Introduction to Digital Image Processing

Part I

Chester F. Carlson Center for Imaging Science, RIT
Creating an Image

Subject  Capture  Process  Display  Human
Digital

From Wikipedia, the free encyclopedia.

For other uses, see Digital (disambiguation).

A digital system is one that uses discrete values rather than a continuous spectrum of values: compare analog. The word comes from the same source as the word digit: the Latin word for fingers (counting on the fingers) as these are used for discrete counting.

The distinction digital versus analog can refer to data storage and transfer, the internal working of an instrument, and the kind of display.

The word "digital" is commonly used in computing.

Digital vs analog

Digital noise

When data are transmitted using analog methods, a certain amount of noise enters into the signal. This can have a myriad of different causes: data transmitted by radio may be received badly, suffer interference from other radio sources, or pick up background radio noise from the rest of the universe. Electric pulses being sent down wires are attenuated by the resistance of the wire, and dispersed by its capacitance, and heat variations can increase or reduce these effects. Whilst digital transmissions are also degraded, any slight variations can be safely ignored.
What is a Digital Image?
Digital Image:

- Rendering of a continuously varying scene with a finite array of picture elements, where each one has a discrete intensity or color
Charge Coupled Device (CCD)
Magnified View of a CCD Array

Close-up of a CCD Imaging Array

Individual pixel element
Spatial Sampling:

- Measuring a continuously varying image at uniformly separated points in space and assigning a value that corresponds to an average light intensity within a small box surrounding each point.
Spatial Aliasing:

- An effect seen in digital images which have been inadequately sampled (too few pixels) which gives rise to a misleading appearance when compared to the original.

- Image distortions caused by spatial aliasing are also known as sampling artifacts.
Online Demo: Spatial Sampling
Quantization:

- The process of taking a set of continuous values and mapping them into a finite number of discrete steps represented by integers.
A *bit* is a value, a position, and an amount of information. Each added bit allows us to double the number of values we can represent with a binary number.

The number of values that can be represented is given by $2^{N_{\text{bits}}}$.

*e.g.*, 4 bits provides $2^4 = 16$ different values.
How Many Steps?

- The simplest kind of digital image is known as a “binary image” because the image contains only two ‘colors’ - white and black.
Binary Images

- Because binary images contain only two colors, we can encode the image using just two numbers, for example:

  - 0 = black
  - 1 = white

```
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
1 1 1 1 1 1 1 0 0 0 0 0 0 0 0
1 1 1 1 1 1 1 1 1 0 0 0 0 0 0
1 1 1 1 1 1 1 1 1 1 1 0 0 0 0
1 1 1 1 1 1 1 1 1 1 1 0 0 0 0
```
2 shades of gray
4 shades of gray
8 shades of gray
256 shades of gray
The number of possible gray levels is controlled by the number of bits/pixel, or the ‘bit depth’ of the image.
Online Demo: Bit Depth
Summary

- Digital image:
  - Rendering of a continuously varying scene with a finite array of picture elements, each one containing a discrete numerical value which represents an intensity
Summary

- Digital images are created by:
  - Spatial sampling
  - Quantizing
Summary

- Spatial sampling:
  - Measuring the scene at uniformly separated points and assigning an average intensity to the pixel at that location
  - The more samples taken, the better resolution of the image
  - Insufficient sampling results in aliasing
Summary

- Quantization:
  - Converting the average intensity of a pixel to a binary integer
Summary

- Number of available intensity levels or colors is determined by the bit depth
  - Most gray scale images use 8 bits (256 levels)
Color Images

- In most cases, we also want to capture color information.
- The way that we capture, store, view, and print color digital images is based on the way that humans perceive color.
Color Images
The eyes have three different kinds of color receptors (‘cones’); one type each for blue, green, and red light.

Color perception is based on how much light is detected by each of the three ‘primary’ cone types (red, green, and blue).
Because we have three kinds of cones, every color that we can see can be made up by combining red, green, and blue light - the three “additive primaries”
RGB Color Images

- The most straightforward way to capture a color image is to capture three images; one to record how much red is at each point, another for the green, and a third for the blue.

- Each one of the color images (‘planes’) is like a grayscale image, but is displayed in R, G, or B.
RGB Color Images

- To capture a color image we record how much red, green, and blue light there is at each pixel.

- To view the image, we use a display (monitor or print) to reproduce the color mixture we captured.

Q) How many different colors can a display produce?
A) It depends on how many bits per pixel we’ve got.

