Character Animation

COS 426
Syllabus

I. Image processing

II. Modeling

III. Rendering

IV. Animation

Image Processing
(Rusty Coleman, CS426, Fall99)

Modeling
(Dennis Zorin, CalTech)

Rendering
(Michael Bostock, CS426, Fall99)

Animation
(Angel, Plate 1)
Computer Animation

• Describing how 3D objects move over time
Computer Animation

- Challenge is balancing between …
  - Animator control
  - Physical realism
Character Animation

- Articulated figure:

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<table>
<thead>
<tr>
<th>Node</th>
<th>Connections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Root</td>
<td>Chest, LHip, RHip</td>
</tr>
<tr>
<td>Chest</td>
<td>Neck, LHip, RHip</td>
</tr>
<tr>
<td>Neck</td>
<td>Head, LHip, RHip</td>
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<tr>
<td>Head</td>
<td>Chest, Neck</td>
</tr>
<tr>
<td>LHip</td>
<td>LKnee, RAkne</td>
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<tr>
<td>LKnee</td>
<td>LAnkle</td>
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<td>LAnkle</td>
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<tr>
<td>RHip</td>
<td>RKnee</td>
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<td>RKnee</td>
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<td>LHip</td>
<td>LHip, RHip</td>
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</tbody>
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Character Animation Methods

- Kinematics
- Dynamics
- Motion capture
Character Animation Methods

• Kinematics
• Dynamics
• Motion capture
Kinematics

• Describe motion of articulated character

\[ X = (x, y) \]
Forward Kinematics

- Animator specifies joint angles: $\Theta_1$ and $\Theta_2$
- Computer finds positions 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 motions can be specified by spline curves
Example: Walk Cycle

• Articulated figure:

Diagram showing the articulation of a figure with joints at hip, knee, upper leg, lower leg, ankle, and foot, with movements described as hip rotation, knee rotation, and ankle rotation.
Example: Walk Cycle

- Hip joint orientation:

Keyframes
Example: Walk Cycle

• Knee joint orientation:
Example: Walk Cycle

- Ankle joint orientation:
Example: Robot

Mihai Parparita, COS 426, Princeton University, 2003
Example: Ice Skating

(Mao Chen, Zaijin Guan, Zhiyan Liu, Xiaohu Qie, CS426, Fall98, Princeton University)
Inverse Kinematics

- What if animator knows position of “end-effector”

\[ X = (x, y) \]

\[ \Theta_1 \]

\[ \Theta_2 \]

l_1

l_2

(0,0)

“End-Effector”
Inverse Kinematics

- Animator specifies end-effector positions: \(X\)
- Computer finds joint angles: \(\Theta_1\) and \(\Theta_2\):

\[
\Theta_2 = \cos^{-1}\left(\frac{x^2 + y^2 - l_1^2 - l_2^2}{2l_1l_2}\right)
\]

\[
\Theta_1 = \frac{-(l_2 \sin(\Theta_2)x + (l_1 + l_2 \cos(\Theta_2))y}{(l_2 \sin(\Theta_2))y + (l_1 + l_2 \cos(\Theta_2))x}
\]
Inverse Kinematics

• End-effector positions can be specified by spline curves

\[ X = (x, y) \]
Inverse Kinematics

• Problem for more complex structures
  ○ System of equations 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 (e.g., minimize energy in motion)
  - Non-linear optimization
Example: Ball Boy

“Ballboy”
Kinematics

• Advantages
  ○ Simple to implement
  ○ Complete animator control

• Disadvantages
  ○ Motions may not follow physical laws
  ○ Tedious for animator
Keyframe Animation

• Advantages
  ◦ Simple to implement
  ◦ Complete animator control

• Disadvantages
  ◦ Motions may not follow physical laws
  ◦ Tedious for animator

Lasseter ‘87
Outline

• Kinematics
   Dynamics
• Motion capture
Dynamics

• Simulation of physics insures realism of motion
Spacetime Constraints

- Animator specifies constraints:
  - What the character’s physical structure is
    » e.g., articulated figure
  - What the character has to do (keyframes)
    » e.g., jump from here to there within 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: particle with jet propulsion
  ◦ $\mathbf{x}(t)$ is position of particle at time $t$
  ◦ $\mathbf{f}(t)$ is force of jet propulsion at time $t$
  ◦ Particle’s equation of motion is:
    
    $$mx'' - \mathbf{f} - mg = 0$$

  ◦ Suppose we want to move from $a$ to $b$ within $t_0$ to $t_1$ with minimum jet fuel:
    
    $$\text{Minimize } \int_{t_0}^{t_1} \mathbf{f}(t)^2 \, dt \text{ subject to } x(t_0) = a \text{ and } x(t_1) = b$$

Witkin & Kass ’88
Spacetime Constraints

- Solve with iterative optimization methods

Witkin & Kass ’88
Spacetime Constraints

• Advantages:
  ◦ Free animator from having to specify details of physically realistic motion with spline curves
  ◦ Easy to vary motions due to new parameters and/or new constraints

• Challenges:
  ◦ Specifying constraints and objective functions
  ◦ Avoiding local minima during optimization
Spacetime Constraints

• Adapting motion: Heavier Base

Original Jump

Heavier Base

Witkin & Kass `88
Spacetime Constraints

• Adapting motion:

Hurdle

Witkin & Kass ’88
Spacetime Constraints

• Adapting motion:

Ski Jump

Witkin & Kass ’88
Spacetime Constraints

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Outline

• Kinematics
• Dynamics

➤ Motion capture
Motion Capture

• Measure motion of real characters and then simply “play it back” with kinematics
Motion Capture

- Measure motion of real characters and then simply “play it back” with kinematics

Captured Motion
Motion Capture

• Advantage:
  ◦ Physical realism

• Challenge:
  ◦ Animator control
Motion Capture

• Editing motion:

Gleicher
Motion Capture

- Motion graphs:

  Motion 1

  Motion 2

  Motion 1

  Motion 2
Motion Capture

• Motion graphs:

Kovacs & Gleicher
Motion Capture

- Retargeting motion:

Original motion data + constraints:

New character:

New motion data:
Motion Capture

- Retargeting motion:

Gleicher
Motion Capture

- Morphing motion:
Summary

• Kinematics
  ◦ Animator specifies poses (joint angles or positions) at keyframes and computer determines motion by kinematics and interpolation

• Dynamics
  ◦ Animator specifies physical attributes, constraints, and starting conditions and computer determines motion by physical simulation

• Motion capture
  ◦ Compute captures motion of real character and provides tools for animator to edit it