Announcements

- HW4 due Friday 12/7.
- Final Exam: Friday 12/14 at 7pm-10pm
- If you’re right handed, please use right handed desks and vice-versa.
- Final Exam review session (Q&A):
  - Wed. 12/12 4:00-4:50, Pepper Canyon Room 121
- Kriegman Office Hours next week:
  Wed 12:30-1:30
  Thurs: 3:30-4:30
Final Exam

- Closed book
- One cheat sheet
  - Single piece of paper any size, handwritten, no photocopying, no physical cut & paste, both sides OK.
- What to study
  - Basically material presented in class, and supporting material from readings
  - If it was in text, but NEVER mentioned in class, it is very unlikely to be on the exam
- Question style:
  - Short answer
  - Some longer problems to be worked out.
- When in doubt write something. There will be partial credit.

Course + TA evaluations

https://academicaffairs.ucsd.edu/Modules/Evals?e4431126
Many kernels yielding many features!

Color images
3 channels

Conv layer features
9 channels

ImageNet

20,000+ categories x ~1000 instances = 14,000,000+ images
Classification: ImageNet Challenge top-5 error

152 layers

ILSVRC’15 ResNet
ILSVRC’14 GoogLeNet
ILSVRC’14 VGG
ILSVRC’13
ILSVRC’12 AlexNet
ILSVRC’11 shallow

Figure source: Kaiming He
Color Cameras: Three kinds of pixels

3 Chip Camera

Optically split incoming light onto three sensors, each responding to different wavelengths

Single sensor with color mosaic overlaid.

The appearance of colors

• Color appearance is strongly affected by (at least):
  – Spectrum of lighting striking the retina
  – other nearby colors (space)
  – adaptation to previous views (time)
  – “state of mind”
4.1 **NEWTON’S SUMMARIZED EXPERIMENT** after experiments with light. Using a point source of light and a prism, Newton separated sunlight into fundamental components. By reversing the rays, he also showed that the decomposition is reversible.

From Foundations of Vision, Brian Wandell, 1995, via B. Freeman slides
**note:** black & white
Light Spectrum

![Light Spectrum Image]

Talking about colors

1. Spectrum –
   - A positive function over interval 400nm-700nm
   - “Infinite” number of values needed.

2. Names
   - red, harvest gold, cyan, aquamarine, auburn, chestnut
   - A large, discrete set of color names

3. R,G,B values
   - Just 3 numbers
Color Reflectance

Measured color spectrum is a function of the spectrum of the illumination and reflectance

\[ C(\lambda) = I(\lambda) \ast R(\lambda) \]

Illumination Spectra

Blue skylight

Incandescent bulb

From Foundations of Vision, Brian Wandell, 1995, via B. Freeman slides
Measurements of relative spectral power of sunlight, made by J. Parkkinen and P. Silfsten. Relative spectral power is plotted against wavelength in nm. The visible range is about 400nm to 700nm. The color names on the horizontal axis give the color names used for monochromatic light of the corresponding wavelength --- the “colors of the rainbow”. Mnemonic is “Richard of York got blisters in Venice”.

Spectral albedoes for several different leaves, with color names attached. Notice that different colours typically have different spectral albedo, but that different spectral albedoes may result in the same perceived color (compare the two whites). Spectral albedoes are typically quite smooth functions. Measurements by E. Koivisto.
Fresnel Equation for Polished Copper

Dialectrics
(e.g., plastics)

Diffuse + specular component
Specularity is the color of the light source
This was model of color for the SUV color space and your home work.
Why is this important?

- The color that is measured by camera depends on
  1. Camera sensors sensetivities
  2. Spectrum of illuminant
  3. Reflectance properties of objects of the scene.
  4. An “object’s color” doesn’t actually make a lot of sense, unless you talk about it under a reference light.
Let’s take a look at color in CoralNet images

Perception of color
Can I adjust the values of $p_1$, $p_2$, $p_3$ so that color on right matches the color on the left?

