Menu February 7, 2017

Topics:
  Texture (cont.)
  Colour

Reading:
  Today: Forsyth & Ponce (2nd ed.) 3.1–3.3

Reminders:
  Midterm exam, in class, Thursday, February 16
  Assignment 4 due Tuesday February 14, start of class

www: http://www.cs.ubc.ca/~little/cpsc425/
piazza: https://piazza.com/ubc.ca/winterterm22015/cpsc425/
Lecture 9: Re-cap

- Texture representation is hard
  — difficult to define, to analyze
  — texture synthesis appears more tractable

- Objective of texture synthesis is to generate new examples of a texture
  — Efros and Leung: Draw samples directly from the texture to generate one pixel at a time. A “data-driven" approach.

- Approaches to texture embed assumptions related to human perception
Spots and Bars (Fine Scale)

Forsyth & Ponce (1st ed.) Figures 9.3–9.4
Spots and Bars (Coarse Scale)

Forsyth & Ponce (1st ed.) Figures 9.3 & 9.5
Laplacian Pyramid

- Building a Laplacian pyramid:
  - Create a Gaussian pyramid
  - Take the difference between one Gaussian pyramid level and the next (before subsampling)

- Properties
  - Also known as the difference-of-Gaussian (DOG) function, a close approximation to the Laplacian
  - It is a band pass filter – each level represents a different band of spatial frequencies

- Reconstructing the original image:
  - Reconstruct the Gaussian pyramid starting at top
Gaussian Pyramid

Forsyth & Ponce (2nd ed.) Figure 4.17
Laplacian Pyramid

Forsyth & Ponce (1st ed.) Figure 9.8
Oriented Pyramids

- Laplacian pyramid is orientation independent

- **Idea:** Apply an oriented filter at each layer
  - represent image at a particular scale and orientation
  - Aside: We do not study details in this course
Oriented Pyramids (cont’d)

Oriented Pyramids (cont’d)

Forsyth & Ponce (1st ed.) Figure 9.14
Final Texture Representation

Steps:

1. Form a Laplacian and oriented pyramid (or equivalent set of responses to filters at different scales and orientations)

2. Square the output (makes values positive)

3. Average responses over a neighborhood by blurring with a Gaussian

4. Take statistics of responses
   — Mean of each filter output
   — Possibly standard deviation of each filter
Today’s Fun Example

Video: Colour optical illusion
Another Colour Illusion

Image credit: Akiyoshi Kitaoka
Light is produced in different amounts at different wavelengths by each light source.

Light is differentially reflected at each wavelength, which gives objects their natural colour (surface albedo).

The sensation of colour is determined by the human visual system, based on the product of light and reflectance.
Relative Spectral Power of Two Standard Illuminants

D65 models sunlight. Illuminant A models incandescent light

Forsyth & Ponce (2nd ed.) Figure 3.4

Relative spectral power plotted against wavelength in nm
Spectral Albedo of Natural Surfaces

Forsyth & Ponce (2nd ed.) Figure 3.6
Colour Appearance

- Reflected light at each wavelength is the product of illumination and surface reflectance at that wavelength

- Surface reflectance often is modeled as having two components:
  - Lambertian reflectance: equal in all directions (diffuse)
  - Specular reflectance: mirror reflectance (shiny spots)
Show a split field to subjects. One side shows the light whose colour one wants to match. The other a weighted mixture of three primaries (fixed lights)
Colour Matching Experiments: I (cont’d)

Figure credit: Brian Wandell, *Foundations of Vision*, Sinauer Associates, 1995
Example 1: Colour Matching Experiment

Example credit: Bill Freeman
Example 1: Colour Matching Experiment (cont’d)

Example credit: Bill Freeman
Example 1: Colour Matching Experiment (cont’d)

Example credit: Bill Freeman
Example 2: Colour Matching Experiment

Example credit: Bill Freeman
Example credit: Bill Freeman
Example 2: Colour Matching Experiment (cont’d)

We say a “negative” amount of $p_2$ was needed to make the match, because we added it to the test color’s side.

The primary color amounts needed for a match:

Example credit: Bill Freeman
Many colours can be represented as a positive weighted sum of $A, B, C$

Write

$$M = a A + b B + c C$$

where the $=$ sign should be read as “matches”

This is additive matching

Defines a colour description system
— two people who agree on $A, B, C$ need only supply $(a, b, c)$
Some colours can’t be matched this way

Instead, we must write

\[ M + aA = bB + cC \]

where, again, the \( = \) sign should be read as “matches”

This is subtractive matching

Interpret this as \((-a, b, c)\)

Problem for designing displays:

Choose phosphors \(R, G, B\) so that positive linear combinations match a large set of colours
Principle of Trichromacy

Experimental facts:

