Visual Computing
Summary

August 31, 2020

Chapter 1

The Digital Image

1.1 What is an image:

Signal: A function depending on some variable with physical meaning

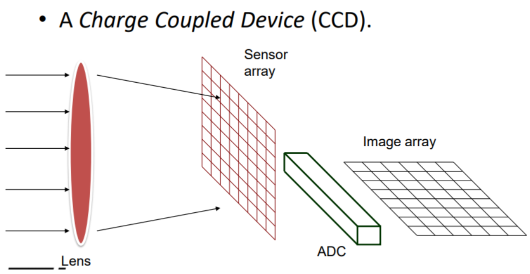
Image: A continuous function. The value can take on physical values. e.g Brightness, temperature, pressure, depth, etc. We distinguish images with:

- **2 variables:** xy- coordinates
- **3 variables:** xy + time (video)

Hence an image is a picture or pattern of a value varying in space and/or time.

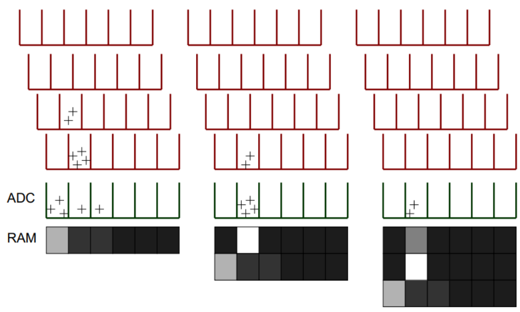
$$f : \mathbb{R}^n \to S$$

1.2 The digital camera



The sensor array: An array of photosites. Each photosite is a bucket of electrical charge and contain a charge proportional to the incident light intensity during exposure.

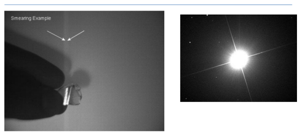
Analog to Digital Conversion: The ADC measures the charge and digitizes the result. The conversion happens line by line. The charges in each photosite move down through the sensor array.



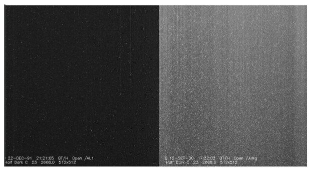
Various errors:

- **Blooming:** The buckets have finite capacity, saturation causes blooming. It happens when a large amount of light gets focused to a single point on your cameras image sensor. This can create so much charge that it actually bleeds from pixel to pixel until it eventually spreads out.

- **Bleeding or Smearing:** During transit buckets still accumulate some charges. The amount is influenced by the time ”in transit” versus the integration time



- **Dark Current:** A relatively small electric current that flows through photosensitive devices even when no photons are entering the device.

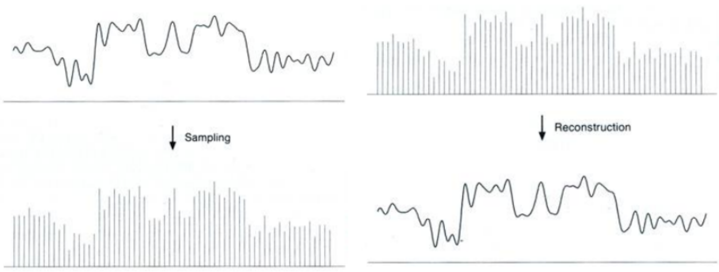


<u>CMOS:</u> Contains the same sensor elements as CCD but each photo sensor has its own amplifier. the benefits:

- Recent technology
- Standard IC technology
- Cheap
- Low Power
- Less sensitive
- Per pixel amplification
- Random pixel access
- Smart pixels
- On chip integration with other components

1.3 Sampling 1D:

Sampling in 1D takes a function, and returns a vector whose elements are values of that function at the sample points.

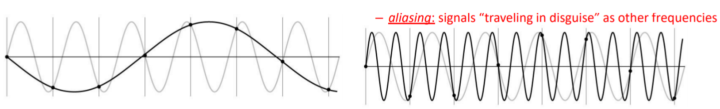


1.3.1 Reconstruction:

Making samples back into a continuous function. This amounts to guessing what the function did in between the individual samples

1.3.2 Undersampling:

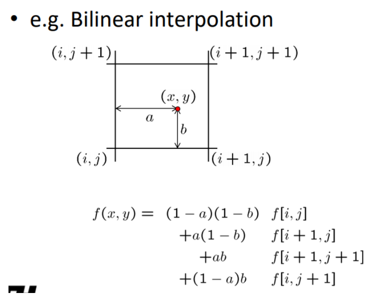
Occurs if not enough sampling points are available. It results in a loss of information and can be indistinguishable from other samples e.g undersampling a sin wave:



1.4 Sampling 2D:

Sampling in 2D takes a function and returns an array. The array can have infinite dimensions and have negative as well as positive indices.

