Introduction to Image Processing

Pejman Habashi

Sep 2022

University of Windsor

Table of contents I

University of Windsor

Introduction

- What is an image?
- An image in the computer is represented as a matrix of pixel values.
- If you look closely at an image on your computer monitor (or any device), you should be able to see the elements of that matrix (pixels)

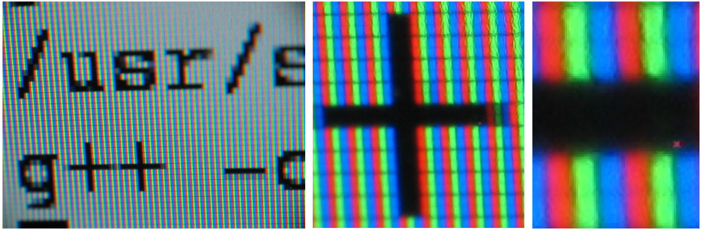


Figure: From Wikimedia: Image taken by Daniel Schwen using an inverse mounted lens.

Pixels

- Pixel is the smallest element of an image.
- Each pixel value represents the intensity of that pixel.
  - For color images, usually each pixel has three channels to store the intensity of red, green, and blue colors (RGB).
  - RGB is not the only color model, but the dominant one (e.g: HSL, HSV, YUV, YCbCr, etc.)
  - For grayscale images, only one channel is required. (since the intensity of all channels are equal)
- The intensity value is usually quantized to consume smaller space on PC.
- For example, the value of intensity of each channel usually stored as an 8 bit value (0-255)
- In extreme cases, each pixel can be represented by one bit, in that case the image would be a binary image

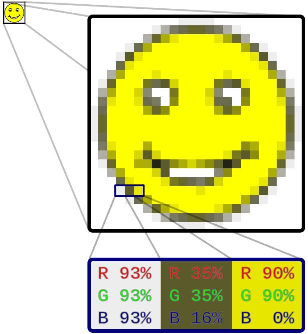


Figure: Raster image, public domain

Grayscale images

- Grayscale images are similar to color images, except that, they have only the intensity of pixels stored.
- This intensity determines how bright a point appears on the screen
- The intensity can vary from totally bright (white) to totally dark (black)
- This mapping can be done in the continuous interval $[0, 1]$, 0 for black and 1 for white
- Another approach which is more common for practical reasons, is to quantize these values to 256 discrete whole numbers in $[0, 255]$, 0 for black and 255 for white

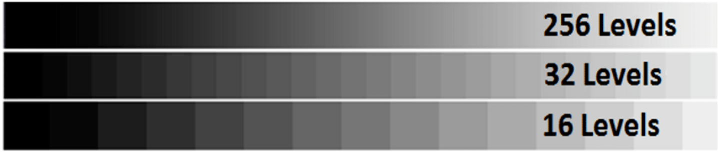
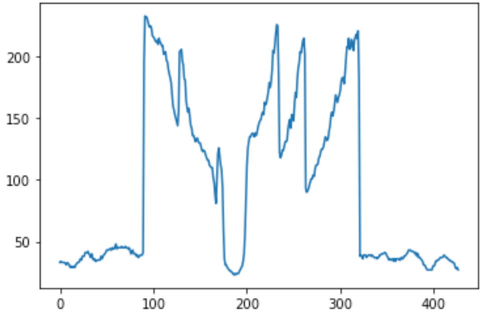
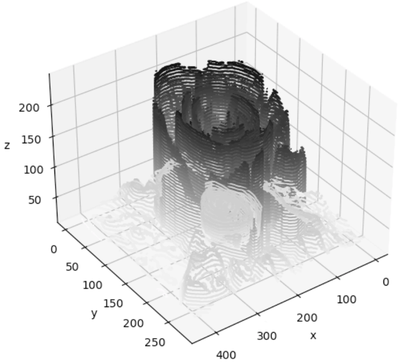


Figure: Image from Saddam Bekhet paper [1].

Image as 2D signal

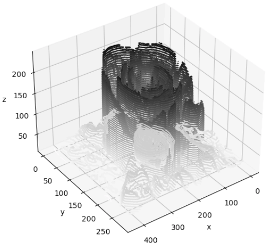
- In signal processing, a signal is a function that conveys information about a phenomenon.
- Eg: Time varying signals, like current, voltage, sound etc.
- The image can be seen as a 2d signal.

