Part 2
Acquiring and Digitalization of Image

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When something can be read without effort, great effort has gone into its writing. ~E. J. Poncela
2. Digital Image Fundamentals
   ► Elements of Visual Perception
   ► Light and the Electromagnetic Spectrum
   ► Image Sensing and Acquisition
   ► Image Sampling and Quantization
   ► Introduction to the MATLAB
   ► Some Basic Relationships between Pixels
   ► An Introduction to the Mathematical Tools Used in Digital Image Processing
What does it mean, to see?

“The plain man’s answer (and Aristotle’s, too) would be, to know what is where by looking. In other words, vision is the process of discovering from images what is present in the world, and where it is.” David Marr, Vision, 1982

Our brain is able to use an image as an input, and interpret it in terms of objects and scene structures.
What does Salvador Dali’s Study for the Dream Sequence in Spellbound (1945) say about our visual perception?

We see a two dimensional image

But, we perceive depth information

light reflected on the retina

converging lines

shadows of the eye
Elements of Visual Perception

FIGURE 2.1
Simplified diagram of a cross section of the human eye.
Rods

They perceive changes in intensity of light independently of color.
They perceive objects in black, white and gray tones.
When people have low light in the darkness of the night, they can still see the surroundings as black and white thanks to these rods. But they can not see color.

Cones

Responsible for color matters.
But they need more light than rods to see.
There are three different cone cells. These are: L type, M type and S type.

FIGURE 2.2
Distribution of rods and cones in the retina.
Elements of Visual Perception

FIGURE 2.3
Graphical representation of the eye looking at a palm tree. Point $C$ is the optical center of the lens.
Çubuk Koni

Işığın tasınma süreci

Kırmızı yeşil mavi

120 milyon 6-7 milyon
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.
FIGURE 2.9 Some well-known optical illusions.
Görsel Algının Unsurları
Görsel Algının Unsurları

► Watch Beau Lotto’s TED talk on “Optical illusions show how we see”.

Video Link: https://www.ted.com/talks/beau_lotto_optical_illusions_show_how_we see?language=tr#t-395398
White light: composed of about equal energy in all wavelengths of the visible Spectrum.

Color

Newton 1666

From Foundations of Vision, by Brian Wandell, Sinauer Assoc., 1995

Video Link: https://www.youtube.com/watch?v=GaDxFvMdi0Q
Light and Electromagnetic Spectrum

\[ \lambda = \frac{c}{v} \quad E = h\nu \quad h: \text{Planck's katsayıısı} \]

**FIGURE 2.10** The electromagnetic spectrum. The visible spectrum is shown zoomed to facilitate explanation, but note that the visible spectrum is a rather narrow portion of the EM spectrum.

Video Link: https://www.youtube.com/watch?v=iyz6W6aJ_jA
https://www.youtube.com/watch?v=HUT1BPyUQQ8
Işık ve Elektromanyetik Spektrum

Video Link: https://www.youtube.com/watch?v=m4t7gTm8K3g
The wavelength of an EM wave required to “see” an object must be of the same size as or smaller than the object.
The Physics of light

Any source of light can be completely described physically by its spectrum: the amount of energy emitted (per time unit) at each wavelength 400 - 700 nm.

Relative spectral power

Wavelength (nm.)

400 500 600 700

Slide credit: A. Efros
The Physics of light

Some examples of the reflectance spectra of surfaces

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

Slide credit: A. Efros

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Electromagnetic waves can be visualized as sinusoidal waves advancing with lambda wavelength.

The colors that humans perceive in an object are determined by the nature of the light reflected from the object.

e.g. green objects reflect light with wavelengths primarily in the 500 to 570 nm range while absorbing most of the energy at other wavelengths.
Light and Electromagnetic Spectrum

► Monochromatic light: void of color
  **Intensity** is the only attribute, from black to white
  Monochromatic images are referred to as gray-scale images

► Chromatic light bands: 0.43 to 0.79 um
  The quality of a chromatic light source:
  **Radiance**: total amount of energy (measured as watt)
  **Luminance (lm)**: the amount of energy an observer perceives from a light source (measured as lumen)
  **Brightness**: a subjective descriptor of light perception that is impossible to measure. It embodies the achromatic notion of intensity and one of the key factors in describing color sensation.
Image Sensing and Acquisition

Transform illumination energy into digital images

FIGURE 2.12
(a) Single imaging sensor.
(b) Line sensor.
(c) Array sensor.
FIGURE 2.15  An example of the digital image acquisition process. (a) Energy ("illumination") source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.
A Simple Image Formation Model

\[ f(x,y) \] is nonzero and finite;

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

\( f (x, y) \): intensity at the point \((x, y)\)
\( i(x, y) \): illumination at the point \((x, y)\)
(the amount of source illumination incident on the scene)
\( r(x, y) \): reflectance/transmissivity at the point \((x, y)\)
(the amount of illumination reflected/transmitted by the object)

where \( 0 < i(x, y) < \infty \) and \( 0 < r(x, y) < 1 \)
Some Typical Ranges of Illumination

