Lecture 16: Animation
Announcements

• Please fill up the team-forming sheet
  - You need to be listed there for us to arrange your presentation
  - Again, you cannot work alone without my approval

• No office hour today

• This Thursday
  - Yaoyi will be giving the lecture

• The last assignment (rope simulator) will be out tonight
Last Lectures

• Light transport
  - Reflection equation
  - Rendering equation

• Materials
  - What is material
  - Common materials
Today

• Measuring materials

• Animation
  - History
  - Keyframe animation
  - Physical simulation
Measuring BRDFs
Measuring BRDFs: Motivation

Avoid need to develop / derive models

- Automatically includes all of the scattering effects present

Can accurately render with real-world materials

- Useful for product design, special effects, ...

Theory vs. practice:

[Bagher et al. 2012]

Slide courtesy of Prof. Ren Ng, UC Berkeley
Image-Based BRDF Measurement

[Marschner et al. 1999]
Measuring BRDFs: gonioreflectometer

Spherical gantry at UCSD

Slide courtesy of Prof. Ren Ng, UC Berkeley
Measuring BRDFs

General approach:

```plaintext
foreach outgoing direction wo
  move light to illuminate surface with a thin beam from wo
for each incoming direction wi
  move sensor to be at direction wi from surface
measure incident radiance
```

Improving efficiency:

- Isotropic surfaces reduce dimensionality from 4D to 3D
- Clever optical systems...
Tabular Representation

Store regularly-spaced samples in

\((\theta_i, \theta_o, |\phi_i - \phi_o|)\)

- Better: reparameterize angles to better match specularities

Generally need to resample measured values to table

Very high storage requirements

MERL BRDF Database
[Matusik et al. 2004]
90*90*180 measurements
Course Roadmap

Rasterization

Ray tracing

Geometry

Animation / simulation
Introduction to Computer Animation
Animation

“Bring things to life”

- Communication tool
- Aesthetic issues often dominate technical issues

An extension of modeling

- Represent scene models as a function of time

Output: sequence of images that when viewed sequentially provide a sense of motion

- Film: 24 frames per second
- Video (in general): 30 fps
- Virtual reality: 90 fps
Historical Points in Animation
(slides courtesy of Prof. Keenan Crane @ CMU)
First Animation

(Shahr-e Sukhteh, Iran 3200 BCE)
History of Animation

(Phenakistoscope, 1831)
First Film

Originaly used as scientific tool rather than for entertainment

Critical technology that accelerated development of animation

Edward Muybridge, “Sallie Gardner” (1878)
First Hand-Drawn Feature-Length (>40 mins) Animation

Disney, “Snow White and the Seven Dwarfs” (1937)
First Digital-Computer-Generated Animation

Ivan Sutherland, “Sketchpad” (1963) – Light pen, vector display
Early Computer Animation

Ed Catmull & Frederick Parke, “Computer Animated Faces” (1972)
Digital Dinosaurs!

Jurassic Park (1993)
First CG Feature-Length Film

Computer Animation - 10 years ago

Sony Pictures Animation, “Cloudy With a Chance of Meatballs” (2009)
Computer Animation - last year

Walt Disney Animation Studios, “Frozen 2” (2019)
Keyframe Animation
Keyframe Animation

Animator (e.g. lead animator) creates keyframes
Assistant (person or computer) creates in-between frames ("tweening")
Keyframe Interpolation

Think of each frame as a vector of parameter values
Keyframe Interpolation of Each Parameter

Linear interpolation usually not good enough

Recall splines for smooth / controllable interpolation
Physical Simulation
Newton’s Law

\[ F = ma \]

- Force
- Mass
- Acceleration
Physically Based Animation

Generate motion of objects using numerical simulation

\[ \mathbf{x}^{t+\Delta t} = \mathbf{x}^t + \Delta t \mathbf{v}^t + \frac{1}{2} (\Delta t)^2 \mathbf{a}^t \]
Example: Cloth Simulation
Example: Fluids

Macklin and Müller, Position Based Fluids
Mass Spring System:
Example of Modeling a Dynamic System
Example: Mass Spring Rope

https://youtu.be/Co8enp8CH34
Example: Hair
Example: Mass Spring Mesh
A Simple Spring

Idealized spring

\[ f_{a \to b} = k_{s} (b - a) \]

\[ f_{b \to a} = -f_{a \to b} \]

Force pulls points together

Strength proportional to displacement (Hooke’s Law)

\( k_{s} \) is a spring coefficient: stiffness

Problem: this spring wants to have zero length
Non-Zero Length Spring

Spring with non-zero rest length

\[ f_{a \rightarrow b} = k_s \frac{b - a}{||b - a||} (||b - a|| - l) \]

Problem: oscillates forever
Dot Notation for Derivatives

If $\mathbf{x}$ is a vector for the position of a point of interest, we will use dot notation for velocity and acceleration:

\[
\begin{align*}
\mathbf{x} \\
\dot{\mathbf{x}} &= \mathbf{v} \\
\ddot{\mathbf{x}} &= \mathbf{a}
\end{align*}
\]
Introducing Energy Loss

Simple motion damping

\[ f = -k_d \dot{b} \]

- Behaves like viscous drag on motion
- Slows down motion in the direction of velocity
- \( k_d \) is a damping coefficient

Problem: slows down all motion

- Want a rusty spring’s oscillations to slow down, but should it also fall to the ground more slowly?
Internal Damping for Spring

Damp only the internal, spring-driven motion

\[ f_b = -k_d \frac{b - a}{\|b - a\|} (\dot{b} - \dot{a}) \cdot \frac{b - a}{\|b - a\|} \]

- Viscous drag only on change in spring length
- Won’t slow group motion for the spring system (e.g. global translation or rotation of the group)
- Note: This is only one specific type of damping
Structures from Springs

Sheets

Blocks

Others
Structures from Springs

Behavior is determined by structure linkages

This structure will not resist shearing

This structure will not resist out-of-plane bending...
Structures from Springs

Behavior is determined by structure linkages

This structure will resist shearing but has anisotropic bias

This structure will not resist out-of-plane bending either...
Structures from Springs

Behavior is determined by structure linkages

This structure will resist shearing.
Less directional bias.

This structure will not resist out-of-plane bending either...
Structures from Springs

They behave like what they are (obviously!)

This structure will resist shearing.
Less directional bias.

This structure will resist out-of-plane bending
Red springs should be much weaker
Example: Mass Spring Dress + Character
Aside: FEM (Finite Element Method) Instead of Springs
Thank you!