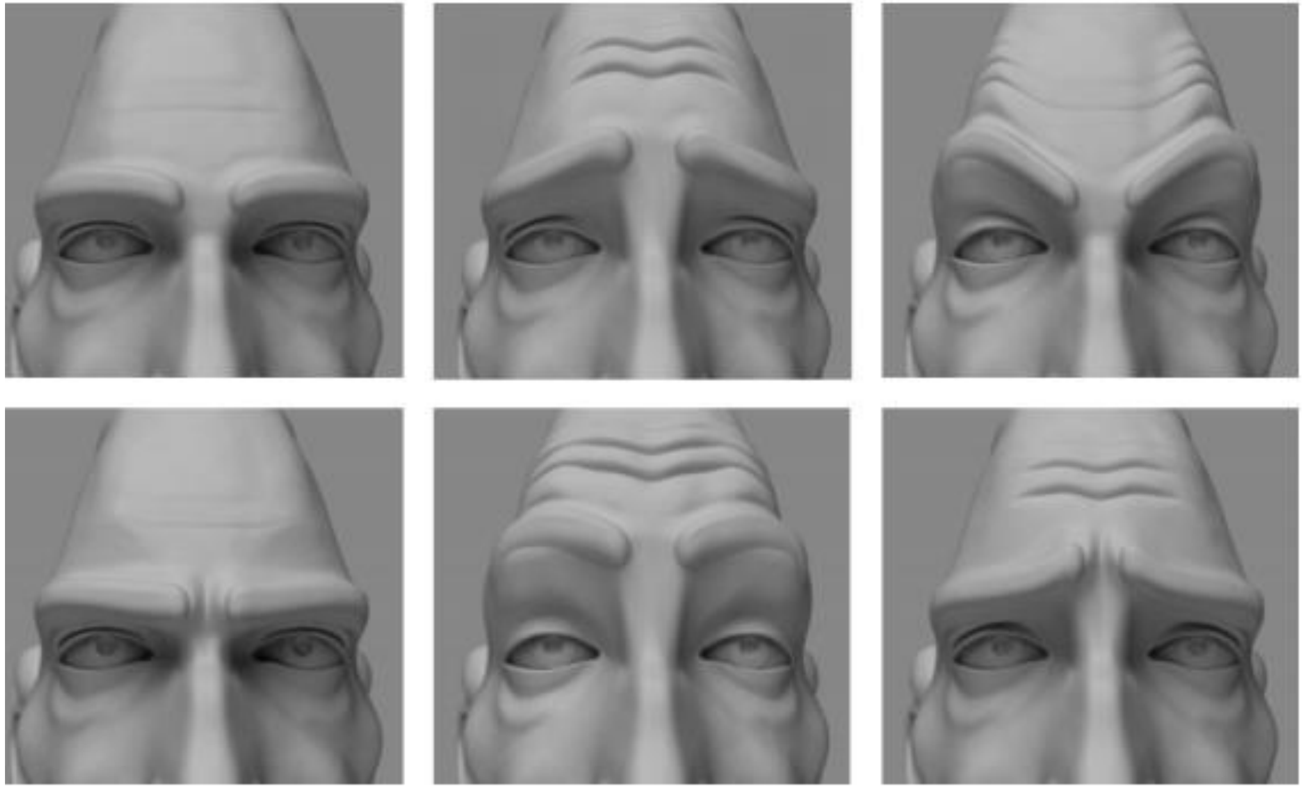
Shape Interpolation

- Often used for facial animation:



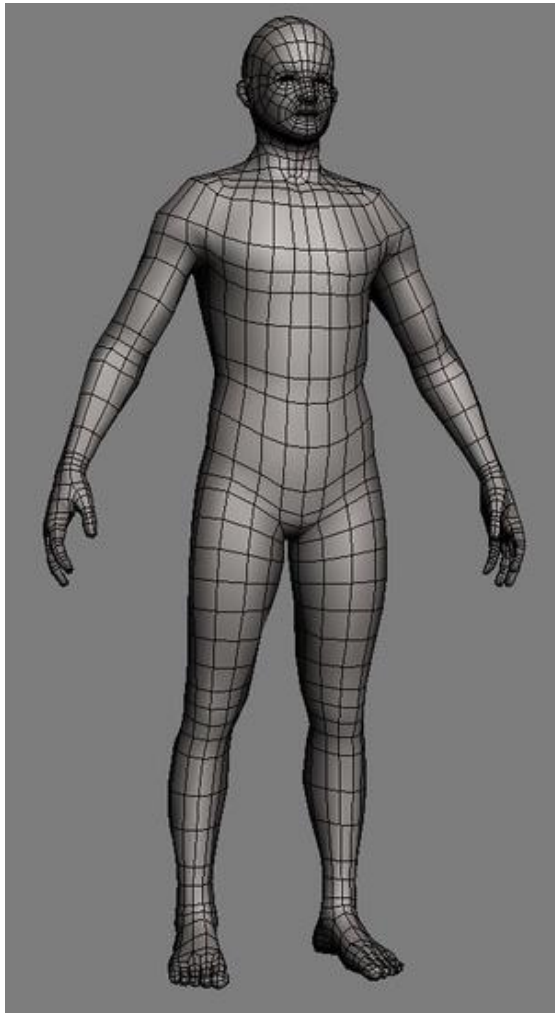
Blendshapes

- Simplest approach to facial animation
- Sculpting facial poses into several meshes of the same topology
- Each mesh is a different shape
- Interpolating several shapes generates animation
- Weighted sum of shapes – weights must add up to 1
- Can define localized shapes in each region of the face, enabling independent control of that region & allowing mixing multiple shapes to create a wide variety of poses