Illumination

**Lumen** — A unit of light flow or luminous flux

**Lumen per square meter (lm/m²)** — The metric unit of measure for illuminance of a surface

- On a clear day, the sun may produce in excess of 90,000 lm/m² of illumination on the surface of the Earth
- On a cloudy day, the sun may produce less than 10,000 lm/m² of illumination on the surface of the Earth
- On a clear evening, the moon yields about 0.1 lm/m² of illumination
- The typical illumination level in a commercial office is about 1000 lm/m²
Some Typical Ranges of Reflectance

Reflectance

- 0.01 for black velvet
- 0.65 for stainless steel
- 0.80 for flat-white wall paint
- 0.90 for silver-plated metal
- 0.93 for snow
Image Sampling and Quantization

Digitizing the coordinate values

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.
FIGURE 2.17 (a) Continuous image projected onto a sensor array. (b) Result of image sampling and quantization.
Representing Digital Images

**FIGURE 2.18**
(a) Image plotted as a surface.
(b) Image displayed as a visual intensity array.
(c) Image shown as a 2-D numerical array (0, .5, and 1 represent black, gray, and white, respectively).
The representation of an $M \times N$ numerical array as

$$f(x, y) = \begin{bmatrix}
  f(0, 0) & f(0, 1) & \ldots & f(0, N-1) \\
  f(1, 0) & f(1, 1) & \ldots & f(1, N-1) \\
  \vdots & \vdots & \ddots & \vdots \\
  f(M-1, 0) & f(M-1, 1) & \ldots & f(M-1, N-1)
\end{bmatrix}$$
The representation of an M×N numerical array as

\[
A = \begin{bmatrix}
  a_{0,0} & a_{0,1} & \cdots & a_{0,N-1} \\
  a_{1,0} & a_{1,1} & \cdots & a_{1,N-1} \\
  \vdots & \vdots & \ddots & \vdots \\
  a_{M-1,0} & a_{M-1,1} & \cdots & a_{M-1,N-1}
\end{bmatrix}
\]
Representing Digital Images

- Discrete intensity interval $[0, L-1]$, $L=2^k$

- The number $b$ of bits required to store a $M \times N$ digitized image

\[ b = M \times N \times k \]
## Representing Digital Images

### 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>
</tr>
<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>
<td>32,768</td>
</tr>
<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>
</tr>
<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>
</tr>
<tr>
<td>2048</td>
<td>4,194,304</td>
<td>8,388,608</td>
<td>12,582,912</td>
<td>16,777,216</td>
<td>20,971,520</td>
<td>25,165,824</td>
<td>29,369,128</td>
<td>33,554,432</td>
</tr>
<tr>
<td>4096</td>
<td>16,777,216</td>
<td>33,554,432</td>
<td>50,331,648</td>
<td>67,108,864</td>
<td>83,886,080</td>
<td>100,663,296</td>
<td>117,440,512</td>
<td>134,217,728</td>
</tr>
<tr>
<td>8192</td>
<td>67,108,864</td>
<td>134,217,728</td>
<td>201,326,592</td>
<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>
Representing Digital Images

[Diagram showing rows, columns, and pixel values for different bands]
Representing Digital Images

Figure: M. J. Black
Representing Digital Images

Figure: M. J. Black
Representing Digital Images

How are these numbers formed?

Source: http://www.comp.dit.ie/bmacnamee/gaip.htm
Spatial and Intensity Resolution

Spatial resolution
- A measure of the smallest discernible detail in an image
- Stated with line pairs per unit distance, dots (pixels) per unit distance, dots per inch (dpi)

Intensity resolution
- The smallest discernible change in intensity level
- Stated with 8 bits, 12 bits, 16 bits, etc.
Spatial and Intensity Resolution

**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.
Spatial and Intensity Resolution

**FIGURE 2.21**
(a) 452 × 374, 256-level image.
(b)–(d) Image displayed in 128, 64, and 32 gray levels, while keeping the spatial resolution constant.
Spatial and Intensity Resolution

Figure 2.21 (Continued)
(e)–(h) Image displayed in 16, 8, 4, and 2 gray levels. (Original courtesy of Dr. David R. Pickens, Department of Radiology & Radiological Sciences, Vanderbilt University Medical Center.)
Spatial and Intensity Resolution

**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.)
Introduction to the MATLAB

► MATLAB = Matrix Laboratory

► “MATLAB is a high-level language and interactive environment that enables you to perform computationally intensive tasks faster than with traditional programming languages such as C, C++ and Fortran.” (www.mathworks.com)

► MATLAB is an interactive, interpreted language that is designed for fast numerical matrix calculations.
Introduction to the MATLAB

- MATLAB has become a standard computing tool for mathematics, engineering and other disciplines at universities.

- MATLAB consists of toolboxes that provide specific results for applications in specific areas.

