Basic Concepts in Digital Image Processing
Now,

Introducing some basic concepts in digital image processing

- Human vision system
- Basics of image acquisition

Reading: Chapter 2.
Human Vision Perception

Perceived intensity is not a simple function of intensity
• Edge
• Simultaneous contrast

Optical illusion
• Illusory contours
• Figure/ground
Optical Illusions: Complexity of Human Vision

FIGURE 2.9 Some well-known optical illusions.
More Optical Illusions

http://www.123opticalillusions.com/

http://brainden.com/optical-illusions.htm
Object Perception

How do we perceive separate features, objects, scenes, etc. in the environment?

- Perception of a scene involves multiple levels of perceptual analysis.
What do we do with all of this visual information??

“Bottom up processing”
• Data-driven
• Sensation reaches brain, and then brain makes sense of it

“Top down processing”
• Cognitive functions informs our sensation
• E.g., walking to refrigerator in middle of night
Now,

Introducing some basic concepts in digital image processing

• Human vision system. Why we need to study human eye?

• Basics of image acquisition
  • Geometry – size, location, …
  • Appearance – color, intensity
**Image Formation in the Eye**

Image is upside down in the retina/imaging plane!

Adjust focus length
- Camera
- Human eye
### Thin lens theory:

\[
\frac{1}{S_1} + \frac{1}{S_2} = \frac{1}{f}
\]

- Increasing the distance from the object to the lens will reduce the size of the image

### Field of View:

\[
\omega = \frac{2 \arctan \frac{d}{f}}{\text{FOV}}
\]

- Large focus length will give a small FOV
Depth of Field & Out of Focus

- DOF is inversely proportional to the focus length
- DOF is proportional to $S_1$

http://www.azuswebworks.com/photography/dof.html
Light and EM Spectrum

http://www.kollewin.com/blog/electromagnetic-spectrum/
Relation Among Wavelength, Frequency and Energy

wavelength ($\lambda$), frequency ($\nu$), and energy ($E$)

$$\lambda = \frac{c}{\nu}, \quad c = 2.998 \times 10^8 \text{ m/s} \text{ is the speed of light}$$

$$E = hv, \quad h \text{ is the Planck's constant}, 6.626068 \times 10^{-34} \text{ m}^2 \text{ kg / s}$$
What size of the object you can “see”? Diffraction-limit.

Airy disk: the size is proportional to wavelength and f-number (focal length/lens dimension)

\[ \sim \lambda \frac{f}{d} \]

http://en.wikipedia.org/wiki/Airy_disc
Light and EM Spectrum

http://www.kollewin.com/blog/electromagnetic-spectrum/
Image Sensing and Acquisition

Illumination energy $\rightarrow$ digital images

Incoming energy is transformed into a voltage

Digitizing the response

FIGURE 2.12
(a) Single imaging sensor.
(b) Line sensor.
(c) Array sensor.
A (2D) Image

An image = a 2D function \( f(x,y) \) where
- \( x \) and \( y \) are spatial coordinates
- \( f(x,y) \) is the intensity or gray level

An digital image:
- \( x, y, \) and \( f(x,y) \) are all finite
- For example \( x \in \{1,2,\ldots,M\} \), \( y \in \{1,2,\ldots,N\} \)

\[
f(x, y) \in \{0,1,2,\ldots,255\}
\]

Digital image processing → processing digital images by means of a digital computer

Each element \((x,y)\) in a digital image is called a pixel (picture element)
A Simple Image Formation Model

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

\[ 0 < f(x, y) < \infty : \text{Image (positive and finite)} \]

Source: \[ 0 < i(x, y) < \infty : \text{Illumination component} \]

Object: \[ 0 < r(x, y) < 1 : \text{Reflectance/transmission component} \]

\[
\begin{align*}
L_{\text{min}} < f(x, y) < L_{\text{max}} & \quad \text{in practice} \\
\text{where } L_{\text{min}} = i_{\text{min}}r_{\text{min}} & \quad \text{and } L_{\text{max}} = i_{\text{max}}r_{\text{max}}
\end{align*}
\]

\[ i(x, y): \quad \text{Sunlight: } 10,000 \text{ lm/m}^2 \text{ (cloudy), } 90,000\text{lm/m}^2 \text{ clear day} \]

\[ r(x, y): \quad \text{Office: } 1000 \text{ lm/m}^2 \]

\[ r(x, y): \quad \text{Black velvet 0.01; white pall 0.8; 0.93 snow} \]
Sampling: Digitizing the coordinate values (usually determined by sensors)

Quantization: Digitizing the amplitude values
Image Sampling and Quantization in a Sensor Array

FIGURE 2.17 (a) Continuous image projected onto a sensor array. (b) Result of image sampling and quantization.
Dynamic Range

\[ L_{\text{min}} < f(x,y) < L_{\text{max}} \quad \text{in practice} \]

where \( L_{\text{min}} = i_{\text{min}} r_{\text{min}} \) and \( L_{\text{max}} = i_{\text{max}} r_{\text{max}} \)

\[ 0 \leq f(x,y) \leq L - 1 \quad \text{and} \quad L = 2^k \]

Dynamic range/contrast ratio:

the ratio of the maximum detectable intensity level (saturation) to the minimum detectable intensity level (noise)

\[ \frac{I_{\text{max}}}{I_{\text{min}}} \]
Representing Digital Images

(a): $f(x,y)$, $x=0, 1, \ldots, M-1$, $y=0, 1, \ldots, N-1$

$x$, $y$: spatial coordinates $\rightarrow$ spatial domain

(b): suitable for visualization

(c): processing and algorithm development

$x$: extend downward (rows)

$y$: extend to the right (columns)

