Computer Animation

Lecture 2.

Basics of Character Animation

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Overview

- Character Animation
- Three methods to create motion of the skeleton
  - Manual
  - Capture human motion
  - Physical simulation
- Manually creating human animation
  - Keyframe animation
  - Postural editing
    - Virtual track ball
    - Inverse Kinematics
  - Hierarchical structure of the body
  - Joint types
    - Translational, hinge, universal, gimbal, free
  - Euler angles
    - Gimbal lock
  - Quaternions
  - Interpolation

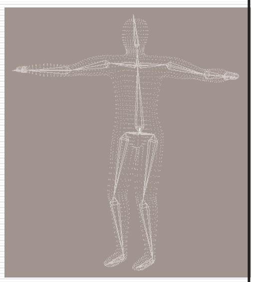
Characters include

- Human models
- Virtual characters
- Animal models



Controlling the skeleton

- Although we see the skin of the 3D character moving, their movements are produced by the control of the skeleton model
- The skin follows the movement of the skeleton

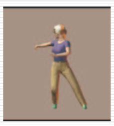


How to produce the movements of the skeleton?

- There are three methods
  - Keyframe animation
  - Use real human motion
  - Use physically based simulation

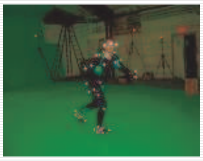
Creating the human motion manually

- We use a method called keyframe animation
- The keyframe postures are designed by the animator
- The inbetween motion is created by interpolation

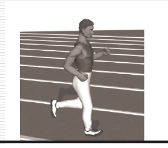
Using real human motion

- There is a device called motion capture system (Mocap)
- The actor wears it, and move in the studio
- The actor's motion is then digitized


Physically-based simulation

- Ragdoll physics
  - Not exerting voluntary torque / forces
  - being knocked down,
  - falling down the stairs
- Voluntary motions
  - jumping,
  - running,
  - somersaults
- by minimizing the energy, or using PD control

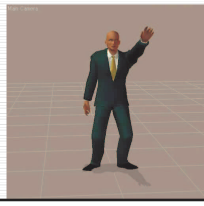



How to produce the movements of the skeleton?

- There are three methods
  - Keyframe animation (Today)
  - Use real human motion
  - Use physically based simulation

Keyframe animation by Poser

- Poser is a commercial software to generate human animation

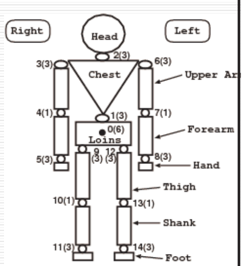



Keyframe animation

- Each postures are created by the user interface
  - Virtual Track Ball (Forward Kinematics)
    - The user clicks the segment and rotates it around the joint origin
    - The movement of the mouse is mapped to the rotation of the joint
  - Inverse Kinematics (IK)
    - The user clicks the segment and drags it in the 3D coordinate
    - The motion of the mouse is mapped to the translation in 3D coordinate
    - The movement of the segment is achieved by moving each joint of the body

Representation of postures

- How can we specify the posture of the avatars?
- The body has a lot of degrees of freedom
- And has a hierarchical structure



Hierarchical structure of the body

- Each joints can have 1 to 6 degrees of freedom
- For rotational joints, usually it is 1, 2, or 3
- The "Root" of the body has 3 degrees of freedom for the translation

