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.
Properties of Human Vision System

Rods vs Cones

Brightness adaptation

Brightness discrimination: Weber Ratio
Human Vision Perception

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

Optical illusion
  • Illusory contours
  • Figure/ground
Perceived Intensity is Not a Simple Function of the Actual Intensity (1)
Perceived Intensity is Not a Simple Function of the Actual Intensity – Simultaneous Contrast

**FIGURE 2.8** Examples of simultaneous contrast. All the inner squares have the same intensity, but they appear progressively darker as the background becomes lighter.
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.

```plaintext
Features

Groups of Features

Objects

Scenes
```
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
**Lens Parameters**

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 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 S1
Light and EM Spectrum

http://www.kollewin.com/blog/electromagnetic-spectrum/
wavelength (\( \lambda \)), frequency (\( \nu \)), and energy (\( E \))

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

\[
E = h\nu, \quad h \text{ is the Planck's constant, } 6.626068 \times 10^{-34} \text{ m}^2 \text{ kg / s}
\]
Light and EM Spectrum

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 → digital images

Incoming energy is transformed into a voltage

Digitizing the response
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 $\rightarrow$ 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

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

\( 0 < f(x, y) < \infty \): Image (positive and finite)

**Source:** \( 0 < i(x, y) < \infty \): Illumination component

**Object:** \( 0 < r(x, y) < 1 \): Reflectance/transmission component

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

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

- **i(x,y):** Sunlight: 10,000 lm/m² (cloudy), 90,000lm/m² clear day
- **Office:** 1000 lm/m²
- **r(x,y):** Black velvet 0.01; white pall 0.8; 0.93 snow
Image Sampling and Quantization

Sampling: Digitizing the coordinate values (usually determined by sensors)

Quantization: Digitizing the amplitude values

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.
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

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

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>
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<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>
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<td>8,192</td>
<td>12,288</td>
<td>16,384</td>
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<td>24,576</td>
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<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>
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<td>196,608</td>
<td>262,144</td>
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<td>458,752</td>
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<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>
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<td>3,145,728</td>
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<td>5,242,880</td>
<td>6,291,456</td>
<td>7,340,032</td>
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<td>67,108,864</td>
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<td>117,440,512</td>
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<td>268,435,456</td>
<td>335,544,320</td>
<td>402,653,184</td>
<td>469,762,048</td>
<td>536,870,912</td>
</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

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.)

Vary the spatial and intensity sampling simultaneously:

FIGURE 2.23  Typical isopreference curves for the three types of images in Fig. 2.22.
Need to resample the image when
- Rescaling
- Geometrical transformation
- The output image coordinates are not discrete

Interpolation methods:
- Nearest neighbor
  - Fast and simple
  - Loss of sharpness
  - Artifacts (checkerboard)
- Bilinear
- Bicubic
  - Images are sharpest
  - Fine details are preserved
  - Slow
**Image Resampling & Interpolation**

**FIGURE 2.24** (a) Image reduced to 72 dpi and zoomed back to its original size (3692 × 2812 pixels) using nearest neighbor interpolation. This figure is the same as Fig. 2.20(d). (b) Image shrunk and zoomed using bilinear interpolation. (c) Same as (b) but using bicubic interpolation. (d)–(f) Same sequence, but shrinking down to 150 dpi instead of 72 dpi [Fig. 2.24(d) is the same as Fig. 2.20(c)]. Compare Figs. 2.24(e) and (f), especially the latter, with the original image in Fig. 2.20(a).
Image Resampling & Interpolation

Forward mapping

Input  Output
Issues on Image Resampling & Interpolation

Missing points in forward mapping

Solution: perform a backward mapping

A hole!
Image Interpolation – Nearest Neighbor

Assign each pixel in the output image with the nearest neighbor in the input image.
Image Interpolation – Bilinear

\[ P' = P(1, 1)(1 - d)(1 - d') + P(1, 2)d(1 - d') + P(2, 1) \cdot d' \]
\[ \cdot (1 - d) + P(2, 2)dd' \]

Image Interpolation – Bicubic

If we know the intensity values, derivatives, and cross derivatives for the four corners (0,0), (0,1), (1,0), and (1,1), we can interpolate any point \((x,y)\) in the region \(x \in [0, 1], y \in [0, 1]\)

\[
\tilde{P}(x, y) = \sum_{i=0}^{3} \sum_{j=0}^{3} a_{ij} x^i y^j \\
\text{Need to solve the 16 coefficients}
\]