Number of bits storing the image

$b = M \times N \times k$
Store an Image

### TABLE 2.1
Number of storage bits for various values of $N$ and $k$.

<table>
<thead>
<tr>
<th>$N/k$</th>
<th>1 ($L = 2$)</th>
<th>2 ($L = 4$)</th>
<th>3 ($L = 8$)</th>
<th>4 ($L = 16$)</th>
<th>5 ($L = 32$)</th>
<th>6 ($L = 64$)</th>
<th>7 ($L = 128$)</th>
<th>8 ($L = 256$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>32</td>
<td>1,024</td>
<td>2,048</td>
<td>3,072</td>
<td>4,096</td>
<td>5,120</td>
<td>6,144</td>
<td>7,168</td>
<td>8,192</td>
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<tr>
<td>64</td>
<td>4,096</td>
<td>8,192</td>
<td>12,288</td>
<td>16,384</td>
<td>20,480</td>
<td>24,576</td>
<td>28,672</td>
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<tr>
<td>128</td>
<td>16,384</td>
<td>32,768</td>
<td>49,152</td>
<td>65,536</td>
<td>81,920</td>
<td>98,304</td>
<td>114,688</td>
<td>131,072</td>
</tr>
<tr>
<td>256</td>
<td>65,536</td>
<td>131,072</td>
<td>196,608</td>
<td>262,144</td>
<td>327,680</td>
<td>393,216</td>
<td>458,752</td>
<td>524,288</td>
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<tr>
<td>512</td>
<td>262,144</td>
<td>524,288</td>
<td>786,432</td>
<td>1,048,576</td>
<td>1,310,720</td>
<td>1,572,864</td>
<td>1,835,008</td>
<td>2,097,152</td>
</tr>
<tr>
<td>1024</td>
<td>1,048,576</td>
<td>2,097,152</td>
<td>3,145,728</td>
<td>4,194,304</td>
<td>5,242,880</td>
<td>6,291,456</td>
<td>7,340,032</td>
<td>8,388,608</td>
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<tr>
<td>2048</td>
<td>4,194,304</td>
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<td>12,582,912</td>
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<tr>
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<td>33,554,432</td>
<td>50,331,648</td>
<td>67,108,864</td>
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<td>100,663,296</td>
<td>117,440,512</td>
<td>134,217,728</td>
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<tr>
<td>8192</td>
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<td>201,326,592</td>
<td>268,435,456</td>
<td>335,544,320</td>
<td>402,653,184</td>
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</tr>
</tbody>
</table>
Spatial Resolution

Spatial resolution: smallest discernible details
- # of line pairs per unit distance
- # of dots (pixels) per unit distance
  - Printing and publishing
  - In US, dots per inch (dpi)

Newspaper → magazines → book

Large image size itself does not mean high spatial resolution!
Scene/object size in the image

1280*960

http://www.shimanodealer.com/fishing_reports.htm

FIGURE 2.20 Typical effects of reducing spatial resolution. Images shown at: (a) 1250 dpi, (b) 300 dpi, (c) 150 dpi, and (d) 72 dpi. The thin black borders were added for clarity. They are not part of the data.
Intensity Resolution

Intensity resolution

- Smallest discernible change in intensity levels
- Using the number of levels of intensities
- False contouring (banding) when $k$ is small - undersampling
Isopreference Curves

Vary the spatial and intensity sampling simultaneously:

FIGURE 2.22  (a) Image with a low level of detail. (b) Image with a medium level of detail. (c) Image with a relatively large amount of detail. (Image (b) courtesy of the Massachusetts Institute of Technology.)

FIGURE 2.23  Typical isopreference curves for the three types of images in Fig. 2.22.
Basic Set and Logical Operations

- $A$ is a set: $A = \{.\}$ e.g. $A = \{1, \ldots, 255\}$ or $A = \{w | w = 1, \ldots, 255\}$
  
  $A = \emptyset$ for empty set

- $a$ is an element of $A (a \in A)$ or $a$ isn’t an element of $A (a \notin A)$

- $A$ is a subset of $B$ if every element in $A$ also is in $B \ (A \subseteq B)$

- $C$ is the union of two sets $A$ and $B \ (C = A \cup B)$

- $C$ is the intersection of $A$ and $B \ (C = A \cap B)$

- Disjoint or mutual exclusive sets \(A \cap B = \emptyset\)

- Set universe is the set of all elements in an application

- Set difference $(A - B = \{w | w \in A, w \notin B\})$
Set Operations Based on Coordinates

A region in an image is represented by a set of coordinates within the region.
Some Basic Relationships between Pixels

Neighbors of a pixel

\[ N_4(p) \]

\[ N_8(p) \]

\[ N_D(p) \]
Adjacency

Adjacency is the relationship between two pixels $p$ and $q$

$V$ is a set of intensity values used to define adjacency

- Binary image: $V=\{1\}$ or $V=\{0\}$
- Gray level image:
  - 4-adjacency
  - 8-adjacency
  - $m$-adjacency

Intensity constraints

Three types of adjacency:

4-adjacency

$$
\begin{array}{ccc}
0 & 1 & 1 \\
0 & 1 & 0 \\
0 & 0 & 1 \\
\end{array}
$$

$q \in N_4(p)$

8-adjacency

$$
\begin{array}{ccc}
0 & 1 & 1 \\
0 & 1 & 0 \\
0 & 0 & 1 \\
\end{array}
$$

$q \in N_8(p)$

$m$-adjacency

$$
\begin{array}{ccc}
0 & 1 & 1 \\
0 & 1 & 0 \\
0 & 0 & 1 \\
\end{array}
$$

$q \in N_D(p)$ and $N_4(q) \cap N_4(p) = \emptyset$

or $q \in N_4(p)$