For a system with 8 bits/pixel in each of the red, green, and blue (a ‘24-bit image’):
RGB Color Images: 24-bit color

- Every pixel in each of the three 8-bit color planes can have 256 different values (0-255)
- If we start with just the blue image plane, we can make 256 different “colors of blue”
RGB Color Images: 24-bit color

- Every pixel in each of the three 8-bit color planes can have 256 different values (0-255)

- If we start with just the blue image plane, we can make 256 different “colors of blue”

- If we add red (which alone gives us 256 different reds):
RGB Color Images: 24-bit color

- Every pixel in each of the three 8-bit color planes can have 256 different values (0-255)
- If we start with just the blue image plane, we can make 256 different “colors of blue”
- If we add red (which alone gives us 256 different reds):
- We can make $256 \times 256 = 65,536$ combination colors because for every one of the 256 reds, we can have 256 blues.
RGB Color Images: 24-bit color

- When we have all three colors together, there are 256 possible values of green for each one of the 65,536 combinations of red and blue:

  - $256 \times 256 \times 256 = 16,777,216$ (‘> 16.7 million colors’)

In a 24-bit image, each pixel has R, G, & B values.

When viewed on a color display, the three images are combined to make the color image.
Two major factors which determine image quality are:

- **Bit depth** -- controlled by number of colors or grey levels allocated for each pixel
- **Spatial resolution** -- controlled by spatial sampling.

Increasing either of these factors results in a larger image file size, which requires more storage space and more processing/display time.
How much memory is necessary to store an image that is 100 x 100 pixels with 8 bits/pixel?

File size (in bits) = Height x Width x Bit Depth

100 x 100 x 8 bits/pixel = 80,000 bits/image
80,000 bits or 10,000 bytes
How much memory is necessary to store an image that is 1280 x 960 pixels with 24 bits/pixel?

File size (in bits) = Height x Width x Bit Depth

$960 \times 1280 \times 24 \text{ bits/pixel} = 29,491,200 \text{ bits/image}$

$29,491,200 \text{ bits} = 3,686,400 \text{ bytes} = 3.5 \text{ MB}$
Summary

- Digital image:
  - Rendering of a continuously varying scene with a finite array of picture elements, each one containing a discrete numerical value which represents an intensity or color
Summary

- Digital images are created by:
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  - Quantizing
Summary

- **Spatial sampling:**
  - Measuring the scene at uniformly separated points and assigning an average intensity to the pixel at that location
  - The more samples taken, the better resolution of the image
  - Insufficient sampling results in aliasing
Summary

- **Quantization:**
  - Converting the average intensity of a pixel to a binary integer
Summary

- Number of available intensity levels or colors is determined by the bit depth
  - Most gray scale images use 8 bits (256 levels)
  - Most color images use 24 bits (16.7 million colors)
Summary

- Resolution and bit depth are major factors in determining the quality of a digital image **AND** the size of the image file
Introduction to Digital Image Processing

Part II

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A simple black & white image is a **volume** of information!

Two dimensions are spatial dimensions (cm for example)

The other dimension is lightness/darkness
Contour Plot:
Another way to represent 3 dimensional information.

Lines are regions of constant gray level.
The Histogram
A statistical way of looking at an image

Step #1: Sample the image
Step #2: Quantize each pixel

Gray Value: $R = 167$

Gray Scale
$R = 255$ is white
$R = 0$ is black
Step #3: Take the gray pixels out of the image.
Step #4: Sort the pixels from darkest to lightest.

There are many pixels at this gray level.

Only a few at these gray levels.
Each pixel in the image has its place in the stacks of rearranged pixels.
Step #5: Form a graph to represent the sorted pixels.
If you use very many levels, the graph becomes sharper.

This is called the image **Histogram**.
The Image Histogram Has Many Uses
Use #1: A way to describe Image "Brightness"

Average R = 50
Average R = 120
Average R = 200
Same Average
R=120

Different Ranges=
Different contrasts

Range = 255
Range = 180
Range = 50
Characterizing Color Images
Summary — Characterizing Digital Images

1. Number of pixels - resolution

2. Bit depth - number of gray levels or colors

3. Histogram - brightness and contrast.

When you start changing the values in the image array, that’s digital image processing.
What is Digital Image Processing?

- Mathematical operations on the numbers that make up a digital picture
- Results in a new digital picture which is different from the original

REMEMBER:
Start with an image -- end with an image
High Noise

Low Noise
Algorithm: for each pixel in the original image, add 55 to its value
The Transfer Function

Initial image

Final image
The Transfer Function

Pixel value in initial image vs. Pixel value in final image
The Transfer Function

Pixel value in final image

Pixel value in initial image
The Transfer Function

Pixel value in initial image

Pixel value in final image
Initial image

Final image

Channel: Gray

Mean: 71.44
Std Dev: 58.38
Median: 53
Pixels: 410400

Level:
Count:
Percentile:
Cache Level: 1

Channel: Gray

Mean: 125.78
Std Dev: 56.78
Median: 100
Pixels: 410400

Level:
Count:
Percentile:
Cache Level: 1
Location of the Transfer Function

Line 1 will result in a brighter final image
Line 2 will result in equal brightness
Line 3 will result in a darker final image
Low Contrast