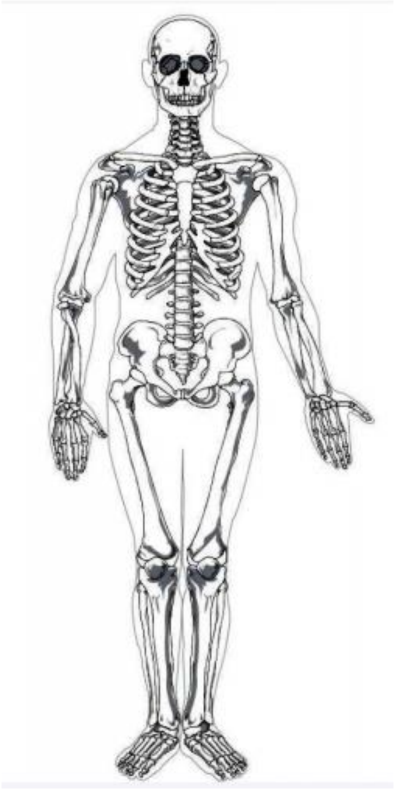
Character Animation

- Animating a character model described as a polygon mesh by moving each vertex in the mesh is <u>impractical</u>
- Instead - specify the motion of characters through the movement of an internal articulated <u>skeleton</u>
  - Movement of the surrounding polygon mesh may then be deduced
- Mesh must deform in a manner that the viewer would expect, <u>consistent</u> with underlying muscle and tissue

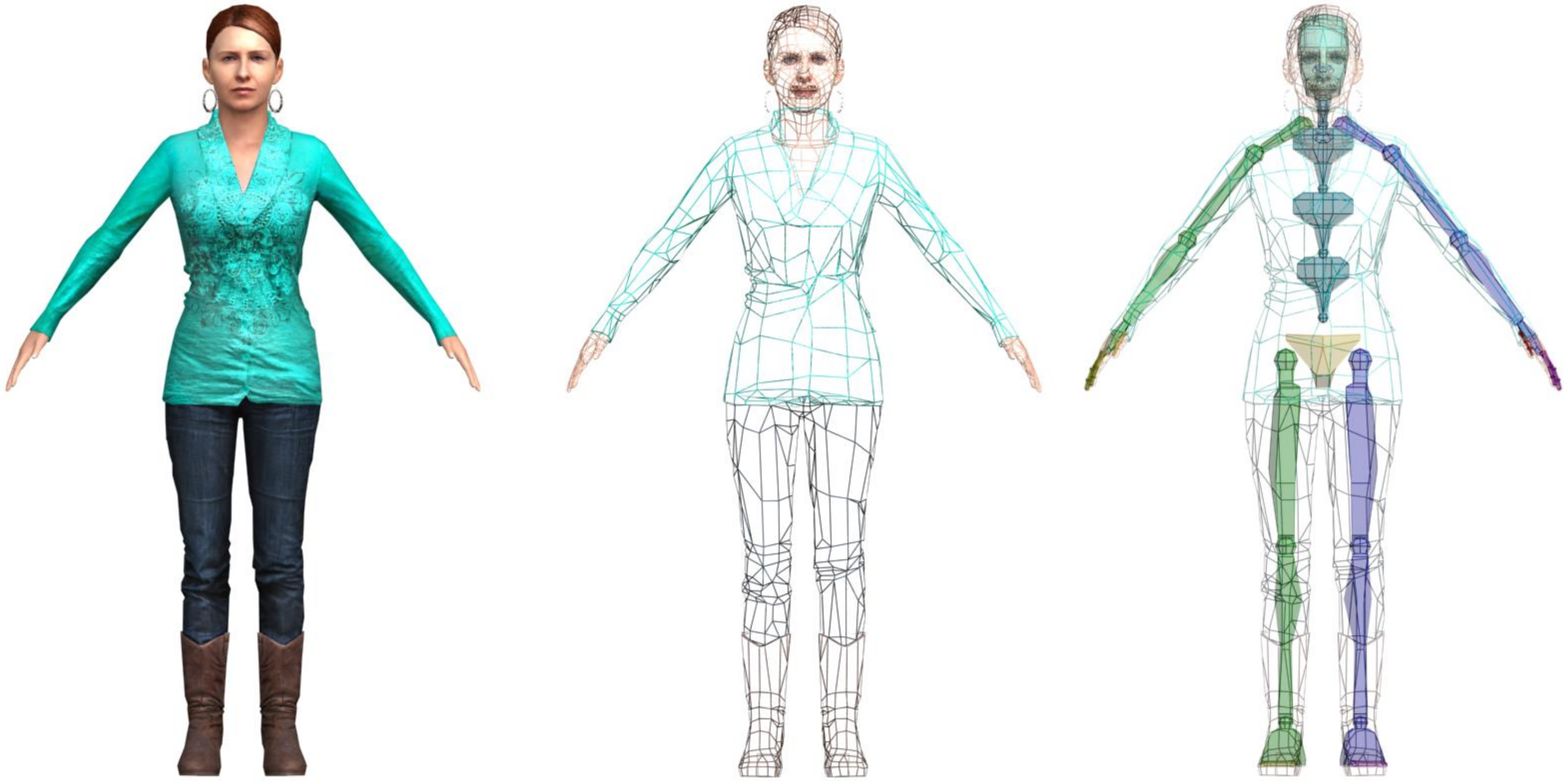


Human Skeleton

- Spine
  - Impractical to model each vertebra
  - Typically use 3/4 spine links
- Shoulders
  - Can translate as well as rotate
  - Wide range of motion
  - Prone to dislocation

