Computer Animation

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(601.457/657)

HB 16.5, 16.6
FvDFH 21.1, 21.3, 21.4
Announcements

• I will hold extra office hours:
  ◦ When: 11/13, 2:15-3:15 pm
  ◦ Location: my office
Overview

• Some early animation history
  ○ http://web.inter.nl.net/users/anima/index.htm
  ○ http://www.public.iastate.edu/~rllew/chrnearl.html

• Principles of animation

• Computer animation
Thaumatrope

- Why does animation work?
- Persistence of vision
- 1824 John Ayerton invents the *thaumatrope*
- Or, 1828 Paul Roget invents the *thaumatrope*
Thaumatrope

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Phenakistoscope

- Invented independently by 2 people in 1832
- Disc mounted on spindle
- Viewed through slots with images facing mirror
- Turning disc animates images
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Zoetrope (1834)

- Images arranged on paper band inside a drum
- Slits cut in the upper half of the drum
- Opposite side viewed as drum rapidly spun
- Praxinoscope is a variation on this
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• Praxinoscope is a variation on this
Mutoscope (1895)

- Coin-operated “flip-book” animation
- Picture cards attached to a drum
- Popular at sea-side resorts, etc.
Animation History

• “Humorous Phases of Funny Faces” (1906)
Key Developments

• Plot
• Creation of animation studios
• Inking on cels

“Felix the Cat”
Otto Messmer (1921)

“Steamboat Willie”
Walt Disney (1928)

“Gertie the Dinosaur”
Windsor McCay (1914)
Key Developments

- Max Fleischer invents rotoscoping (1921)
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Key Developments

• “Flowers and Trees”, 1932:
  ° Uses color, wins Academy Award

• “Snow White” (aka “Disney’s Folly”), 1937:
  ° $1.4 million to make
  ° 750 artists
  ° Highest grossing ($8 million)
Animation Uses

- Entertainment
- Education
- Propaganda
Overview

• Some early animation history
• Principles of animation
• Computer animation
Principles of Traditional Animation

How do we communicate aspects of the animation that are not strictly visual?

- Rigidity
- Weight
- Mood
- Intent
- Focus
- Etc.
Principles of Traditional Animation

1. Squash and Stretch
- Give a sense of weight and flexibility to drawn objects

The Illusion of Life (http://the12principles.tumblr.com/)
https://en.wikipedia.org/wiki/12_basic_principles_of_animation
Principles of Traditional Animation

2. Anticipation
• Prepare the audience for an action, and make the action appear more realistic

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Principles of Traditional Animation

3. Staging
• Direct the audience's attention, and make it clear what is of greatest importance in a scene

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https://en.wikipedia.org/wiki/12_basic_principles_of_animation
Principles of Traditional Animation

4. Straight Ahead Action and Pose-to-Pose Action

○ Drawing a scene frame by frame from beginning to end vs.
○ Drawing a few key frames, and filling in intervals later

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https://en.wikipedia.org/wiki/12_basic_principles_of_animation
5. Follow Through and Overlapping Action

• Render movement more realistically, and help give the impression that characters follow the laws of physics

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https://en.wikipedia.org/wiki/12_basic_principles_of_animation
Principles of Traditional Animation

6. Slow In and Out
- Use more drawings near the beginning and end of an action, emphasizing the extreme poses

The Illusion of Life (http://the12principles.tumblr.com/)
https://en.wikipedia.org/wiki/12_basic_principles_of_animation
7. Arcs
• following implied "arcs" for greater realism

The Illusion of Life (http://the12principles.tumblr.com/)
https://en.wikipedia.org/wiki/12_basic_principles_of_animation
8. Secondary Action
• Adding secondary actions to the main action gives a scene more life
Principles of Traditional Animation

9. Timing

• The number of drawings or frames for a given action, which translates to the speed of the action on film

The Illusion of Life (http://the12principles.tumblr.com/)
https://en.wikipedia.org/wiki/12_basic_principles_of_animation
10. Exaggeration

- Remain true to reality, just present it in a wilder, more extreme form

The Illusion of Life (http://the12principles.tumblr.com/)
https://en.wikipedia.org/wiki/12_basic_principles_of_animation
Principles of Traditional Animation

11. Solid Drawing

- Take into account forms in three-dimensional space, or giving them volume and weight

The Illusion of Life (http://the12principles.tumblr.com/)
https://en.wikipedia.org/wiki/12_basic_principles_of_animation
Principles of Traditional Animation

12. Appeal

• The viewer feels the character is real and interesting

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Principles of Traditional Animation

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- Weight
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- Etc.