Algorithm: “stretch” the histogram by defining max and min values in initial image as black and white (0 and 255), and evenly distribute all intermediate values between them

Normal Contrast
Curve 1 will result in a more contrast in the final image
Curve 2 will result in equal contrast in the final image
Curve 3 will result in a less contrast in the final image
Mapping

- First class of mathematical operations that can be performed on images

- Definition:
  - Creating a pixel value for the final image by employing a computational rule that uses only the value of the corresponding pixel in the initial image
  - Same rule is applied to all pixels, no matter where they are located
  - This rule can be described in terms of a transfer function
Online Demos

Contrast Manipulation

Histogram Stretching
Question...

- What does the transfer function look like?
What will the final image look like?
Introduction to Digital Image Processing

Part III

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Question…

- What will the final image look like?

![Image of two football players]
threshold = 100
Question...

- What does the transfer function look like?
Review

- Digital images can be characterized by:
  - Resolution
  - Bit depth
  - Histogram
Review

- Histogram
  - Number of pixels at each allowable gray level in a digital image
Digital image processing:
Performing mathematical operations on the numbers that make up a digital image which results in a new image different from the original
Review

◆ One class of mathematical operations that can be performed on digital images is called **mapping**
  ◆ Creating a pixel value for the final image by employing a computational rule that uses only the value of the corresponding pixel in the initial image
  ◆ This rule can be described in terms of a transfer function
Review

- Shape and location of the transfer function gives an indication of how the initial image is being changed
Examples of mapping operations include:

- Changes to brightness
- Changes to contrast
- Thresholding
Arithmetic Combination of Images

- Next class of operations
- Apply an arithmetic function to corresponding pixel values of two different images, resulting in a new, third image
Image Addition

\[
\begin{array}{cc}
0 & 130 \\
180 & 200 \\
\end{array}
\quad + \quad
\begin{array}{cc}
100 & 125 \\
180 & 30 \\
\end{array}
= \begin{array}{cc}
100 & 255 \\
255 & 230 \\
\end{array}
\]
Image Subtraction

\[
\begin{array}{cc}
0 & 130 \\
180 & 200 \\
\end{array}
\] \quad - \quad \begin{array}{cc}
100 & 125 \\
180 & 30 \\
\end{array} \quad = \quad \begin{array}{cc}
0 & 5 \\
0 & 170 \\
\end{array}
\]
Image Multiplication

\[
\begin{array}{cc}
0 & 130 \\
180 & 200 \\
\end{array}
\times
\begin{array}{cc}
100 & 125 \\
180 & 30 \\
\end{array}
= \begin{array}{cc}
0 & 255 \\
255 & 255 \\
\end{array}
\]
Image Division

\[
\begin{array}{cc}
0 & 130 \\
180 & 200 \\
\end{array} \\
\begin{array}{cc}
100 & 125 \\
180 & 30 \\
\end{array}
\]

= 

\[
\begin{array}{cc}
0 & 1 \\
1 & 6 \\
\end{array}
\]
Noise Reduction

Noise: variations in an image not related to the content of the scene
\text{average} = \{ \text{noise} \}
Online Demo:

Image Averaging and Noise Removal
Convolutions

- Third class of mathematical operations that can be performed on images
- Also known as “neighborhood operations”
- Pixel values in new image are computed from *groups* of pixels located near those of the output pixel
- The relative weighting of the neighboring pixels is given by a matrix called a kernel
average
Digital Image with Kernel Overlay

Kernel Times Image

Sum Of Products

Input Image

Output Image

Choose A Kernel

Smoothing Kernel

Store Output Value

Output Values
Online Demo: Convolution Kernel Mask Operations
Sharpening Filter

Original

Filtered
Edge Finding Filter

Original

Filtered
Embossing Filter

Original

Filtered
Summary: Classes of Operations

- Mappings
  - Adjust brightness and contrast
- Arithmetic combinations of images
  - Averaging for noise reduction
- Convolutions (filters)
  - Noise reduction
  - Sharpening and softening
  - Edge detection
  - Etc.
Introduction to Digital Image Processing

Part IV

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What is Digital Image Processing?

- Mathematical operations on the numbers that make up a digital picture
- Results in a new digital picture which is different from the original

REMEMBER:
Start with an image -- end with an image
What is Digital Image Analysis?

- Using the numbers in digital pictures to get useful information or solve a problem

REMEMBER:
Start with an image -- end with an answer
Answers

- Width of Genesee River = 193 feet
- Length of “Quarter Mile” = 0.41 mile
- Length of Perimeter Road = 3.1 miles
- Area inside Perimeter Road = 346 acres
- Number of cars in “E” Lot = 226