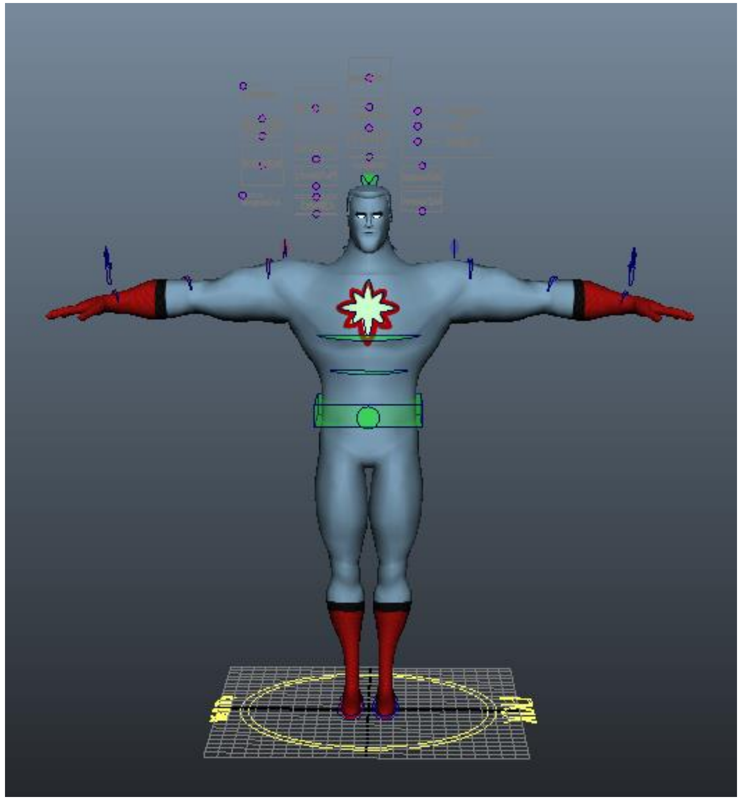


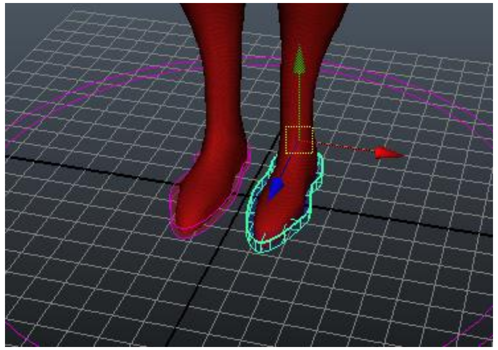
Skeleton

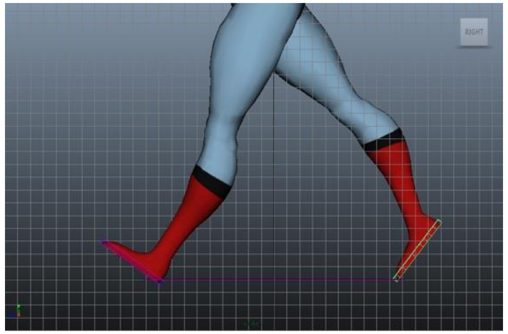


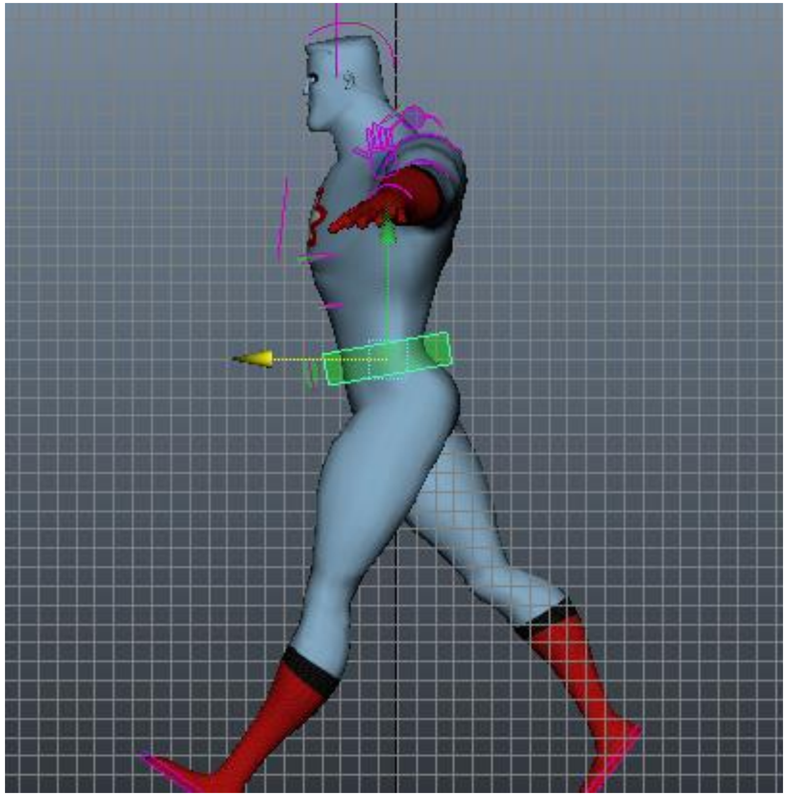
Rigging

- Create an articulated skeleton by adjusting its joints









Rigid Body Limitations

- Consider human joints:
  - When they bend, the body shape bends as well
  - No distinct parts
- We cannot represent this with rigid bodies
  - Or the pieces would separate, where there should be stretching or compression

Skinning

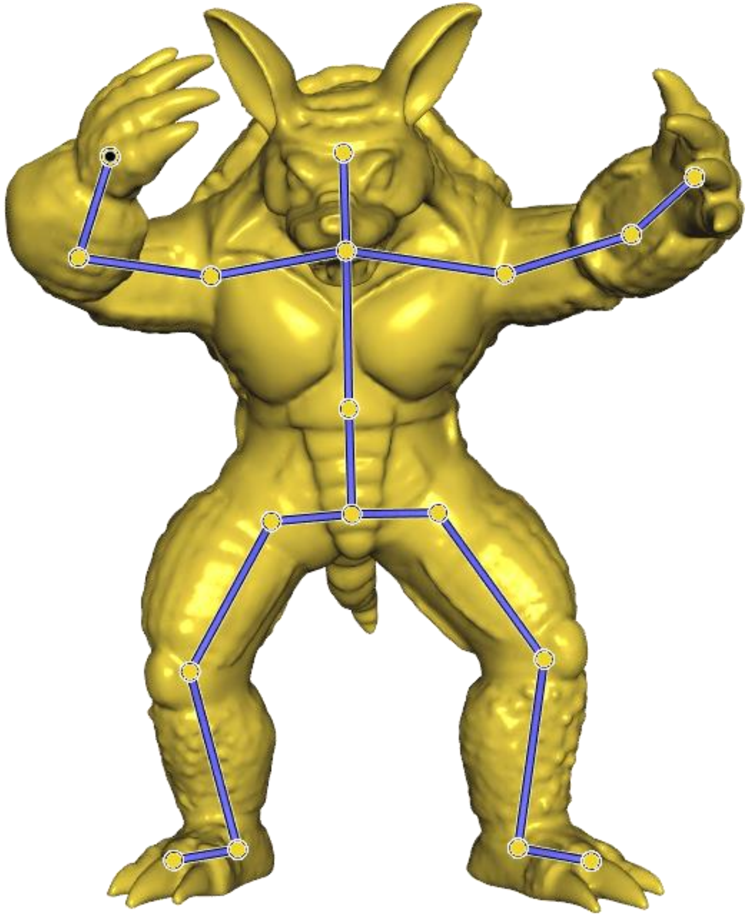
- Skinning is the process of attaching a renderable skin to an underlying articulated skeleton.

