Skeletons and Skin
CMSC425.01 Spring 2019

Still at tables ...
Administrivia

• Next Hw and Project 2 coming still coming ...

• Mini-lectures still coming – videos on single topics (Panopto on Elms)

• The M-word – Midterm. Monday April 1st.
Today’s question

Animating articulated figures: Skeletons and Skin
Skeletons and rigging

• Character animation
  • Create a skeleton
  • Define transforms between parts
  • Interpolate transforms to move
  • Rig with “flesh”
  • Create behavior animations
  • Blend between animations for smooth actions in game

• Can find as Unity Assets
• Use Mecanim tool
• https://www.youtube.com/watch?v=HPwu7elwjV8
Unity: Mecanim
Skeleton: bones and joints, bind pose

(a) (b) (c)
Skeletal model as joint tree
Motion as transform propagation

• Queen's wave
  • Use wrist (j5) to rotate hand
  • Use elbow (j4) to rotate forearm
  • Use shoulder (j3) to rotate arm

• Parent relation
  • p(j) = parent joint
  • p(j5) = j4

• Rotating parent rotates child
• Rotating child does not rotate parent
Traversing joint tree with transform stack

• Start with transform $M = I$ (identity)
• Visit $j_0$
  • $M' = M*M_{j0}$
• Visit $j_1$
  • $M'' = M*M_{j1}$
  • Push $M''$ on stack
• Visit $j_2$
  • $M''' = M''*M_{j2}$
  • Transform points attached to $j_2$
  • Pop stack
• Visit $j_3$
  • $M'''' = M'''*M_{j3}$

• Multiply on right down a branch
• Push when need to revisit
• Apply $M$ to points on branch
Scene graph – similar tree for all objects

- Directed graph of all objects in scene
- Nodes have shape, appearance, transform, camera, light info
Joint constraints: degrees of freedom (DOF)

• Number of rotations supported by joint
  • Knee – 1 degree
  • Foot – 2 degrees
  • Wrist?
  • Elbow?
  • Shoulder?

• Limits on each joint
  • Rotation in range \([\text{angle1}, \text{angle2}]\)
Aside: Learn figure animation, learn robots
Kinematics – study of motion w/out forces

• **Kinematics**
  - Forward – given joints and transformations, estimate end position
  - Reverse – given end position estimate transformations

• Forward – “easy”
• Reverse – hard!
Joint transformations: simple

- Initial: resting pose
- $T_{[j_1 \leftarrow j_0]} = M_{T(2, 0)}$
- $T_{[j_1 \leftarrow j_0]} \cdot p = M_{T(2, 0)} \cdot (1, 0) = (3, 0)$
Joint transformations: simple

- Initial: resting pose
- $T_{[j_1\leftarrow j_0]} = M_{T(2,0)}$
- $T_{[j_1\leftarrow j_0]} \cdot p = M_{T(2,0)} \cdot (1,0,1) = (3,0,1)$
- Rotate wrist 45 degrees in $j_0$ coordinates
- $M_{R(45)} \cdot (1,0,1) = (\frac{\sqrt{2}}{2}, \frac{\sqrt{2}}{2}, 1)$
Joint transformations: simple

• Initial: resting pose

• $T_{[j_1 \leftarrow j_0]} = M_{T(2,0)}$

• $T_{[j_1 \leftarrow j_0]} * p_{j_0} = M_{T(2,0)} * (1,0,1) = (3,0,1)$

• Rotate wrist 45 degrees in $j_0$ coordinates

• $M_{R(45)} * (1,0,1) = \left(\frac{\sqrt{2}}{2}, \frac{\sqrt{2}}{2}, 1\right)$

• Rotate shoulder 45 degrees in $j_1$ coordinates

• $p''_{j_1} = M_{R(45)} * T_{[j_1 \leftarrow j_0]} * p'_{j_0} = (\sqrt{2}, 1 + \sqrt{2}, 1)$
Coordinate transformations – points (location)

\[ G.x[F] = (2, 1, 0) \]
\[ G.y[F] = (-1, 2, 0) \]
\[ G.o[F] = (4, 2, 1) \]

\[ F.x[G] = \left( \frac{2}{5}, -\frac{1}{5}, 0 \right) \]
\[ F.y[G] = \left( \frac{1}{5}, \frac{2}{5}, 0 \right) \]
\[ F.o[G] = (-2, 0, 1) \]
Coordinate transforms – vectors (orientation)

\[ p[F] = (1, 3, 1) \]
\[ \vec{v}[F] = (3, -1, 0) \]

\[ p[G] = (-1, 1, 1) \]
\[ \vec{v}[G] = (1, -1, 0) \]
Arm example

• Three joints
  • Wrist: \( k \) \( T[k <-> j] \)
  • Elbow: \( j \) \( T[j <-> i] \)
  • Shoulder: \( l \)

• Binding pose
  • Translations
  • One reflection
Forward kinematics – rotate elbow, shoulder

- Have binding transforms
  - $T[k \leftarrow j]$
  - $T[j \leftarrow i]$

- Have two rotations
  - $M_{R}(30)$
  - $M_{R}(45)$

- Apply in what order?
Summary

• Animated character has
  Skeleton which has
    Joints which have
      Transforms
Meta joints

• Collocated joints

• Simplify transforms

• Each joint has rotation around one axis - 1 DOF

• Combine to get multiple DOFs

• No translation
Animating skeletons

• Key framing.

• Motion capture.
  • https://www.youtube.com/watch?v=tNqGT2wnNSM

• Goal oriented.

• Also – parametric equations
  • Pick ups in Project 1b
Data representation of motion/animation

- Joint positions over time
  - $T$ – translation
  - $Q$ – Quaternion

- Interpolation between key frames/samples
  - Cubic for position
  - Spherical for quaternions
Skinning

• Bind mesh to bone between joints
• Moves with parent joint

• Problems
  • Cracking and distortion
Skinning

• Bind mesh to bone between joints
• Moves with parent joint

• Problems
  • Cracking and distortion

• Cheats!
  • Use fantasy character with disconnected parts
  • Use robot with mechanical joints that require no skinning
Blending at joints

• Bind mesh vertices to **one** joint
• Move with joint (bone between)
• Cracks!

• Bind to **two** joints
• Interpolate

![Reference pose](image1)
![Each vertex bound to one joint](image2)
![Vertices bound to both joints](image3)
Weighted linear blending

\[ v_0 = \frac{3}{4} v_1 + \frac{1}{4} v_2 \]
State of art rigging – muscles and more