1.4.1 Reconstruction continuous signals:



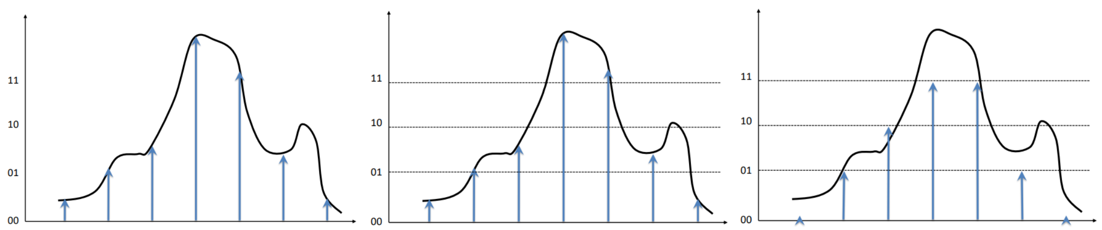
1.4.2 Nyquist Frequency:

Half the sampling frequency of a discrete signal processing system. The signals max frequency (bandwidth) must be smaller than this.

1.4.3 Quantization:

Real valued function gets digital values (integer values). Quantization is lossy i.e the orignial signal cannot be reconstructed anymore. Simple quantization uses equally spaced levels with k intervals:

$$k = 2^b$$



1.4.4 Image Properties:

Geometric Resolution: How many pixels per area

Radiometric Resolution: How many bits ber pixel

1.5 Image Noise

The different types of common Noise models:

- **Gaussian noise:**

$$I(x, y) = f(x, y) + c$$

where $c \sim N(0, \sigma^2)$ so that

$$p(c) = (2\pi\sigma^2)^{-1} e^{\frac{-c^2}{2\sigma^2}}$$

- **Poisson noise:**

$$p(k) = \frac{\lambda^k e^{-\lambda}}{k!}$$

- **Rician noise:**

$$p(I) = \frac{I}{\sigma^2} e^{\frac{-(I^2+f^2)}{2\sigma^2}} I_0(\frac{If}{\sigma^2}$$

- **Multiplicative noise:**

$$I = f + fc$$

Signal to noise ration (SNR) An index of image quality:

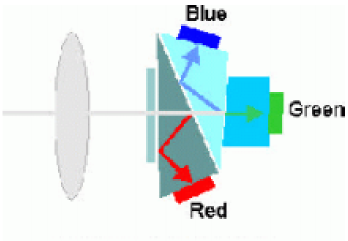
$$s = \frac{F}{\sigma} \text{ where } F = \frac{1}{XY} \sum_{x=1}^{X} \sum_{y=1} Y f(x, y)$$

Peak Signal to Noise Ration (PSNR)

$$s_{peak} = \frac{F_{max}}{\sigma}$$

1.6 Color Cameras:

Prism Color Camera: Seperates the light into 3 beams using a dichroic prism



Filter mosaic: Filter is coated directly on sensor

Filter wheel: Rotate multiple filters in front of lens. This is only suitable for static scenes.

Prism vs. mosaic vs. wheel

approach	Prism	Mosaic	Wheel
# sensors	3	1	1
Separation	High	Average	Good
Cost	High	Low	Average
Framerate	High	High	Low
Artefacts	Low	Aliasing	Motion
Bands	3	3	3 or more
	High-end cameras	Low-end cameras	Scientific applications

Chapter 2

Image Segmentation:

Image segmentation is the concept of partitioning an image into regions of interest.

Complete Segmentation: A finite set of regions $R_1, ..., R_N$, such that

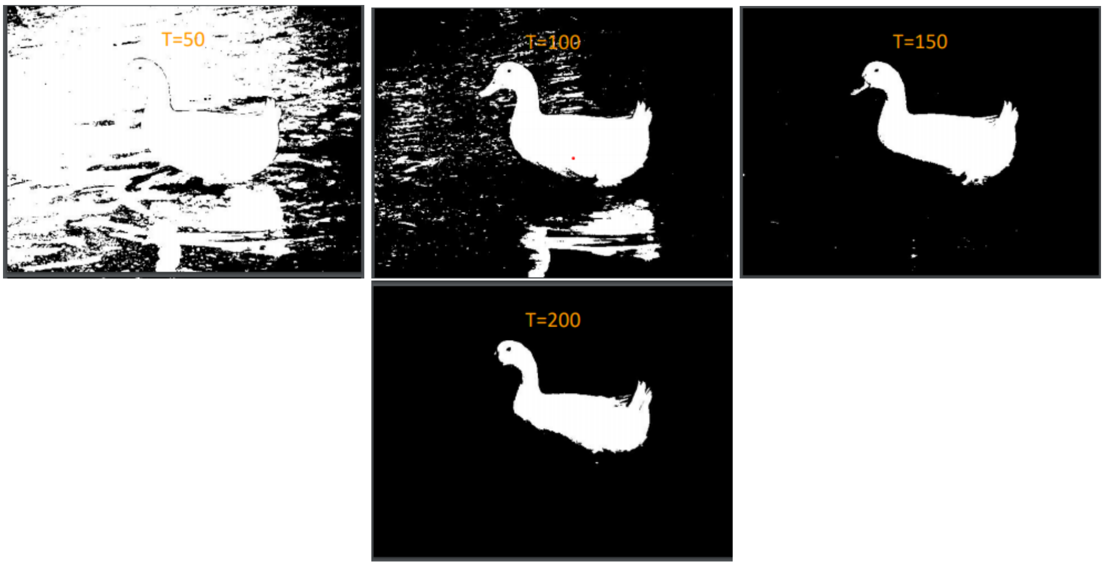
$$I = \bigcup_{i=1}^{N} R_i \text{ and } R_i \cap R_j = \phi \quad \forall i \neq j$$

Where I is an image.