- **Binding** refers to the initial attachment of the skin to the underlying skeleton and assigning any necessary information to the vertices

- Each vertex in the mesh can be attached to more than one joint, each attachment affecting the vertex with a different strength or weight.

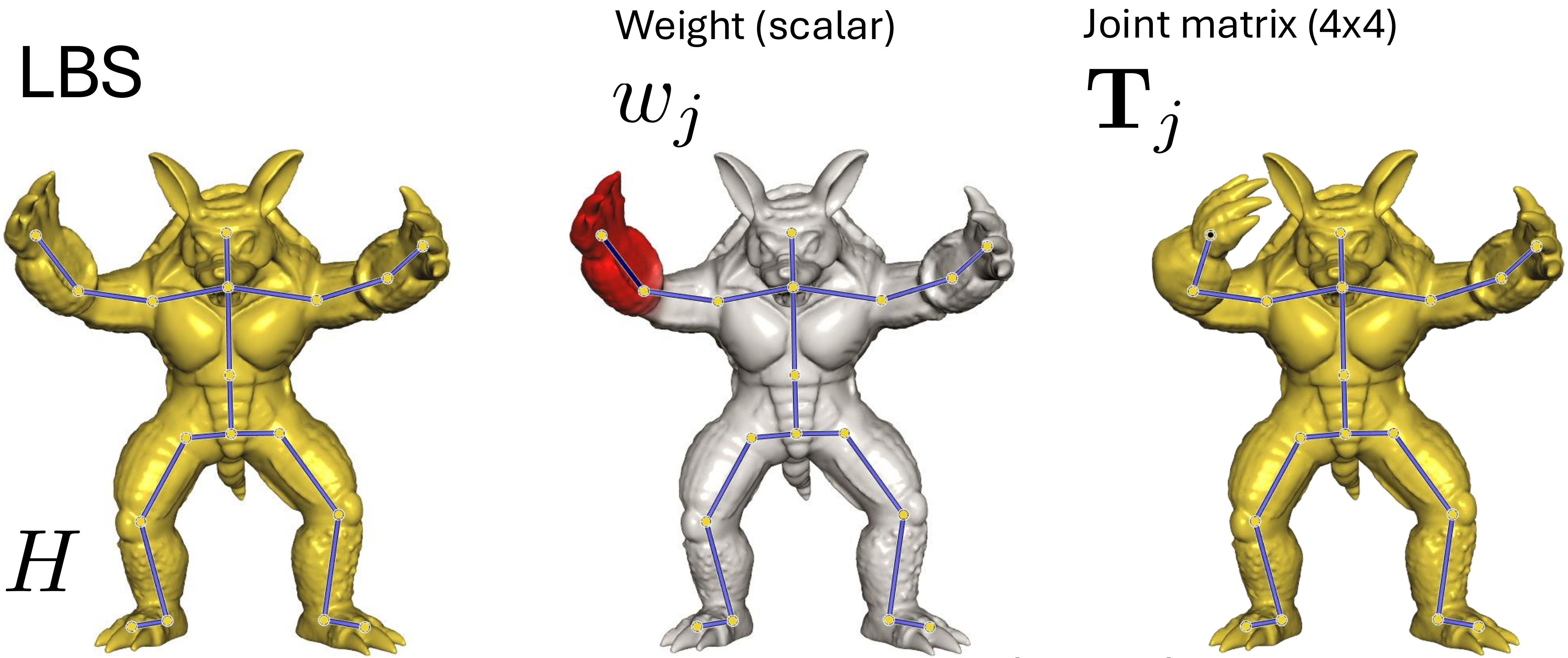
Linear Blend Skinning (LBS)

- Linear blend skinning determines the new position of a vertex by linearly combining the results of the vertex transformed rigidly with each bone.
- A scalar weight is given to each influencing bone and the weighted sum gives the vertex's position in the new pose
- Weights set such that sum of all weights for a vertex = 1
- Widely adopted in the graphics industry



Jacobson et al., Skinning: Real-time Shape Deformation, SIGGRAPH 2014 courses

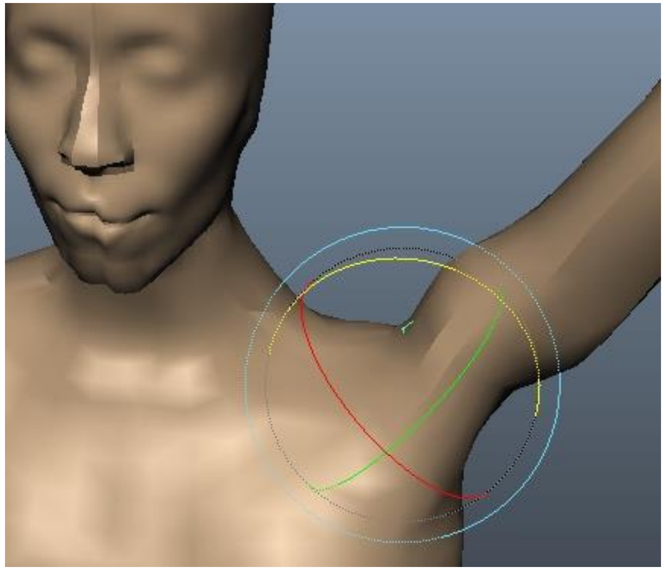
LBS

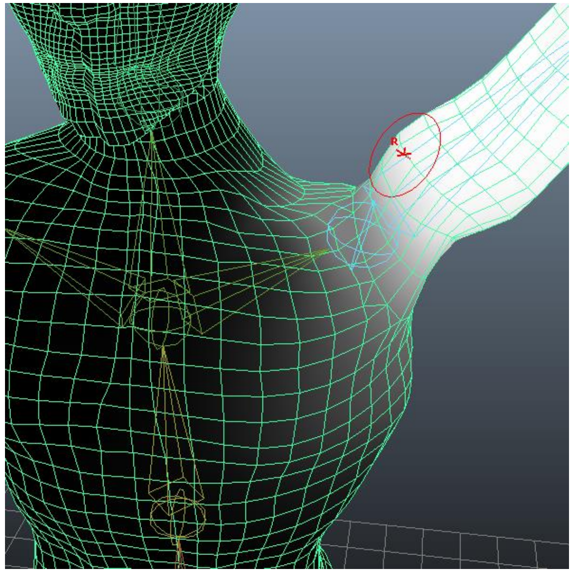


$$\mathbf{v}' = \sum_{j \in H} w_j(\mathbf{v}) \mathbf{T}_j \begin{pmatrix} \mathbf{v} \\ 1 \end{pmatrix}$$