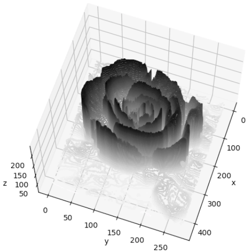


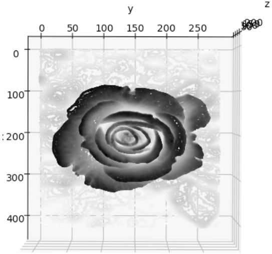


University of Windsor

Image as 2D Signal (cont.)







What is image processing?

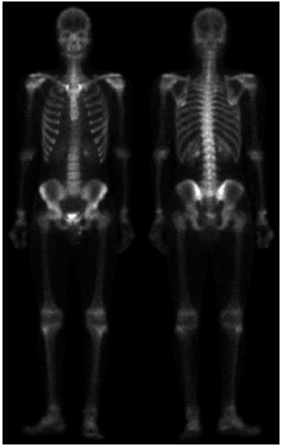
- Image processing refers to the processing of images as input to produce images or other source of information as output
- The output is usually an image, but sometimes, is not
  - e.g: given an image of screws on a belt, the output might be the number of screws in the image
- The image processing usually aims as improving the image for human perception
- Other examples:
  - Image enhancement
  - Image editing
  - Image compression
  - Image display and printing

Closely related fields to image processing

- **Image Processing**
  - Usually work directly on pixel values
  - Low level
  - **E.g:** Image transformations, image enhancement, noise removal, image restoration, feature detection, compression, etc.
- **Image Analysis**
  - Usually work on features extracted from images
  - Mid level
  - **E.g:** Image segmentation, image registration, image matching, 3D reconstruction, etc.
- **Computer Vision**
  - Use artificial intelligence and machine learning
  - High level operations
  - **E.g:** Object detection, face recognition, shape analysis, human activity recognition, etc.

Applications

Image Enhancement



Noise Removal

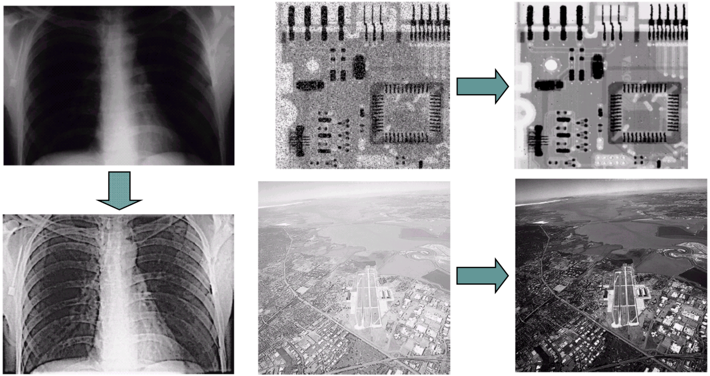
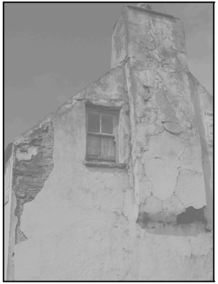
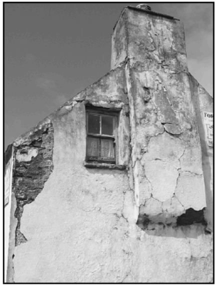


