Lecture 16: Animation
Announcements

• My temporary office hour at 10-11AM on Thursday (this week only)

• Tentative arrangement for next Wednesday
  - No class

• Assignment 8 (Mass-Spring system) will be out on Thursday
  - Related to the next lecture
  - But this lecture should be enough for you to get started (and finish)

• Final Exam (or rather, midterm II) is on Jun 13
  - Specific time and location TBD
Last Lecture

• Color
  – What is color
  – Color perception
  – Color reproduction / matching
Today

• Color
  - Color reproduction / matching (finishing up)
  - Color spaces

• Animation
  - History
  - Keyframe animation
  - Physical simulation
Color Reproduction / Matching
CIE RGB Color Matching Experiment

Same setup as additive color matching before, but primaries are monochromatic light (single wavelength) of the following wavelengths defined by CIE RGB standard:

- 700 nm
- 546.1 nm
- 435.8 nm

The test light is also a monochromatic light.

?? nm
CIE RGB Color Matching Functions

Graph plots how much of each CIE RGB primary light must be combined to match a monochromatic light of wavelength given on x-axis.

Careful: these are not response curves or spectra!
Color Reproduction with Matching Functions

For any spectrum $s$, the perceived color is matched by the following formulas for scaling the CIE RGB primaries

\[
R_{\text{CIE RGB}} = \int_{\lambda} s(\lambda) \bar{r}(\lambda) \, d\lambda
\]

\[
G_{\text{CIE RGB}} = \int_{\lambda} s(\lambda) \bar{g}(\lambda) \, d\lambda
\]

\[
B_{\text{CIE RGB}} = \int_{\lambda} s(\lambda) \bar{b}(\lambda) \, d\lambda
\]

Careful: these are not response curves or primary spectra!
Color Reproduction with Matching Functions

For any spectrum $s$, the perceived color is matched by the following formulas for scaling the CIE RGB primaries

Written as vector dot products:

$$R_{\text{CIE RGB}} = s \cdot \bar{r}$$
$$G_{\text{CIE RGB}} = s \cdot \bar{g}$$
$$B_{\text{CIE RGB}} = s \cdot \bar{b}$$

Matrix formulation:

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix}_{\text{CIE RGB}} = \begin{bmatrix} \bar{r} \\ \bar{g} \\ \bar{b} \end{bmatrix} s$$

Careful: these are not response curves or primary spectra!

Slide courtesy of Prof. Ren Ng, UC Berkeley
Color Spaces
Color Spaces

Need three numbers to specify a color

• but what three numbers?

• a color space is an answer to this question
Color Spaces

Common example: display color space

- define colors by what R, G, B scalar values will produce them on your monitor
  - (in math, \( s = rR + gG + bB \) for some spectra \( r, g, b \))
- device dependent (depends on gamma, phosphors, gains, ...)
  - therefore if I choose R,G,B by looking at my display and send it to you, you may not see the same color
- also leaves out some colors (limited gamut), e.g. vivid yellow
Standard Color Spaces

Standardized RGB (sRGB)

- makes a particular monitor RGB standard
- other color devices simulate that monitor by calibration
- widely adopted today
- gamut (?) is limited
A Universal Color Space: CIE XYZ

Imaginary set of standard color primaries X, Y, Z

• Primary colors with these matching functions do not exist

• Y is luminance (brightness regardless of color)

Designed such that

• Matching functions are strictly positive

• Span all observable colors
Separating Luminance, Chromaticity

Luminance: \( Y \)

Chromaticity: \( x, y, z \), defined as

\[
x = \frac{X}{X + Y + Z}
\]
\[
y = \frac{Y}{X + Y + Z}
\]
\[
z = \frac{Z}{X + Y + Z}
\]

- since \( x + y + z = 1 \), we only need to record two of the three
- usually choose \( x \) and \( y \), leading to \((x, y)\) coords at a specific brightness \( Y \)
CIE Chromaticity Diagram

The curved boundary

- named spectral locus
- corresponds to monochromatic light (each point representing a pure color of a single wavelength)

Any color inside is less pure

- i.e. mixed

Pure (saturated) spectral colors around the edge of the plot

Less pure (desaturated) colors in the interior of the plot

White at the centroid of the plot (1/3, 1/3)
Gamut

Gamut is the set of chromaticities generated by a set of color primaries

Different color spaces represent different ranges of colors

So they have different gamuts, i.e. they cover different regions on the chromaticity diagram
Gamut

sRGB is a common color space used throughout the internet.

Slide courtesy of Prof. Ren Ng, UC Berkeley
Perceptually Organized Color Spaces
HSV Color Space (Hue-Saturation-Value)

Axes correspond to artistic characteristics of color

Widely used in a “color picker”
Perceptual Dimensions of Color

Hue

- the “kind” of color, regardless of attributes
- colorimetric correlate: dominant wavelength
- artist’s correlate: the chosen pigment color

Saturation

- the “colorfulness”
- colorimetric correlate: purity
- artist’s correlate: fraction of paint from the colored tube

Lightness (or value)

- the overall amount of light
- colorimetric correlate: luminance
- artist’s correlate: tints are lighter, shades are darker
CIELAB Space (AKA L*a*b*)

A commonly used color space that strives for perceptual uniformity

- L* is lightness (brightness)
- a* and b* are color-opponent pairs
  - a* is red-green
  - b* is blue-yellow
Opponent Color Theory

There’s a good neurological basis for the color space dimensions in CIE LAB

- the brain seems to encode color early on using three axes:
  - white — black, red — green, yellow — blue
- the white — black axis is lightness; the others determine hue and saturation
Opponent Color Theory

• one piece of evidence: you can have a light green, a dark green, a yellow-green, or a blue-green, but you can’t have a reddish green (just doesn’t make sense)
  • thus red is the opponent to green

• another piece of evidence: afterimages (following slides)
Everything is Relative

Edward H. Adelson

Slide courtesy of Prof. Ren Ng, UC Berkeley
Everything is Relative
Everything is Relative
Everything is Relative
Everything is Relative
Everything is Relative
Everything is Relative
Everything is Relative
CMYK: A Subtractive Color Space

Subtractive color model

• The more you mix, the darker it will be

Cyan, Magenta, Yellow, and Key

Widely used in printing

Question:

• If mixing C, M and Y gives K, why do you need K?
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 Keenan Crane)
First Animation

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

(Phenakistoscope, 1831)
First Film

Originally 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)
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

Slide courtesy of Prof. Ren Ng, UC Berkeley
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 \quad Mass \quad Acceleration
Physically Based Animation

Generate motion of objects using numerical simulation

\[ x^{t+\Delta t} = x^t + \Delta t v^t + \frac{1}{2} (\Delta t)^2 a^t \]
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

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

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

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

Slide courtesy of Prof. Ren Ng, UC Berkeley
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 $x$ is a vector for the position of a point of interest, we will use dot notation for velocity and acceleration:

\[
x \\
\dot{x} = v \\
\ddot{x} = a
\]
Introducing Energy Loss

Simple motion damping

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

- Behaves like viscous drag on motion
- Slows down motion in the direct of motion
- \( k_d \) 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

Slide courtesy of Prof. Ren Ng, UC Berkeley
Structures from Springs

Sheets

Blocks

Others

Slide courtesy of Prof. Ren Ng, UC Berkeley
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
Thank you!