Jacobson et al., Skinning: Real-time Shape Deformation, SIGGRAPH 2014 courses

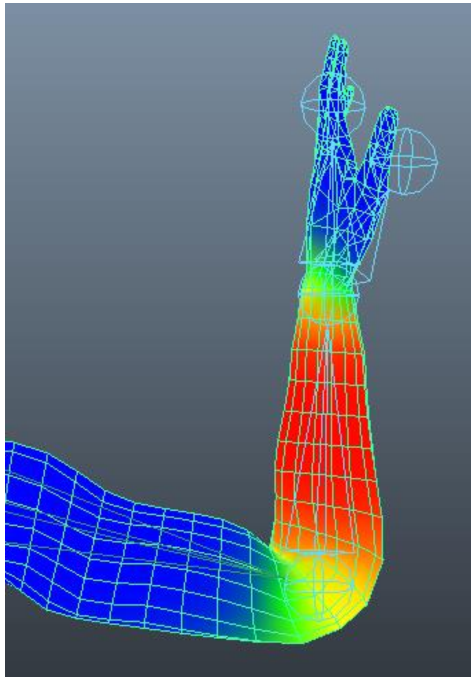
Weight Painting

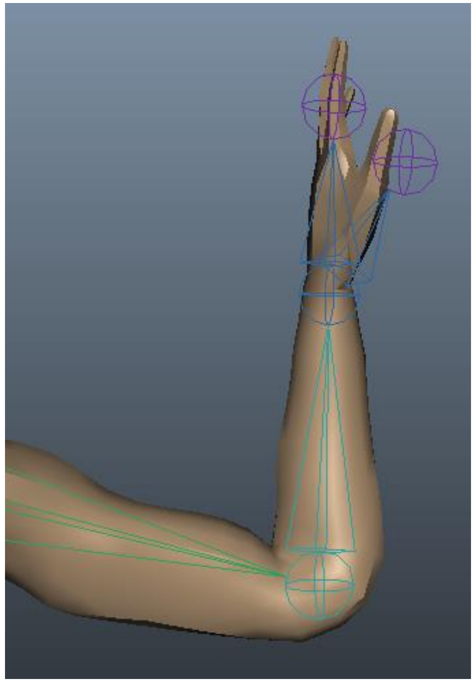




- The weight for each joint can be automatically computed.

- However, sometimes skinning results in geometry distortions.





- In practice, the weights can be edited by using manual weight painting tools to reduce distortions.

Motion Capture

- The process of translating a live performance into a digital performance

Mocap vs. Traditional animation

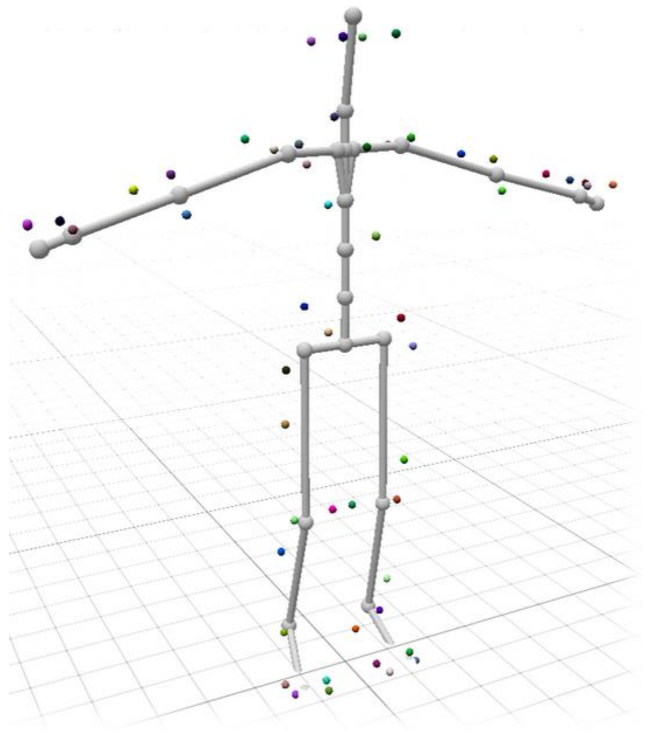
- Advantages
  - Realistic human motion
  - More rapid results can be obtained
  - The amount of work does not vary with the complexity or length of the performance
  - Complex movement and realistic physical interactions can be easily re-created
  - Mocap technology allows one actor to play multiple roles within a single film.