2.1 Thresholding

Thresholding is a simple segmentation process which produces a binary image B. It labels each pixel "in" or "out" of the region of interest by comparison of the greylevel with a threshold T:

$$B(x,y) = \begin{cases} 1 & \text{if } I(x,y) \geq T \\ 0 & \text{if } I(x,y) < T \end{cases}$$



2.2 ROC Analysis

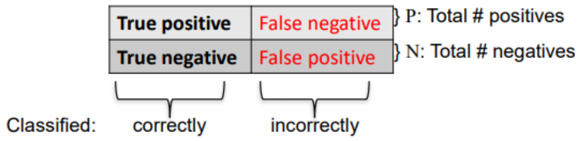
ROC = Recieveer Operating Characteristic

An ROC curve characterizes the performance of a binary classifier. A binary classifier distinguishes between two different types of things e.g:

- Healthy/afflicted patients
- Pregnancy tests
- Object detection
- Foreground/background image pixels

2.2.1 Classification Error

Binary classifiers make errors. There are two inputs to a binary classifier i.e positives and negatives but there are four possible outcomes in any test:



2.2.2 ROC Curve

Characterizes the error trade-off in binary classification tasks. It plots the TP (True-positive) against the FP (False-positive) fraction

$$\text{TP fraction (sensitivity): } \frac{\text{True positive count}}{P}$$
$$\text{FP fraction (1-specificity): } \frac{\text{False positive count}}{N}$$

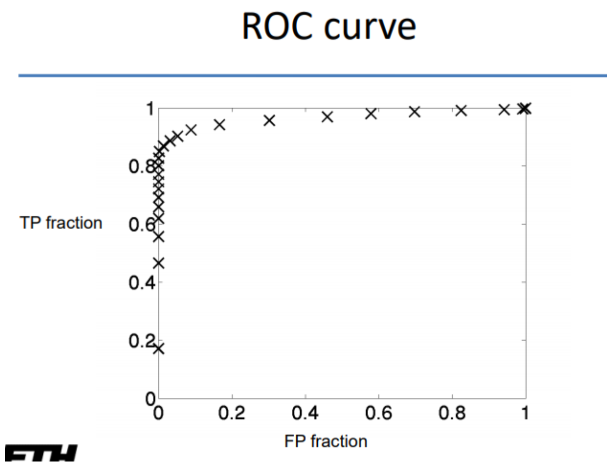
An ROC curve always passes through (0,0) and (1,1)
We choose an operating point by assigning a relative costs and values to each outcome:

- V_{TN} Value of true negative
- V_{TP} Value of a true positive
- C_{FN} Cost of a false negative
- C_{FP} Cost of a false positive

We choose the point on the ROC curve with gradient:

$$\beta = \frac{N}{P}\frac{V_{TN}+C_{FP}}{V_{TP}+C_{FN}}$$

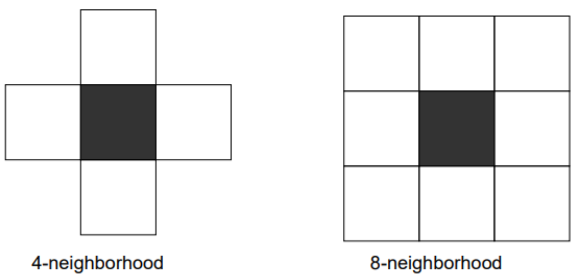
For simplicity we often set $V_{TN} = V_{TP} = 0$



In reality we use 2-3 seperate sets of test data:

1. **Training set:** For tuning the algorithm
2. **Validation set:** For tuning the performance score
3. **Test set:** To get a final performance score on the tuned algorithm

2.3 Pixel Connectivity:



Pixel Neighbourhood:

Pixel Paths:

- A 4-connected path between pixels p_1 and p_n is a set of pixels $\{p_1, p_2, ..., p_n\}$ such that p_i is a 4-neighbour of p_{i+1} i=1,...,n-1
- A 8-connected path, p_i is an 8-neighbour of p_{i+1}

Connected Regions:

- A region is 4-connected if it contains a 4-connected path between any two of its pixels
- A region is 8-connected if it contains an 8-connected path between any two of its pixels

2.4 Image Labelling

Connected components Labelling: Labels each connected component of a binary image with a seperate number