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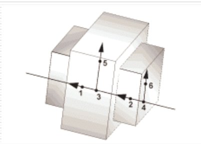
JOINT Hips
  ┌JOINT Spine
  │    JOINT Spine1
  │        ┌JOINT head
  │        ├JOINT LeftShoulder1
  │        │    JOINT LeftArm
  │        │        JOINT LeftForeArm
  │        │            JOINT LeftHand
  │        └JOINT RightShoulder
  │             JOINT RightArm
  │                 JOINT RightForeArm
  │                     JOINT RightHand
  ├JOINT RightUpLeg
  │    JOINT RightLeg
  │        JOINT RightFoot
  │            JOINT RightToes
  └JOINT LeftUpLeg
       JOINT LeftLeg
           JOINT LeftFoot
               JOINT LeftToes
```

Joints

- The Degrees of Freedom (DOF) is defined for various joints
- There are several kinds of joints
  - Translational joint (1,2,3DOF)
  - hinge joints (1 DOF)
  - Universal joint (2 DOF)
  - Gimbal joint (3 DOF)
  - Free joint (3DOF)

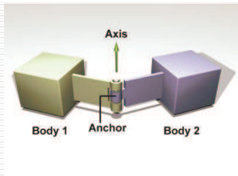
Translational joint

- A sliding joint
- Can be 1,2 or 3 DOF



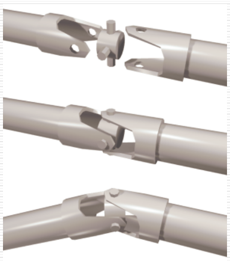
Hinge Joint

- A 1 DOF rotational joint
- Can be defined by the axis of rotation
- Used to define the knee or elbow



Universal Joint

- 2DOF
- Rotation around 2 axes
- It consists of a pair of ordinary hinges located close together, but oriented at 90° relative to each other.



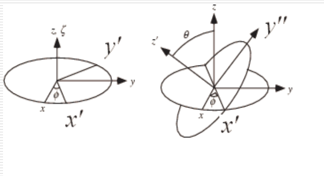
3DOF rotational joints

- Shoulder, hip, neck
- Two ways to represent the rotations
  - Gimbal joint (Euler Angles)
  - Free joint (Quaternions)

Gimbal joint : Euler Angles

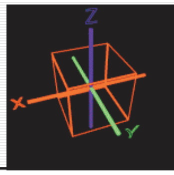
- 3DOF joints
- Rotation defined by the three axes and the angle of rotation around them
- the rotation order has to be specified such as X-Y-Z, Z-X-Y, Y-Z-X, etc

The one below is Z-X



Gimbal Lock

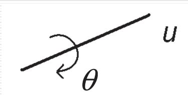
- two rotational axis of an object pointing in the same direction
- For example for rotation defined in the order of X-Y-Z
- Gimbal lock occurs when you rotate the object down the Y axis 90 degrees.
- The X and Z axis get pointed down the same axis
- 1DOF is lost



Free joint : Quaternion

- Do not have to worry about gimbal lock
- The rotation is represented by a vector of four components (w, x, y, z)
- A rotation about the unit vector $\boldsymbol{u}$ by an angle θ makes a quaternion

  $(\cos(\theta/2),\ u_x \sin(\theta/2),\ u_y \sin(\theta/2),\ u_z \sin(\theta/2))$



Generalized coordinates

A vector to specify the posture of the body
$(q_1, q_2, q_3, q_4, q_5, q_6, q_7, \ldots, q_n)$

Usually, the first three numbers : location of the root
The next three numbers : orientation of root
The rest: the joint angles of the body

Interpolation

The generalized coordinates can be interpolated by

- Linear interpolation

S(t) = (1-t) * P_0 + t * P_1 (Linear interpolation)
2 control points

- Bsplines
  (uniform cubic b-spline) 4 control points

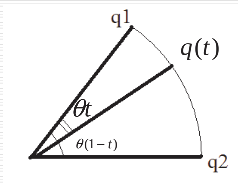
$$\mathbf{S}_i(t) = \begin{bmatrix} t^3 & t^2 & t & 1 \end{bmatrix} \frac{1}{6} \begin{bmatrix} -1 & 3 & -3 & 1 \\ 3 & -6 & 3 & 0 \\ -3 & 0 & 3 & 0 \\ 1 & 4 & 1 & 0 \end{bmatrix} \begin{bmatrix} \mathbf{p}_{i-1} \\ \mathbf{p}_i \\ \mathbf{p}_{i+1} \\ \mathbf{p}_{i+2} \end{bmatrix} \quad \text{for } t \in [0, 1]$$

Interpolation of Quaternions

- interpolation of two rotations (SLERP)
- Changing the orientation from q1 to q2 by rotating around a single axis $\boldsymbol{u}$
- θ angle of rotation around $\boldsymbol{u}$ to change from q1 to q2

$$\theta = \arccos(q_1 \bullet q_2)$$

$$q(t) = \frac{\sin \theta(1-t)}{\sin \theta} q_1 + \frac{\sin \theta t}{\sin \theta} q_2$$



Problems with interpolation

Problem:

- Important constraints might not be satisfied
  - The feet on the ground can slide
- Solutions
  - Insert many keyframes
  - Specify the position of the joints and use inverse kinematics to calculate the joint angles

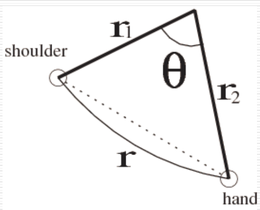
Inverse Kinematics

- Forward Kinematics: calculating the joint positions from the joint angles
- Inverse Kinematics : Calculate the joint angles based on the joint positions
  - Many different approaches
    - Analytical approaches (analytical solution exists)
    - Jacobian-based methods (compute by optimization)
  - Often used in robotics

Analytical Approaches

- Using an analytical solver for calculating the joint angles
- e.g. suppose the positions of the wrist and shoulder are given, calculate the elbow angle

$$\theta = \arccos \frac{r_1^2 + r_2^2 - r^2}{2 r_1 r_2}$$

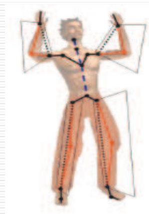


An example of an analytical approach

Divide the human body into five sections

- Torso, legs and arms
- For each section, calculate the joint angles based on the position of the end joints
- e.g., calculating the elbow joint angle by the position of the wrist and shoulder

Can further specify the angles of the independent joints, like those of the fingers, head, etc.



Jacobian-based method

Iteratively updating the generalized coordinates so that the position constraints are satisfied

- Minimizing the sum of squares of the increment
- Constrained optimization

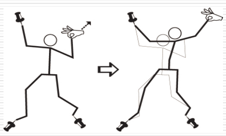
$$\Delta\theta = \arg\min_{\Delta\theta} \Delta\theta^T \Delta\theta$$

$$\text{s.t. } \Delta r = J \Delta\theta$$

Δr : movements of constrained segment

$\Delta\theta$: updates of the generalized coords

J : a matrix that correlates the position of the segments and the generalized coords



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  - Quaternions
  - Interpolation
  - Problem with interpolation
  - Inverse kinematics

Readings

- Quaternions tutorial, ftp://ftp.cis.upenn.edu/pub/graphics/shoemake/quatut.ps.Z
- Blender (a free modeling software) tutorial http://homepages.inf.ed.ac.uk/tkomura/can/blender/tutorial.html
- Inverse kinematics with Blender http://www.blender.org/development/release-logs/blender-240/inverse-kinematics/