- Three primaries work for most people, provided we allow subtractive matching
  - Exceptional people can match with two or only one primary
  - This likely is caused by biological deficiencies

- Most people make the same matches
  - There are some anomalous trichromats, who use three primaries but match with different combinations
Human Cone Sensitivities

Figure credit: Brian Wandell, *Foundations of Vision*, Sinauer Associates, 1995
Two lights whose spectral power distributions appear identical to most observers are called *metamers*.
Grassman’s Laws

For colour matches:

— symmetry: \( U = V \iff V = U \)
— transitivity: \( U = V \) and \( V = W \) \(\Rightarrow\) \( U = W \)
— proportionality: \( U = V \iff tU = tV \)
— additivity: if any two (or more) of the statements

\[
U = V, \\
W = X, \\
(U + W) = (V + X)
\]

are true, then so is the third

These statements mean that colour matching is, to an accurate approximation, linear.
Representing Colour

- Describing colours accurately is of practical importance — e.g. Manufacturers are willing to go to a great deal of trouble to ensure that different batches of their product have the same colour.

- This requires a standard system for representing colour.
Linear Colour Spaces

*A choice of primaries yields a linear colour space* — the coordinates of a colour are given by the weights of the primaries used to match it.

Choice of primaries is equivalent to choice of colour space.

**RGB:** Primaries are monochromatic energies, say 645.2 nm, 526.3 nm, 444.4 nm.

**CIE XYZ:** Primaries are imaginary, but have other convenient properties. Colour coordinates are \((X, Y, Z)\), where \(X\) is the amount of the \(X\) primary, etc.
RGB Colour Matching Functions

- Primaries monochromatic
- Wavelengths 645.2, 526.3 and 444.4 nm
- Negative parts means some colours can be matched only subtractively

Forsyth & Ponce (2nd ed.) Figure 3.9
CIE XYZ Colour Matching Functions

CIE XYZ: Colour matching functions are positive everywhere, but primaries are imaginary. Usually draw $x$, $y$, where

$$x = X/(X + Y + Z)$$

$$y = Y/(X + Y + Z)$$

Overall brightness is ignored.
Geometry of Colour (CIE)

- White is in the center, with saturation increasing towards the boundary.
- Mixing two coloured lights creates colours on a straight line.
- Mixing 3 colours creates colours within a triangle.
- Curved edge means there are no 3 actual lights that can create all colours that humans perceive!
RGB Colour Space

The sub-space of CIE colours that can be displayed on a typical computer monitor (phosphor limitations keep the space quite small)
Uniform Colour Spaces

- Usually one cannot reproduce colours exactly

- This means it is important to know whether a colour difference would be noticeable to a human viewer
Uniform Colour Spaces

McAdam Ellipses: Each ellipse shows colours perceived to be the same

10 times actual size
Forsyth & Ponce (2nd ed.) Figure 3.14

Actual size
Uniform Colour Spaces

- McAdam ellipses demonstrate that differences in $x$, $y$ are a poor guide to differences in perceived colour.

- A **uniform colour space** is one in which differences in coordinates are a good guide to differences in perceived colour — example: CIE LAB.
HSV Colour Space

- The coordinates of a colour in a linear space like RGB or CIE XYZ may not necessarily...
  
  — encode properties that are common in language or important in applications
  
  — capture human intuitions about the topology of colours, e.g. hue relations are naturally expressed in a circle
HSV Colour Space

More natural description of colour for human interpretation

**Hue**: attribute that describes a pure colour

— e.g. ’red’, ’blue’

**Saturation**: measure of the degree to which a pure colour is diluted by white light

— pure spectrum colours are fully saturated

**Value**: intensity or brightness

Hue + saturation also referred to as chromaticity.
HSV Colour Space

Image credit: Gonzalez and Woods, 2008
Colour Constancy

- Image colour depends on both light colour and surface colour

- **Colour constancy:** determine hue and saturation under different colours of lighting

- It is surprisingly difficult to predict what colours a human will perceive in a complex scene
  — depends on context, other scene information

- Humans can usually perceive
  — the colour a surface would have under white light
  — the colour of the reflected light (separate surface colour from measured colour)
Colour Constancy

A classic experiment by Land and McCann
Environmental Effects

- Chromatic adaptation: If the human visual system is exposed to a certain colour light for a while, colour perception starts to skew.

- Contrast effects: Nearby colours affect what is perceived.
Summary

- Approaches to texture exploit pyramid (i.e. scaled) and oriented representations
- Human colour perception
  - colour matching experiments
  - additive and subtractive matching
  - principle of trichromacy
- RGB and CIE XYZ are linear colour spaces
- Uniform colour space: differences in coordinates are a good guide to differences in perceived colour
- HSV colour space: more intuitive description of colour for human interpretation
- (Human) colour constancy: perception of intrinsic surface colour under different colours of lighting