- The image processing toolbox, which is one of them, consists of the sum of MATLAB functions (M-functions or M-files) developed for solving problems related to digital image processing.
Introduction to the MATLAB

• MATLAB window components:
  Workspace
    > Displays all the defined variables
  Command Window
    > To execute commands in the MATLAB environment
  Command History
    > Displays record of the commands used
  File Editor Window
    > Define your functions
Introduction to the MATLAB

- MATLAB Help is an extremely powerful assistance to learning MATLAB
- Help not only contains the theoretical background, but also shows demos for implementation
- MATLAB Help can be opened by using the HELP pull-down menu
Introduction to the MATLAB

- Any command description can be found by typing the command in the search field.
- As shown above, the command to take square root (sqrt) is searched.
- We can also utilize MATLAB Help from the command window as shown.
Introduction to the MATLAB

More about the Workspace

- `who, whos` – current variables in the workspace
- `save` – save workspace variables to `.mat` file
- `load` – load variables from `.mat` file
- `clear` – clear workspace variables
Introduction to the MATLAB

Matrices in MATLAB

• Matrix is the main MATLAB data type
• How to build a matrix?
  – \( A = \begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \\ 7 & 8 & 9 \end{bmatrix}; \)
  – Creates matrix \( A \) of size 3 x 3
• Special matrices:
  – \( \text{zeros}(n,m), \ \text{ones}(n,m), \ \text{eye}(n,m), \ \text{rand}(), \ \text{randn}() \)
Introduction to the MATLAB

Basic Operations on Matrices

- All operators in MATLAB are defined on matrices: +, -, *, /, ^, sqrt, sin, cos, etc.
- Element-wise operators defined with a preceding dot: .* , . / , . ^
- \texttt{size(A)} – size vector
- \texttt{sum(A)} – columns sums vector
- \texttt{sum(sum(A))} – sum of all the elements
Variable Name in Matlab

- Variable naming rules
  - must be unique in the first 63 characters
  - must begin with a letter
  - may not contain blank spaces or other types of punctuation
  - may contain any combination of letters, digits, and underscores
    - are case-sensitive
    - should not use Matlab keyword

- Pre-defined variable names
  - pi
Introduction to the MATLAB

Logical Operators

- ==, <, >, (not equal) ~=, (not) ~

- \texttt{find(‘condition’)} – Returns indexes of A’s elements that satisfy the condition
Introduction to the MATLAB

Logical Operators (cont.)

• Example:

```matlab
>> A = [7 3 5; 6 2 1], Idx = find(A < 4)

A =

    7 3 5
    6 2 1

Idx =

    3
    4
    6
```
Introduction to the MATLAB

Flow Control

- MATLAB has five flow control constructs:
  - if statement
  - switch statement
  - for loop
  - while loop
  - break statement
Introduction to the MATLAB

\[
\text{if}
\]

- IF statement condition
  - The general form of the IF statement is
    \[
    \text{IF expression} \\
    \text{statements} \\
    \text{ELSEIF expression} \\
    \text{statements} \\
    \text{ELSE} \\
    \text{statements} \\
    \text{END}
    \]
Introduction to the MATLAB

switch

• SWITCH – Switch among several cases based on expression
• The general form of SWITCH statement is:

```
SWITCH switch_expr
    CASE case_expr,
        statement, ..., statement
    CASE {case_expr1, case_expr2, case_expr3, ...}
        statement, ..., statement
    ... 
    OTHERWISE
        statement, ..., statement
END
```
Introduction to the MATLAB

for

- FOR repeats statements a specific number of times

- The general form of a FOR statement is:

  ```matlab
  FOR variable=expr
    statements
  END
  ```
Introduction to the MATLAB

while

• WHILE repeats statements an indefinite number of times
• The general form of a WHILE statement is:

  WHILE expression
  statements
  END
Introduction to the MATLAB

Scripts and Functions

• There are two kinds of M-files:

  – Scripts, which do not accept input arguments or return output arguments. They operate on data in the workspace

  – Functions, which can accept input arguments and return output arguments. Internal variables are local to the function
Functions in MATLAB (cont.)

- Example:
  - A file called STAT.M:
    ```matlab
    function [mean, stdev]=stat(x)
    %STAT Interesting statistics.
    n=length(x);
    mean=sum(x)/n;
    stdev=sqrt(sum((x-mean).^2)/n);
    
    - Defines a new function called STAT that calculates the mean and standard deviation of a vector. Function name and file name should be the SAME!
Visualization and Graphics

- `plot(x, y), plot(x, sin(x))` – plot 1D function
- `figure, figure(k)` – open a new figure
- `hold on, hold off` – refreshing
- `axis([xmin xmax ymin ymax])` – change axes
- `title('figure title')` – add title to figure
- `mesh(x_ax, y_ax, z_mat)` – view surface
- `contour(z_mat)` – view z as topo map
- `subplot(3,1,2)` – locate several plots in figure
Introduction to the MATLAB

Saving your Work

- `save mysession`
  
  \% creates mysession.mat with all variables
- `save mysession a b`
  
  \% save only variables a and b
- `clear all`
  
  \% clear all variables
- `clear a b`
  
  \% clear variables a and b
- `load mysession`
  
  \% load session
References


► Lecture Notes, BIL717-Image Processing, Erkut Erdem

► Lecture Notes, EBM537-Image Processing, F.Karabiber