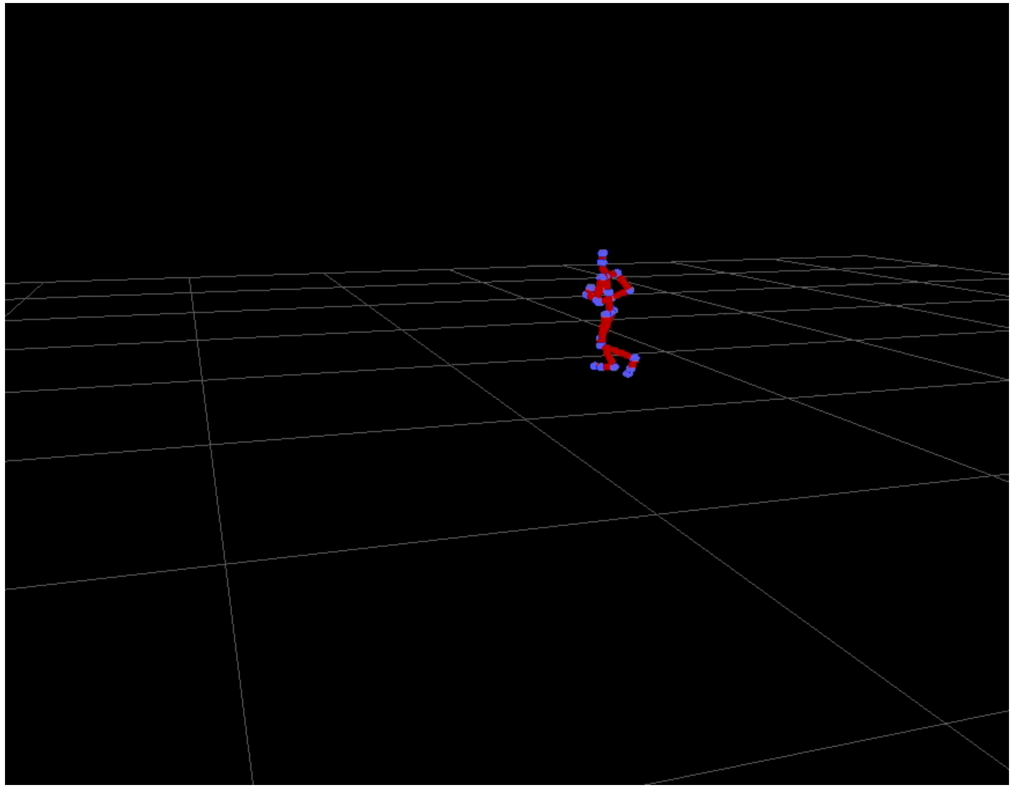
Motion Capture

- Reflective markers
- Actor is shot by multiple cameras
- Each camera has a light source
- Light is reflected by the markers back to the camera
- The 3D location of the markers are computed by stereo vision

Computing the joint angles

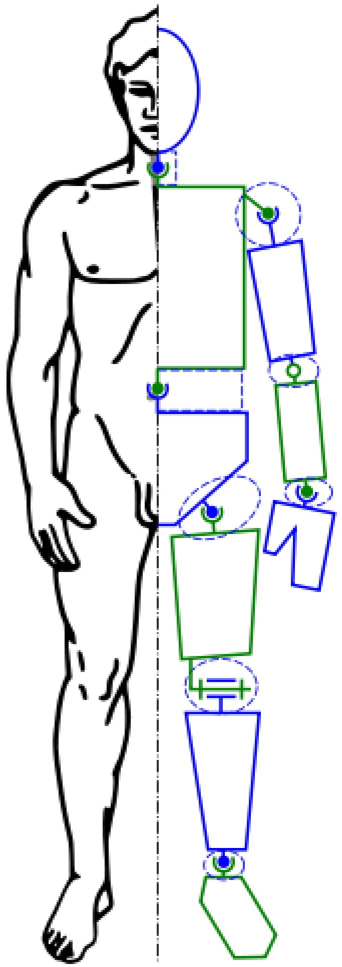
- The joint angles are computed, based on the marker positions





Kinematics

- Describes the positions of the body parts as a function of the joint angles.
- **Forward** kinematics
  - Low level approach where animator has to explicitly specify all motions of every part of the animated structure
  - Each node in hierarchy inherits movement of all nodes above it
- **Inverse** kinematics
  - Requires only the position of the ends of the structure
  - Functions as black box - controls detailed movement of entire structure

