Recap from Lecture 2

Pinhole camera model
Perspective projections
Lenses and their flaws
Focus
Depth of field
Focal length and field of view

Chapter 2 of Szeliski
What is wrong with this picture?
Capturing Light… in man and machine

Many slides by Alexei A. Efros

CS 129: Computational Photography
James Hays, Brown, Spring 2011
Digital camera

A digital camera replaces film with a sensor array

- Each cell in the array is light-sensitive diode that converts photons to electrons
- Two common types
  - Charge Coupled Device (CCD)
  - CMOS
Sensor Array

**FIGURE 2.17** (a) Continuous image projected onto a sensor array. (b) Result of image sampling and quantization.
Sampling and Quantization

**FIGURE 2.16** Generating a digital image: (a) Continuous image, (b) A scan line from $A$ to $B$ in the continuous image, used to illustrate the concepts of sampling and quantization, (c) Sampling and quantization, (d) Digital scan line.
Interlace vs. progressive scan

1st field: Odd field

2nd field: Even field

One complete frame using interlaced scanning

One complete frame using progressive scanning

Progressive scan

Interlace


Slide by Steve Seitz
Rolling Shutter
The Eye

The human eye is a camera!

- **Iris** - colored annulus with radial muscles
- **Pupil** - the hole (aperture) whose size is controlled by the iris
- What’s the “film”?
  - photoreceptor cells (rods and cones) in the **retina**
The Retina

Cross-section of eye

Cross section of retina

Ganglion axons
Ganglion cell layer
Bipolar cell layer
Receptor layer
Pigmented epithelium
What humans don’t have: tapetum lucidum
Two types of light-sensitive receptors

**Cones**
- cone-shaped
- less sensitive
- operate in high light
- color vision

**Rods**
- rod-shaped
- highly sensitive
- operate at night
- gray-scale vision
Rod / Cone sensitivity

- Dazzling light; bright sun on snow
- Outdoors in full sunlight
- Outdoors under a tree on a sunny day
- Comfortable indoor illumination; night sports events
- Threshold for perception of color; bright moonlight
- Threshold when dark-adapted

Distribution of Rods and Cones

Night Sky: why are there more stars off-center?  
Averted vision: http://en.wikipedia.org/wiki/Averted_vision
Eye Movements

Saccades

Can be consciously controlled. Related to perceptual attention. 200ms to initiation, 20 to 200ms to carry out. Large amplitude.

Microsaccades


Ocular microtremor (OMT)

Involuntary. High frequency (up to 80Hz), small amplitude.
Electromagnetic Spectrum

Human Luminance Sensitivity Function

http://www.yorku.ca/eye/photopik.htm
Why do we see light of these wavelengths?

...because that's where the Sun radiates EM energy.
Any patch of light can be completely described physically by its spectrum: the number of photons (per time unit) at each wavelength 400 - 700 nm.
Some examples of the spectra of light sources

A. Ruby Laser

B. Gallium Phosphide Crystal

C. Tungsten Lightbulb

D. Normal Daylight

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The Physics of Light

Some examples of the reflectance spectra of surfaces

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>% Photons Reflected</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td></td>
</tr>
<tr>
<td>700</td>
<td></td>
</tr>
<tr>
<td>Red</td>
<td></td>
</tr>
<tr>
<td>Yellow</td>
<td></td>
</tr>
<tr>
<td>Blue</td>
<td></td>
</tr>
<tr>
<td>Purple</td>
<td></td>
</tr>
</tbody>
</table>

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The Psychophysical Correspondence

There is no simple functional description for the perceived color of all lights under all viewing conditions, but ……

A helpful constraint:
Consider only physical spectra with normal distributions

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Variance ↔ Saturation

Wavelength

# Photons

high
medium
low
hi.
med.
low

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Area ↔ Brightness

# Photons

Wavelength

bright

dark

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Physiology of Color Vision

Three kinds of cones:

- Why are M and L cones so close?
- Why are there 3?
Most birds, and many other animals, have cones for ultraviolet light. Some humans, mostly female, seem to have slight tetrachromatism.
More Spectra

metamers
Practical Color Sensing: Bayer Grid

Estimate RGB at ‘G’ cells from neighboring values

http://www.cooldictionary.com/words/Bayer-filter.wikipedia
Color Image
Images in Matlab

• Images represented as a matrix
• Suppose we have a NxM RGB image called “im”
  – \( \text{im}(1,1,1) = \) top-left pixel value in R-channel
  – \( \text{im}(y, x, b) = \) y pixels down, x pixels to right in the \( b \)th channel
  – \( \text{im}(N, M, 3) = \) bottom-right pixel in B-channel
• \texttt{imread(filename)} returns a uint8 image (values 0 to 255)
  – Convert to double format (values 0 to 1) with \texttt{im2double}
Color spaces

How can we represent color?

Color spaces: RGB

Default color space

Some drawbacks
• Strongly correlated channels
• Non-perceptual

Color spaces: HSV

Intuitive color space

- **H**: $H=(S=1, V=1)$
- **S**: $S=(H=1, V=1)$
- **V**: $V=(H=1, S=0)$
Color spaces: YCbCr

Fast to compute, good for compression, used by TV
Color spaces: L*a*b*

“Perceptually uniform”* color space

\[ L(a=0,b=0) \]

\[ a(L=65,b=0) \]

\[ b(L=65,a=0) \]
Project #1

• How to compare R,G,B channels?
• No right answer
  • Sum of Squared Differences (SSD):
    \[
    ssd(u, v) = \sum_{(x,y) \in N} \left[ I(u + x, v + y) - P(x, y) \right]^2
    \]
  • Normalized Correlation (NCC):
    \[
    ncc(u, v) = \frac{\sum_{(x,y) \in N} \left[ I(u + x, v + y) - \bar{I} \right] \left[ P(x, y) - \bar{P} \right]}{\sqrt{\sum_{(x,y) \in N} \left[ I(u + x, v + y) - \bar{I} \right]^2} \sqrt{\sum_{(x,y) \in N} \left[ P(x, y) - \bar{P} \right]^2}}
    \]
Image half-sizing

This image is too big to fit on the screen. How can we reduce it?

How to generate a half-sized version?
Throw away every other row and column to create a 1/2 size image - called *image sub-sampling*
Image sub-sampling

1/2 1/4 (2x zoom) 1/8 (4x zoom)

Aliasing! What do we do?
Gaussian (lowpass) pre-filtering

Solution: filter the image, *then* subsample

- Filter size should double for each $\frac{1}{2}$ size reduction. Why?
Subsampling with Gaussian pre-filtering

Gaussian 1/2  G 1/4  G 1/8
Compare with...

1/2

1/4 (2x zoom)

1/8 (4x zoom)

Slide by Steve Seitz
Gaussian (lowpass) pre-filtering

Solution: filter the image, *then* subsample

- Filter size should double for each $\frac{1}{2}$ size reduction. Why?
- How can we speed this up?
Image Pyramids

Known as a **Gaussian Pyramid** [Burt and Adelson, 1983]
- In computer graphics, a *mip map* [Williams, 1983]
- A precursor to *wavelet transform*
A bar in the big images is a hair on the zebra’s nose; in smaller images, a stripe; in the smallest, the animal’s nose.

Figure from David Forsyth
What are they good for?

Improve Search

- Search over translations
  - Like project 1
  - Classic coarse-to-fine strategy
- Search over scale
  - Template matching
  - E.g. find a face at different scales

Pre-computation

- Need to access image at different blur levels
- Useful for texture mapping at different resolutions (called mip-mapping)
Gaussian pyramid construction

Repeat
  • Filter
  • Subsample

Until minimum resolution reached
  • can specify desired number of levels (e.g., 3-level pyramid)

The whole pyramid is only 4/3 the size of the original image!