Luxo Junior
Overview

• Some early animation history
• Principles of animation

• Computer animation
  ◦ Keyframe animation
  ◦ Articulated figures
  ◦ Kinematics and dynamics
Keyframe Animation

- Define character poses at specific time steps called “keyframes”
Keyframe Animation

• Interpolate variables describing keyframes to determine poses for character “in-between”
Articulated Figures

- Character poses described by set of rigid bodies connected by “joints”
Articulated Figures

- Well-suited for humanoid characters

Diagram:
- Root
  - Chest
    - Neck
      - Head
    - LCollar
      - LShld
        - LElbow
          - LWrist
      - RElbow
        - RWrist
    - RCollar
      - RShld
      - RKnee
        - RAnkle
    - LHIp
      - LKnee
        - LANkle
    - RHIp

References:
Rose et al. `96
Example: Walk Cycle

- Articulated figure:

```
Hip
   ├── Upper leg
     │   ├── Knee
     │       ├── Lower leg
     │           └── Ankle
     │               └── Foot
     └── Upper leg (hip rot)
           └── Hip rotate
               └── Lower leg (knee rot)
                               └── Hip rotate + knee rot
                                   └── Foot (ankle rot)
```
Example: Walk Cycle

- Hip joint orientation:
Example: Walk Cycle

• Knee joint orientation:
Example: Walk Cycle

• Ankle joint orientation:
Example: Walk Cycle

http://www.ischool.utexas.edu/~luna73/architecture/
Keyframe Animation

- In-betweening (translation):
  - Cubic spline interpolation – maybe not be good enough
    » May not follow physical laws

Recall: Convex hull containment

Lasseter `87
Keyframe Animation

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  - Cubic spline interpolation – maybe not be good enough
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Lasseter `87
Articulated Figures

- In-betweening (rotation)
  - Interpolate angles, not positions, between key-frames

Good arm

Bad arm
Kinematics and Dynamics

• **Kinematics:** *Study of motion w/o regard for the cause*
  - Considers only motion
  - Determined by positions, velocities, accelerations

• **Dynamics:** *Study of the cause of motion*
  - Considers underlying forces
  - Compute motion from initial conditions and physics
Example: 2-Link Structure

- Two links connected by rotational joints

\[ X = (x,y) \]

\( l_1 \) \( l_2 \)

(0,0) "End-Effector"
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: 2-Link Structure

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

\[ X = (x, y) \]

\[ l_1 \]

\[ l_2 \]

(0,0)

\[ \Theta_1 \]

\[ \Theta_2 \]

“End-Effector”
Inverse Kinematics

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

\[
\begin{align*}
X &= (x, y) \\
\Theta_2 &= \cos^{-1}\left(\frac{x^2 + y^2 - l_1^2 - l_2^2}{2l_1l_2}\right) \\
\Theta_1 &= \frac{-(l_2 \sin(\Theta_2))x + (l_1 + l_2 \cos(\Theta_2))y}{(l_2 \sin(\Theta_2))y + (l_1 + l_2 \cos(\Theta_2))x}
\end{align*}
\]
Inverse Kinematics

• End-effector positions can be specified by splines
Inverse Kinematics

• Problem for more complex structures
  ◦ System of equations is usually under-defined
  ◦ Multiple (or no) 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
Summary of Kinematics

• Forward kinematics
  ◦ Specify conditions (joint angles)
  ◦ Compute positions of end-effectors

• Inverse kinematics
  ◦ “Goal-directed” motion
  ◦ Specify goal positions of end effectors
  ◦ Compute conditions required to achieve goals

Inverse kinematics provides easier specification for many animation tasks, but it is computationally more difficult.
Dynamics

• Simulation of physics insures realism of motion

Lasseter `87
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 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 the constraints
- Example: particle with jet propulsion
  - \( x(t) \) is position of particle at time \( t \)
  - \( f(t) \) is the directional force of jet propulsion at time \( t \)
  - Particle’s equation of motion is:
    \[
    0 = m(x'' - g) - f
    \]
  - Move from \( a \) to \( b \) within \( t_0 \) to \( t_1 \), minimizing
    \[
    \int_{t_0}^{t_1} |f(t)|^2 dt
    \]
  - Such that:
    \[
    x(t_0) = a, \quad x'(t_0) = 0, \quad x(t_1) = b, \quad \text{and} \quad x'(t_1) = 0
    \]
Spacetime Constraints

Discretize time steps \( \{x_0, \cdots, x_N\} \):

\[
x'_i = \frac{x_i - x_{i-1}}{h}
\]

\[
x''_i = \frac{x_{i+1} - 2x_i + x_{i-1}}{h^2}
\]

\[
f_i = m \left( \frac{x_{i+1} - 2x_i + x_{i-1}}{h^2} - g \right)
\]

Minimize

\[
\int_{t_0}^{t_1} |f(t)|^2 dt \approx h \sum_i |f_i|^2 = hm^2 \sum_i \left\| \frac{x_{i+1} - 2x_i + x_{i-1}}{h^2} - g \right\|^2
\]

subject to \( x_{-1} = x_0 = a \) and \( x_N = x_{N+1} = b \).

Witkin & Kass `88
Spacetime Constraints

For simple scenarios:

- Solve a linear system
  \[ Ax = b \]

For complex scenarios:

- Solve using iterative optimization techniques

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
Dynamics

- Other physical simulations:
  - Rigid bodies
  - Soft bodies
  - Cloth
  - Liquids
  - Gases
  - etc.

  Hot Gases
  *(Foster & Metaxas `97)*

  Cloth
  *(Baraff & Witkin `98)*