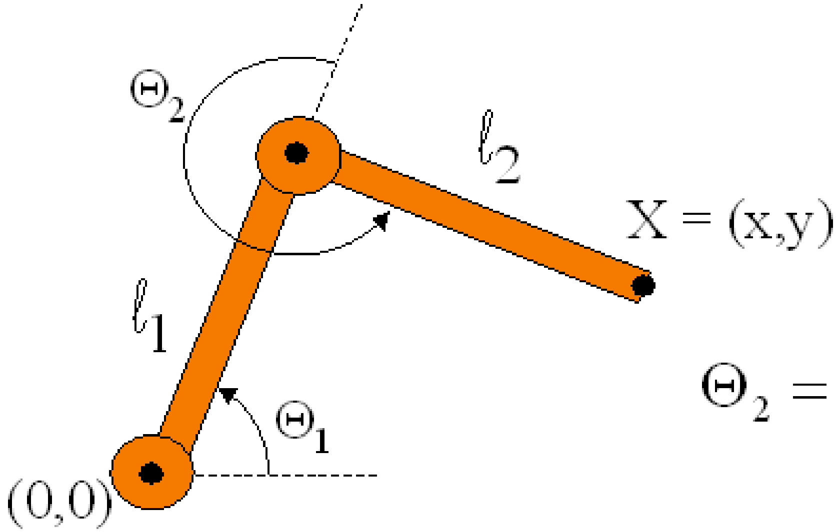


Inverse kinematics

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

Inverse Kinematics

- Animator specifies end-effector positions
- Computer finds joint angles



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

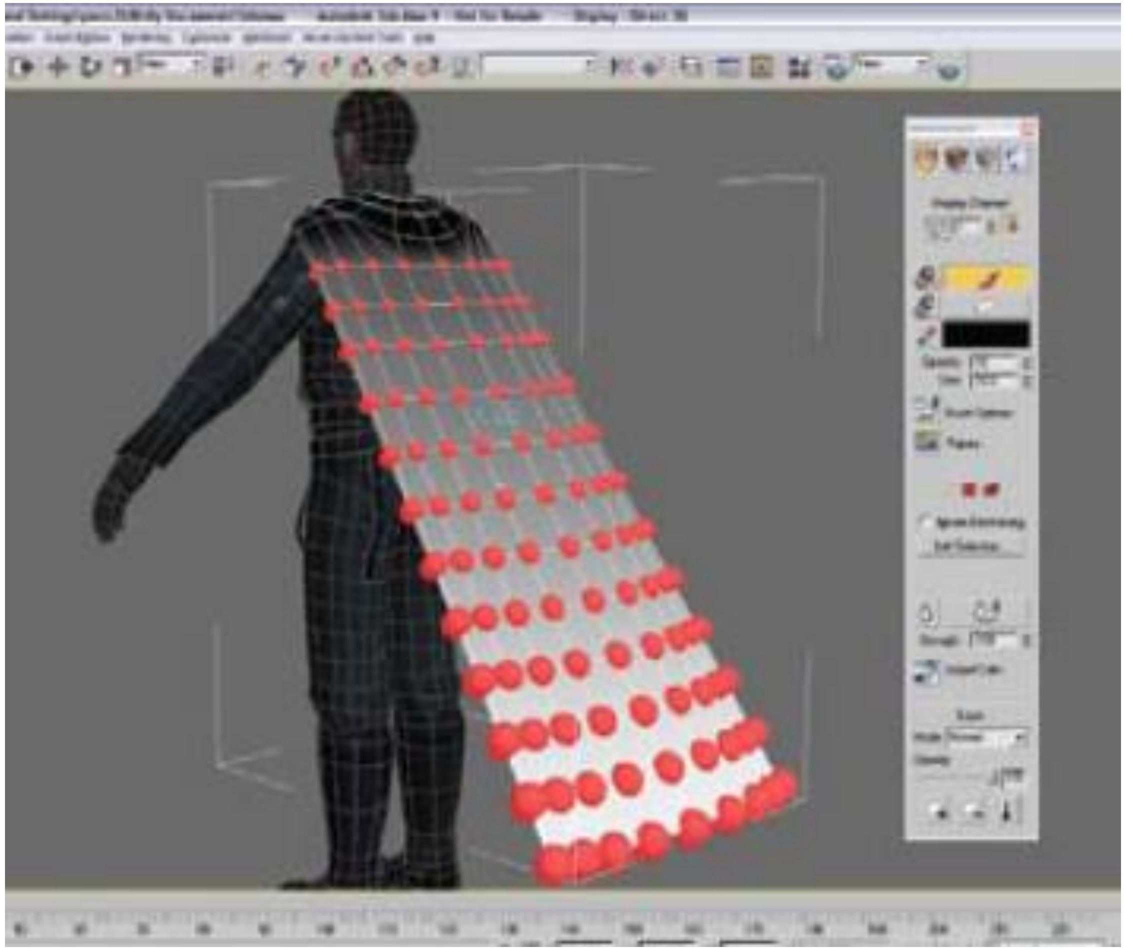
$$\Theta_1 = \frac{-(l_2 \sin(\Theta_2)x + (l_1 + l_2 \cos(\Theta_2))y}{(l_2 \sin(\Theta_2))y + (l_1 + l_2 \cos(\Theta_2))x}$$

Physically based Animation

Physically based animation

- Forces are used to maintain relationships among geometric elements
- Modelling the physics usually incurs a high computation expense, but is flexible
- Example: for cloth, an animator can set parameters that indicate type and thickness of cloth material, and wrinkles occur naturally, rather than specifying exact positions of wrinkles

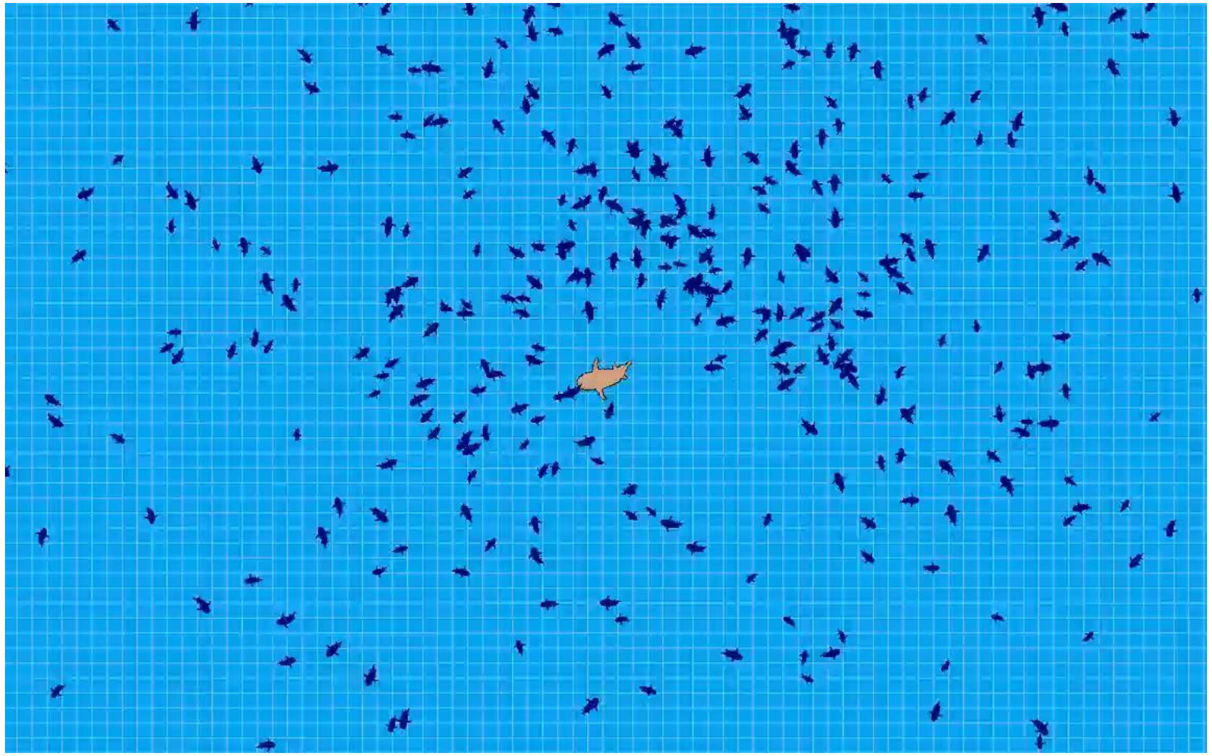
Cloth Simulation



Hair Simulation

Behavioural Animation

- A type of procedural animation
- Autonomous character determines its own actions to some extent
- This gives the character some ability to improvise (obstacle avoidance and goal seeking)



Reynolds et al., Flocks, Herds, and Schools: A Distributed Behavioral Model in Computer Graphics, SIGGRAPH 1987.

