Image Fundamentals; Human Visual System

Human eye
Eye's receptors

- **Rods and Cones**
  - **Cones**
    - Roughly 6-7 million
    - Concentrated in the fovea
    - Highly sensitive to color
  - **Rods**
    - 75-150 million
    - Not involved in color vision
    - Sensitive to low-level illumination
    - Help give an overall picture of the field of view

#### Receptor distribution

![Receptor distribution graph](chart)

- # of rods or cones per mm^-2
- Blind spot
- Degrees from fovea
- Fovea
- Cones
- Rods
"See" your blind-spot

Close your left eye and stare at the cross mark in the diagram with your right eye

Optics of the eye

\[
\frac{15}{100} = \frac{X}{17}
\]

X = 2.55mm

15m

100 m

17mm
Human visual acuity

Visual acuity of a normal eye is 1/60 of a degree

\[
\frac{X}{2} = D \tan \left( \frac{\theta}{2} \right)
\]

Visual acuity calculations

\[X = \text{size of object}\]
\[D = \text{distance from object}\]

Thus,

\[X = 2 \times D \tan(1/120 \text{ degree})\]
\[X = 2 \times D \times 0.00014544\]
\[X = 0.00029088 \times D\]

How far can we be from an 1mm object and still see it?

\[
\frac{1\text{mm}}{0.00029088} = D \quad D = 3.437 \text{ meters}
\]
Human sampling

fovea

Human sampling
Some Terms

Light
radiant energy that is capable
of exciting the retina

Luminous Flux
"Light energy per time"
Measured in Lumens

Luminous Intensity
"Luminous Flux per solid angle"
Measured in Candela

Illuminance
"Luminous Flux incident on a surface". Not to be confused with Luminance which considers "projected" area (direction). Measured in "Lux"

Luminance
"Luminous Intensity" per projected area in a given direction
Measured in Candela per sq meter (a nit)

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Brightness is subjective attribute of light to which humans assign based on the response they perceive
(often confused with luminance)
Talking about “visual” effects

• It is hard to quantify visual effects
  - Measurable quantities vs. perceived effect
  - Luminance vs. Brightness
    • Depends on the conditions
    • Depends on the person!
• Note that there is a difference in
  - Light, Intensity, Luminance, Brightness
  - But don’t get upset about it
  - People (including myself) will use these terms incorrectly

Human eye and brightness

• Can distinguish around 64 shades of brightness \[2^{**6}\]

• BUT, it is very adaptive to different lighting conditions
Mach Band Effect

Perceived brightness changes around strong edges.

Interesting Facts about Human Visual System

• Simultaneous Contrast
Visual Masking

Threshold intensity increases at background with large non-uniform spatial, temporal changes.

Image representation

\[ f(x,y) \]
Image representation

- Discretized in both
  - Spatial coordinates
  - Brightness

Similar to a matrix in Linear Algebra

Individual elements are called:
- image elements, picture elements, (image points)
- "pels" pixels

Image model

- \( f(x, y) = \text{intensity} \)
  - intensity equal some response to luminance

- \( 0 \leq f(x, y) \leq +\text{inf} \)
Image model

- Basic nature of $f(x,y)$ has two components:
  - $f(x,y) = i(x,y) \times r(x,y)$

- $i(x,y)$ is illumination
  - $0 \leq i(x,y) \leq +\infty$

- $r(x,y)$ is reflectance component
  - $0 \leq r(x,y) \leq 1$
Image model

We will call intensity of a monochrome image, its gray level (I)

\[ 0 \leq L_{\text{min}} \leq I \leq L_{\text{max}} \]

\[ [L_{\text{min}}, L_{\text{max}}] \] the gray scale

\[ L_{\text{min}} = i_{\text{min}} \times r_{\text{min}} \]
\[ L_{\text{max}} = i_{\text{max}} \times r_{\text{max}} \]

Sampling and quantization

\[ f(x,y) = i(x,y) \times r(x,y) \]

i and r are continuous functions thus f(x,y) can be continuous
Digital Imaging

- Charge-Coupled Device (CCD)
  - linear array (scanner)
  - array array (camera CCD)
  - consist of photosite elements
    - silicon imaging elements that have a voltage output proportional to the intensity of the incident light

Photosites

light energy

output voltage
Line scan sensor

Area scan sensor

14
Image sampling/resolution

\[ f(x,y) = i(x,y) \cdot r(x,y) \]

Sample rate is the image resolution

Spatially Discretized
A digital image is discrete

\[ f(x,y) \sim \begin{pmatrix}
  f(0,0) & f(0,1) & \ldots & f(0, m-1) \\
  f(1,0) & f(1,1) & \ldots & f(1, m-1) \\
  \vdots & \vdots & \ddots & \vdots \\
  f(n-1,0) & f(n-1,1) & \ldots & F(n-1,m-1)
\end{pmatrix} \]

Effects of spatial resolution
Intensity quantization

$f(x)$

$x$

$[L_{\text{min}}, L_{\text{max}}]$  

# of gray levels

$L_{\text{max}}$

# of gray levels

# gray levels
Effects of intensity quantization

Storage requirements

Amount of memory needed

$M \times N \times \text{(bits-per-gray-level)}$

$M =$ number of columns

$N =$ number of rows
Some common resolutions and quantization

• Gray level = 256 (8bits) (Why?)

• Common Resolutions
  - PAL TV
  - NTSC TV
  - 720 x540
  - 640x480

RGB Color

• Red, Green, Blue Color Bands
  - Arbitrary color can be expressed as a combination of $C = aR+bG+cB$

• 8 bits per band (24bits Color)
  - rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr (24 bit)
  - Sometimes “packed” as 4 bytes
    - RGBA (A is alpha)
    - Why 32bits?

• Note: There are other “color spaces”
  - YIQ, HSI, CMY, . . .
High-Dynamic Range

The real world is high dynamic range.

HDR Capture
• Take Multiple Exposure (for a static scene)
HDR Display

Dynamic range: 50,000:1

http://www.cs.ubc.ca/~heidrich/Projects/HDRDisplay/

Often consider bands separately for IP

Color image → red
Color image → green
Color image → blue
Useful Conversion

- RGB to gray-scale (intensity)
  - Obtain intensity component from RGB
    \[ I = \frac{(R + G + B)}{3} \]
  - Proper Conversion
    \[ I = 0.299R + 0.587G + 0.114B \]
    (if you can’t convert, use the G band)

Which is brightest?

Blue  Red  Green
Conclusion

• Background information
  - Human Visual System
  - Image Fundamentals
  - Spatial and Intensity Quantization
  - Image Formation

• Readings
  - Ch 2.1 - 2.4