Figure: Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Contrast Adjustment



Low Contrast

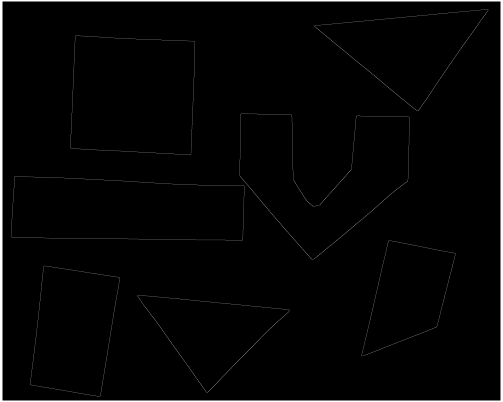


Original Contrast

High Contrast

University of Windsor

Edge Detection



Edge Detection

Image segmentation

Region Segmentation

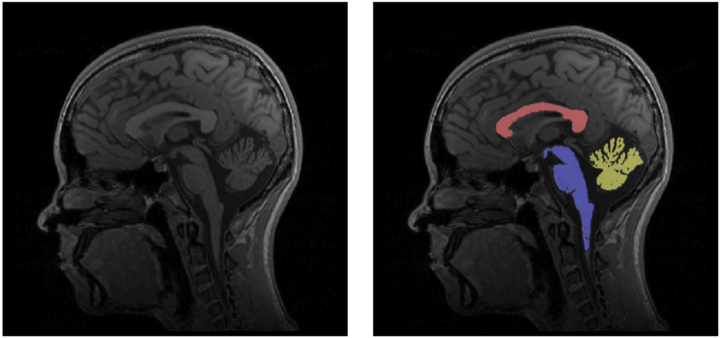
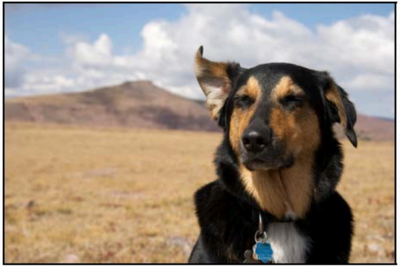
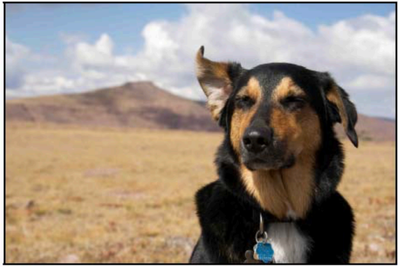


Image Compression



Original, 2.1MB



JPEG Compression, 308KB (15%)

Image Restoration

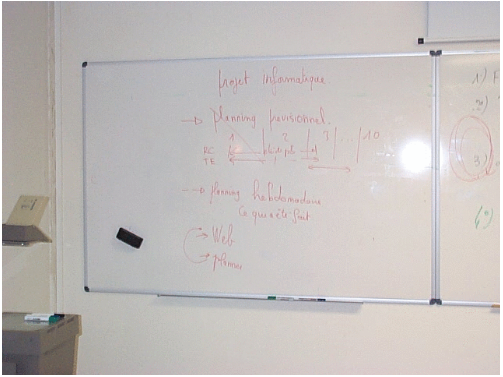
Damaged Image

Restored Image

Figure: Images taken from M. Bertalmio, G. Sapiro, C. Ballester: Image Inpaiting, SIGGRAPH 2000

University of Windsor

Geometry transformations



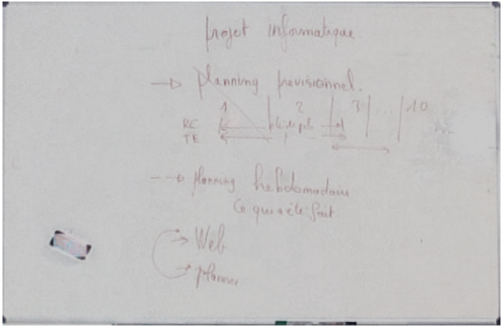


Image Formation

Image Formation

- A regular digital camera usually capture images by focusing reflected light from surfaces into one plane (sensor) and quantize those values.
- The lens focuses light on the sensor.
- Optionally for color cameras, there is a color filter array (CFA), which filters certain colors to pass though
- The sensors are light-sensitive cells, that can perceive the amount of light that reached them and transforms it into a digital signal.
- These signals then aggregated to form a digital image

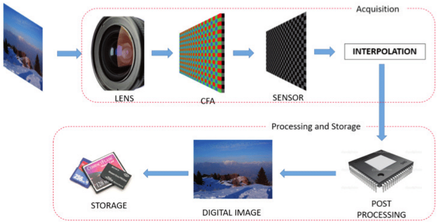
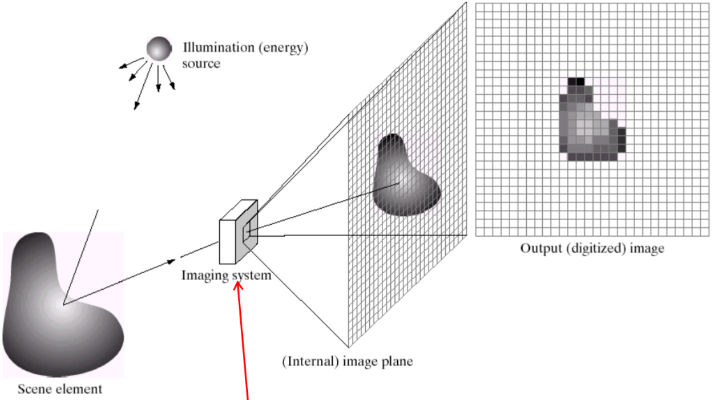


Figure: Image from Fausto Galvan and Sebastiano Battiato [2]

Image Formation II



Example: a camera
Converts light to image

Credits: Gonzales and Woods

University of Windsor

Pinhole camera model

- From the mathematical point of view, the projection of 3D world into 2D image can be described with the pinhole camera model.
- This model states the mathematical relationship between the coordinates of a point in 3D space and its projection onto the image plane.