Crowds Animation

Sensory System

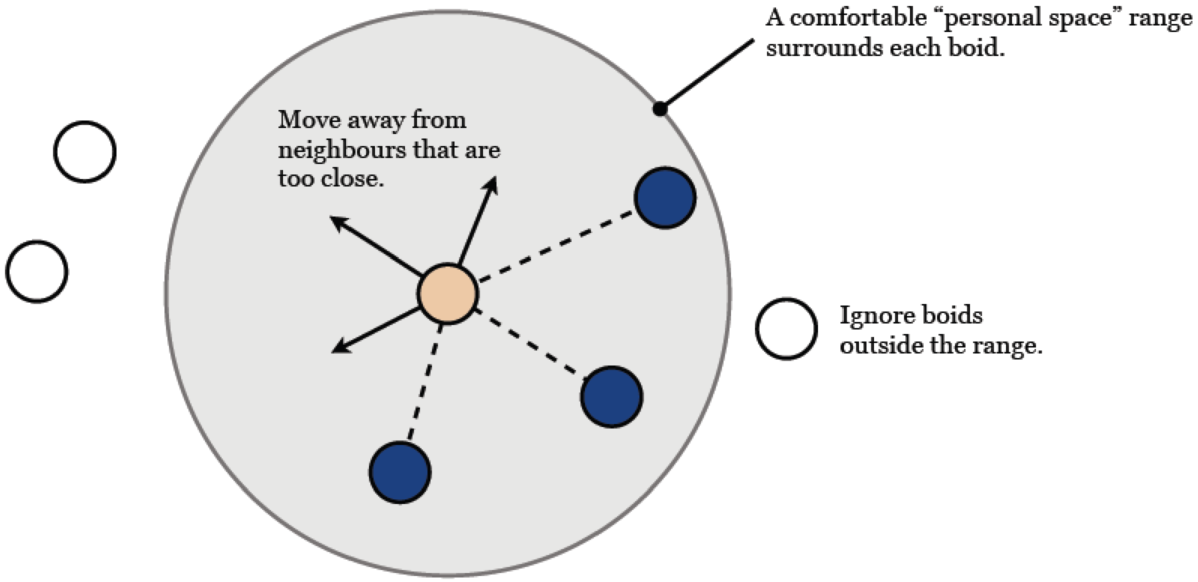
- Each boid has direct access to the whole scene's geometric description, but flocking requires that it **reacts only to flockmates** within a certain small neighborhood around itself.

- The neighborhood is characterized by:
  - a *distance* (measured from the center of the boid) and
  - an *angle,* measured from the boid's direction of flight.

- Flockmates outside this local neighborhood are ignored.

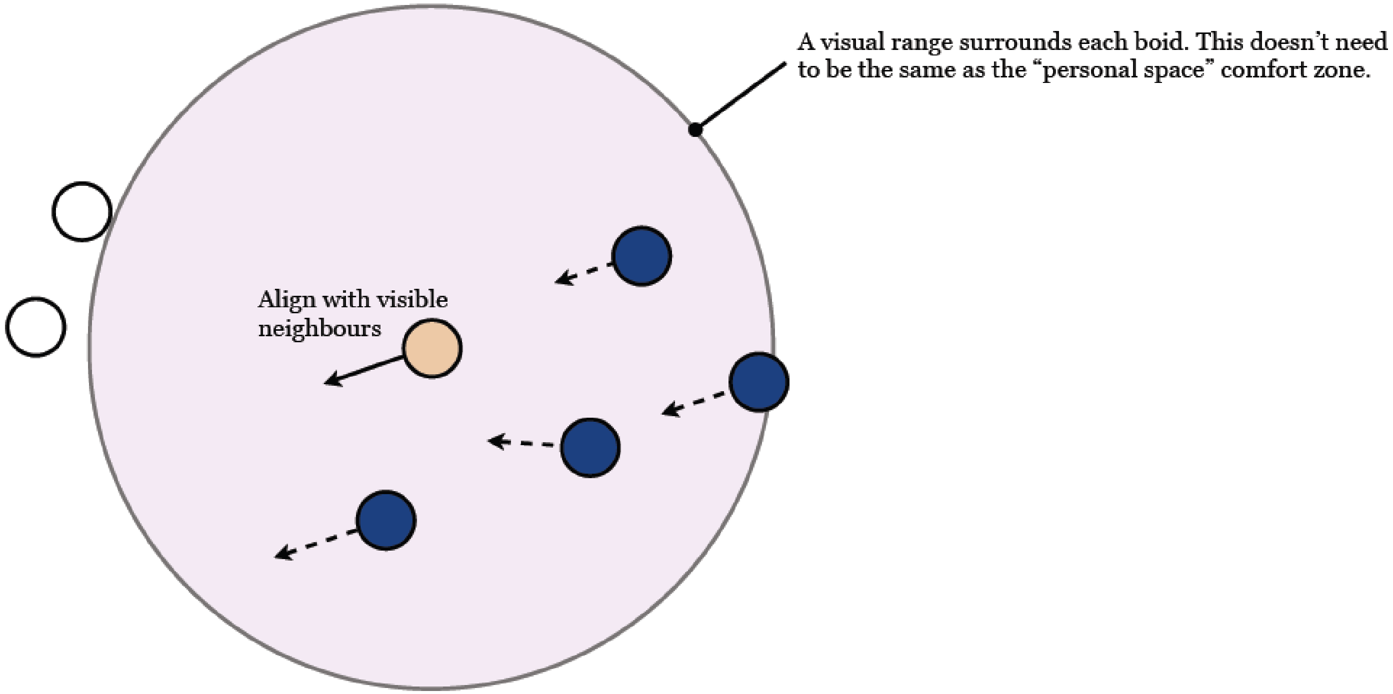
Rule 1: Separation

- An easy way to avoid collisions with a flock of other boids is by keeping your distance from them



Rule 2: Alignment

- Another way to avoid collisions with a flock of other boids is by flying in the same direction as your visible neighbours.



Rule 3: Cohesion

- A flock is a group flying together. We don't want the birds to fly too far apart so we add a localised flock centering tendency.