Exposure, Demosaicing and White Balance

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Pset 1

• Due Tuesday 2/27
• Demosaicing (a.k.a. Bayer interpolation)
• White balance
SLR

“I'll be conducting an SLR intro today during my office hours (2:30)“  --Fredo
Exposure

- Two main parameters:
  - Aperture (in f stop)
  - Shutter speed (in fraction of a second)

- Reciprocity
  - The same exposure is obtained with an exposure twice as long and an aperture area half as big
  - Hence square root of two progression of f stops vs. power of two progression of shutter speed
  - Reciprocity can fail for very long exposures

From Photography, London et al.
Reciprocity

- Assume we know how much light we need
- We have the choice of an infinity of shutter speed/aperture pairs

- What will guide our choice of a shutter speed?
- What will guide our choice of an aperture?
Reciprocity

• Assume we know how much light we need
• We have the choice of an infinity of shutter speed/aperture pairs

• What will guide our choice of a shutter speed?
  – Freeze motion vs. motion blur, camera shake

• What will guide our choice of an aperture?
  – Depth of field, diffraction limit

• Often we must compromise
  – Open more to enable faster speed (but shallow DoF)
Small aperture (deep depth of field), slow shutter speed (motion blurred). In this scene, a small aperture (f/16) produced great depth of field; the nearest paving stones as well as the farthest trees are sharp. But to admit enough light, a slow shutter speed (1/8 sec) was needed; it was too slow to show moving pigeons sufficiently. It also meant that a tripod had to be used to hold the camera steady.
Medium aperture (moderate depth of field), medium shutter speed (some motion sharp). A medium aperture (f/4) and shutter speed (1/125 sec) sacrifice some background detail to produce recognizable images of the birds. But the exposure is still too long to show the motion of the birds' wings sharply.

From Photography, London et al.
Large aperture (shallow depth of field), fast shutter speed (motion sharp). A fast shutter speed (1/500 sec) stops the motion of the pigeons so completely that the flapping wings are frozen. But the wide aperture (f/2) needed gives so little depth of field that the background is now out of focus.
Questions?
Metering

• Photosensitive sensors measure scene luminance
• Usually TTL (through the lens)
• Simple version: center-weighted average

• Assumption? Failure cases?
  – Usually assumes that a scene is 18% gray
  – Problem with dark and bright scenes
Metering

- Centered average
- Spot
- Smart metering
  - Nikon 3D matrix
  - Canon evaluative
- Incident
  - Measure incoming light

Choice on Nikon

http://www.mir.com.my
Nikon 3D Color Matrix


- Learning from database of 30,000 photos
- Multiple captors (segments)
- Exposure depends on
  - Brightness from each segments
  - Color
  - Contrast
  - Distance
  - Focus (where is the subject)
Exposure & metering

- The camera metering system measures how bright the scene is.
- In Aperture priority mode, the photographer sets the aperture, the camera sets the shutter speed.
- In Shutter-speed priority mode, the photographers sets the shutter speed and the camera deduces the aperture.
  - In both cases, reciprocity is exploited.
- In Program mode, the camera decides both exposure and shutter speed (middle value more or less).
- In Manual, the user decides everything (but can get feedback).
Pros and cons of various modes

• Aperture priority (My favorite, I use it 90% of the time)
  – Direct depth of field control
  – Cons: can require impossible shutter speed (e.g. with f/1.4 for a bright scene)

• Shutter speed priority
  – Direct motion blur control
  – Cons: can require impossible aperture (e.g. when requesting a 1/1000 speed for a dark scene)
    • Note that aperture is somewhat more restricted

• Program
  – Almost no control, but no need for neurons

• Manual
  – Full control, but takes more time and thinking
Recap: Metering

• Measure scene brightness
• Some advanced modes that take multiple sources of information
• Still an open problem
Questions?
Sensitivity (ISO)

- Third variable for exposure

From dpreview.com
Questions?
CCD color sampling

- Problem: a photosite can record only one number
- We need 3 numbers for color
What are some approaches to sensing color images?

- Scan 3 times (temporal multiplexing)
- Use 3 detectors (3-ccd camera)
- Use offset color samples (spatial multiplexing)
- Multiplex in the depth of the sensor (Foveon)
Some approaches to color sensing

- Scan 3 times (temporal multiplexing)
  - Drum scanners
  - Flat-bed scanners
  - Russian photographs from 1800’s
- Use 3 detectors
  - High-end 3-tube or 3-ccd video cameras
- Use spatially offset color samples (spatial multiplexing)
  - Single-chip CCD color cameras
  - Human eye
- Multiplex in the depth of the sensor
  - Foveon
Bayer RGB mosaic

• Each photosite has a different color filter
Bayer RGB mosaic

• Why more green?
  – We have 3 channels and square lattice don’t like odd numbers
  – It’s the spectrum “in the middle”
  – More important to human perception of luminance
Demosaicing

- Interpolate missing values
Demosnaicing

• Simplest solution: downsample!
  – Nearest-neighbor reconstruction

• Problem: resolution loss (and megapixels are so important for marketing!)
Linear interpolation

- Average of the 4 or 2 nearest neighbors
  - Linear (tent) kernel

- Smoother kernels can also be used (e.g. bicubic) but need wider support
Typical errors in spatial multiplexing approach.