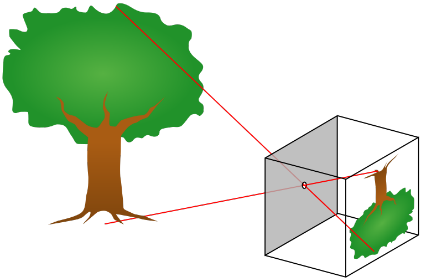


Figure: Pinhole camera model (public domain)

Pinhole camera model cont.

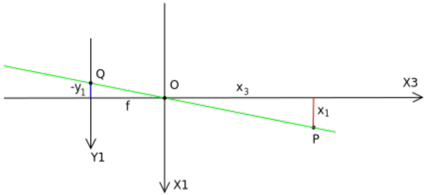


Figure: Pinhole camera model (public domain)

- The similarity of triangles in the figures, led to the following conclusion:

$$\begin{cases} \frac{-y_1}{f} = \frac{x_1}{x_3} \Rightarrow y_1 = -\frac{fx_1}{x_3} \\ \frac{-y_2}{f} = \frac{x_2}{x_3} \Rightarrow y_2 = -\frac{fx_2}{x_3} \end{cases}$$

- This can be summarized as:

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = -\frac{f}{x_3} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$$

Image Processing

Image operations on pixel basis

Different operation on images can be defined and used to process them.

- Mathematical operations
- Logical operations: usually involve a bitmap image (And, Or, Xor, Not)
  - E.g: A bit map image can be used as a mask for another image
- Image Filtering
- Color mappings (not covered in this presentation)
- Histogram Analysis (not covered in this presentation)
- Morphological operations (not covered in this presentation)
- Geometry transformation operations (not covered in this presentation)
- etc.

Mathematical Operations I

- Images represented as matrices, so addition and subtraction should be familiar operations.
- Adding to those operations, there is elementwise division and multiplications.
- Sometimes, the operation done on a Region of Interest (ROI), where a sub-matrix of original image used for operation
  - E.g: two images can be blended together

Mathematical Operations II

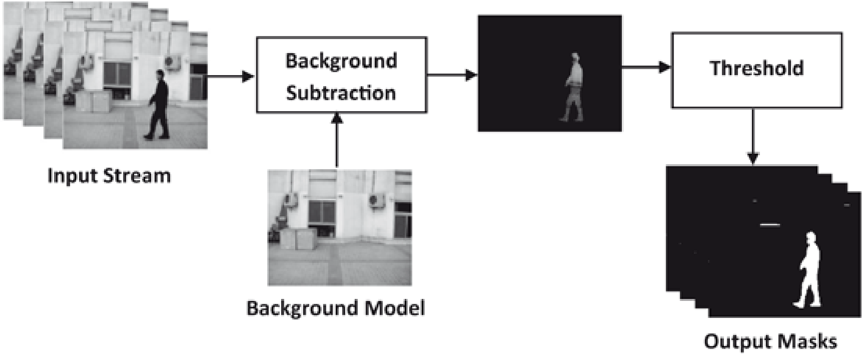


Figure: Image from [4]

Logical Operations

- The logical operations are coming from logical gates (and/or/not) and their combinations.
- The effect of not operation on binary images, is similar to complement of sets
- The effect of and operation on binary images, is similar to intersection of sets
- The effect of or operation on binary images, is similar to union of sets.

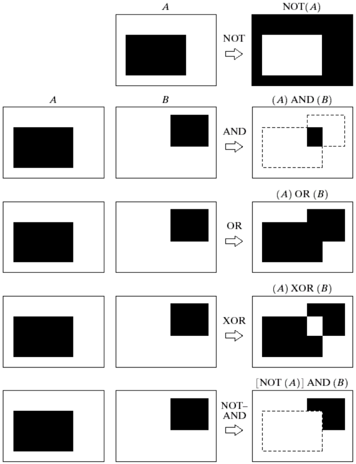


Image filtering: Convolution

- The convolution of two 1D signals is defined as:

$$(f * g)(t) = \int_{-\infty}^{+\infty} f(\tau)g(t-\tau)\,d\tau$$

- In discrete world, the convolution integral will be replaced with a summation
- For discrete 2D signal, we will have a double summation after multiplication
- In practice, we use a signal which is zero everywhere and non zero in small area, we call the non-zero portion the kernel.
- In discrete world, this kernel would be a matrix.