Not on a computer Screen

Color matching experiment 1
Color matching experiment 1

Test/Probe color

Color matching experiment 1

Test/Probe color
Color matching experiment 1

Test/Probe color

The primary color amounts needed for a match

$p_1$, $p_2$, $p_3$

Color matching experiment 2

Test/Probe color
Color matching experiment 2

Test/Probe color

CSE252a, Fall 2018
The principle of trichromacy

- Experimental facts:
  - Three primaries will work for most people if we allow subtractive matching
    - Exceptional people can match with two or only one primary.
    - This could be caused by a variety of deficiencies, e.g. color blindness.
  - Most people make the same matches.
    - There are some anomalous trichromats, who use three primaries but make different combinations to match.
Three types of cones: R, G, B

Response of k’th cone = \( \int \rho_k(\lambda)E(\lambda)d\lambda \)

There are three types of cones
S: Short wave lengths (Blue)
M: Mid wave lengths (Green)
L: Long wave lengths (Red)

- Three attributes to a color
- Three numbers to describe a color

Color matching functions

- Choose primaries, say \( P_1(\lambda), P_2(\lambda), P_3(\lambda) \)
- For monochromatic (single wavelength) energy function, what amounts of primaries will match it?
- i.e., For each wavelength \( \lambda \), determine how much of A, of B, and of C is needed to match light of that wavelength alone.
  \[
  p_1(\lambda) \\
  p_2(\lambda) \\
  p_3(\lambda)
  \]
- These are color matching functions
RGB:
- Primaries are monochromatic, energies are 645.2nm, 526.3nm, 444.4nm.
- Color matching functions have negative parts -> some colors can be matched only subtractively.

CIE XYZ:
- Color matching functions are positive everywhere, but primaries are fictitious (have negative values for some wavelengths).
Color spaces

- Linear color spaces describe colors as linear combinations of primaries
- Choice of primaries = choice of color matching functions = choice of color space
- Color matching functions, hence color descriptions, are all within linear transformations
- RGB: primaries are monochromatic, energies are 645.2nm, 526.3nm, 444.4nm. Color matching functions have negative parts -> some colors can be matched only subtractively.
- CIE XYZ: Color matching functions are positive everywhere, but primaries are fictitious (have negative values for some wavelengths)

Color Spaces

There are many different color spaces, with each describing a color using three numbers:

1. RGB
2. HLS
3. YCrCb
4. HSV
5. CMY
6. YIQ (NTSC),
7. YUV (PAL),
8. CIExyz,
9. CIELAB
10. SUV

In general a color represented in one color space (say HLS) can be converted and represented in a second color space (say RGB), unless the result falls outside of the gamut of the second space.
RGB Color Cube

- Block of colors for \((r, g, b)\) in the range 0, \(\cdots\), 1
- Convenient to have an upper bound on coefficient of each primary.
- In practice:
  - primaries given by monitor phosphors, LCD filters, etc
  - (phosphors are the materials on the face of old CRT monitor screen that glow when struck by electrons)

CIE -XYZ and x-y

\[
x = \frac{X}{X + Y + Z}
\]
\[
y = \frac{Y}{X + Y + Z}
\]
CIE xyY (Chromaticity Space)

HSV Hexcone
Non-linear color space: Hue, Saturation, Value
AKA: Hue, Saturatation, Intensity (HIS)

Hexagon arises from projection of cube onto plane orthogonal to (R,G,B) = (1,1,1)
**Metameric Lights (Metamers)**

\[
I_k = \int \rho_k(\lambda)E_1(\lambda)d\lambda \\
I'_k = \int \rho_k(\lambda)E_2(\lambda)d\lambda
\]

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### 4.11 Metameric Lights

Two lights with these spectral power distributions appear identical to most observers and are called metamers. (A) An approximation to the spectral power distribution of a tungsten bulb. (B) The spectral power distribution of light emitted from a conventional television monitor whose three phosphor intensities were set to match the light in panel A in appearance.

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**Color Constancy**

- Ability of people to perceive an object’s color as being the same (or nearly the same), irrespective of the illumination color.

- E.g., when you go from indoor to outdoor lighting, the color of your clothes doesn’t seem to change.
The Dress

: Is it white & gold, or black and blue?
Color Constancy
+
Bistable Interpretations
The Dress

- If lighting is interpreted as blue light, the dress is seen as white-gold.

- If lighting is interpreted as reddish, the dress is seen as blue-black.

- Note blue light at top-right and reddish light at bottom-right

Thank You