• Color fringes.
CCD color filter pattern

detector (simplified for simpler visualization)
Typical color moire patterns

Blow-up of electronic camera image. Notice spurious colors in the regions of fine detail in the plants.
The cause of color moire

Fine black and white detail in image mis-interpreted as color information.
Black and white edge falling on color CCD detector

Black and white image (edge)

Detector pixel colors
Color sampling artifact

Interpolated pixel colors, for grey edge falling on colored detectors (linear interpolation).
Color sampling artifacts
How many of you have seen color fringe artifacts from the camera sensor mosaics of cameras you own?
Human Photoreceptors

3.4 THE SPATIAL MOSAIC OF THE HUMAN CONES. Cross sections of the human retina at the level of the inner segments showing (A) cones in the fovea, and (B) cones in the periphery. Note the size difference (scale bar = 10 μm), and that, as the separation between cones grows, the rod receptors fill in the spaces. (C) Cone density plotted as a function of distance from the center of the fovea for seven human retinas; cone density decreases with distance from the fovea. Source: Curcio et al., 1990.

(From Foundations of Vision, by Brian Wandell, Sinauer Assoc.)
Fig. 2. L, M and S cone mosaics for two humans: JW (a nasal and a temporal location is shown, labeled JWN and JWT, respectively); and AN, and one macaque, M5. L, M and S cones are shown as red, green and blue dots respectively. For JWN, a patch of central cones was not identified due to a capillary that obscured those cones. All mosaics are shown to the same scale. Scale bar = 5 μm.

Have any of you seen color sampling artifacts from the spatially offset color sampling in your own visual systems?
Where I’ve seen color fringe reconstruction artifacts in my ordinary world

http://static.flickr.com/21/31393422_23013da003.jpg
Brewster’s colors—evidence of interpolation from spatially offset color samples

Scale relative to human photoreceptor size: each line covers about 7 photoreceptors.
Motivation for median filter interpolation

The color fringe artifacts are obvious; we can point to them. Goal: can we characterize the color fringe artifacts mathematically? Perhaps that would lead to a way to remove them…
R-G, after linear interpolation
Median filter

Replace each pixel by the median over N pixels (5 pixels, for these examples).
Generalizes to “rank order” filters.

Spike noise is removed

Monotonic edges remain unchanged
Degraded image
Radius 1 median filter
Radius 2 median filter
R – G, median filtered (5x5)
Median Filter Interpolation

- Perform first interpolation on isolated color channels.
- Compute color difference signals.
- Median filter the color difference signal.
- Reconstruct the 3-color image.
Two-color sampling of BW edge

Luminance profile
Two-color sampling of BW edge

Luminance profile

True full-color image
Two-color sampling of BW edge

Sampled data
Two-color sampling of BW edge

Sampled data

Linear interpolation

Color difference signal

Median filtered color difference signal
Recombining the median filtered colors

Linear interpolation

Median filter interpolation
Beyond linear interpolation between samples of the same color

- Luminance highs
- Median filter interpolation
- Regression
- Gaussian method
- Regression, including non-linear terms
- Multiple linear regressors
Other possibilities

• CMY mosaic
  – Pro: gather more light per photosite
  – Con: not directly what we want, potential loss of color sensitivity
Foveon sensor

- Red gets absorbed preferably
- The deeper in the silicon, the bluer

- Pros: no demosaicing
- Cons: potentially more noise, lower resolution in practice
Extension

• Mosaicing can be used to gather more information
  – Use neutral density filters to get more dynamic range
  – Polarizers
  – Etc.
• Shree Nayar’s work, Fuji’s super CCD
Questions?
White balance & Chromatic adaptation

• Different illuminants have different color temperature

• Our eyes adapt to this:
  Chromatic adaptation
  – We actually adapt better in brighter scenes
  – This is why candlelit scenes still look yellow
White balance problem

• When watching a picture on screen or print, we adapt to the illuminant of the room, not that of the scene in the picture
• The eye cares more about objects’ intrinsic color, not the color of the light leaving the objects
• We need to discount the color of the light source
White balance & Film

- Different types of film for fluorescent, tungsten, daylight
- Need to change film!

- Electronic & Digital imaging are more flexible
Von Kries adaptation

• Multiply each channel by a gain factor
• Note that the light source could have a more complex effect
  – Arbitrary 3x3 matrix
  – More complex spectrum transformation
Best way to do white balance

- Grey card:
- Take a picture of a neutral object (white or gray)
- Deduce the weight of each channel
- If the object is recorded as $r_w$, $g_w$, $b_w$ use weights $1/r_w$, $1/g_w$, $1/b_w$
Without grey cards

• We need to “guess” which pixels correspond to white objects
Grey world assumption

• The average color in the image is grey
• Use weights

\[
\frac{1}{\int_{image} r'} \int_{image} g' \int_{image} b
\]

• Note that this also sets the exposure/brightness
• Usually assumes 18% grey
Brightest pixel assumption

• Highlights usually have the color of the light source
  – At least for dielectric materials
• Do white balance by using the brightest pixels
  – Plus potentially a bunch of heuristics
  – In particular use a pixel that is not saturated/clipped
end