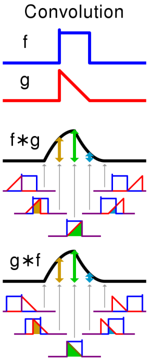


Figure: The 1D-convolution

Image filtering

- Image filtering is the process of convolving a filter with the image and producing the new image as filtered image.
- The convolution is the process of calculating a weighted sum over neighborhoods of the pixel.
- The weights are usually determined by the filter kernel.

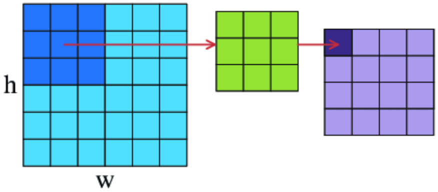


Figure: The 2D-convolution

Identity Kernel

Figure: Original Image

$$\mathbf{I} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

Figure: The filtered image

Pixel shifting Kernel

Figure: Original Image

$$PS = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \end{bmatrix}$$

Figure: The filtered image

Low pass filter

Figure: Original Image

$$L = \frac{1}{9}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

Figure: The filtered image

High pass filter

Figure: Original Image

$$I - L = \frac{1}{9}\begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix}$$

Figure: The filtered image

Image Sharpening

Figure: Original Image

$$2I - L = \frac{1}{9}\begin{bmatrix} -1 & -1 & -1 \\ -1 & 17 & -1 \\ -1 & -1 & -1 \end{bmatrix}$$

Figure: The filtered image

Gaussian low pass

Figure: Original Image

$$G = \frac{1}{16}\begin{bmatrix} 1 & 2 & 1 \\ 2 & 6 & 2 \\ 1 & 2 & 1 \end{bmatrix}$$

Figure: The filtered image

Gaussian high pass

Figure: Original Image

$$I - G = \frac{1}{16}\begin{bmatrix} -1 & -2 & -1 \\ -2 & 12 & -2 \\ -1 & -2 & -1 \end{bmatrix}$$

Figure: The filtered image

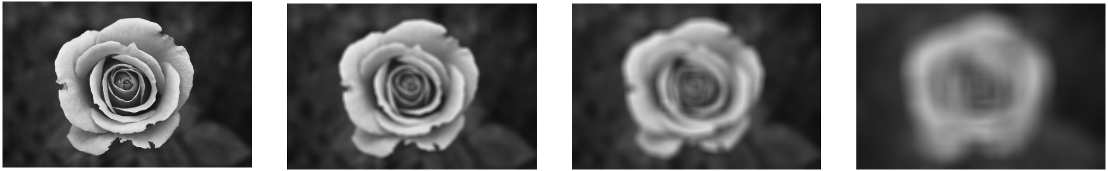
Gaussian sharpening

Figure: Original Image

$$2I - G = \frac{1}{16}\begin{bmatrix} -1 & -2 & -1 \\ -2 & 28 & -2 \\ -1 & -2 & -1 \end{bmatrix}$$

Figure: The filtered image

Kernel size



Original | 7×7 | 15×15 | 41×41

Conclusion

Conclusion

- Images are a matrix of pixel values
- Image processing is the direct processing of pixel values of an image to produce other images
- Image processing is a broad concept, we have just scratched the surface today.
- Mathematical operations and Logical operations are very common to manipulate the content of images
- Filters represented by a kernel can be used to apply different transformations on the images.
- Filtering can be used to reduce noise, blur, sharpen the image, or to perform many different operations on the image.

Saddam Bekhet and Amr Ahmed.
Graph-based video sequence matching using dominant colour graph profile (dcgp).
Signal, Image and Video Processing, 12(2):291–298, 2018.

Fausto Galvan and Sebastiano Battiato.
Image/video forensics: Theoretical background, methods and best practices part two–from analog to digital world.

Rafael C Gonzalez and Paul Wintz.
Digital image processing(book).
Reading, Mass., Addison-Wesley Publishing Co., Inc.(Applied Mathematics and Computation, (13):451, 1977.

Soharab Hossain Shaikh, Khalid Saeed, and Nabendu Chaki.
Moving object detection using background subtraction.
In *Moving Object Detection Using Background Subtraction*, pages 15–23. Springer, 2014.

University of Windsor