CSCI435 – Computer Vision

Lecture 1

Subject Overview

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Lecture Overview

- What Computer Vision is and why this subject may be useful for your engineering degree
- What you need to know about the subject structure and the assessment process

CSCI435 Objectives

On successful completion of this subject, students are expected to:

- understand fundamentals of computer vision
- understand system level design issues and system integration issues
- design and implement in software major components of machine vision systems

Method of Presentation

Structuring of CSCI435 will help you to study fundamental theoretical concepts and get practical skills in developing computer vision applications

- Lectures : 2 hours per week, 13 lectures
- Assignments : 3 assignments

This is a 6 credit point subject. According to Course Rule 003, this requiter **at least 12 hour per week**, including self-directed study

Assessment

Assessment Items	Percentage of Final Mark		Due Date
	Marks for item	Minimum required to pass subject	
Lectures		Satisfactory attendance	weeks 1 - 13
Assignments	60 marks		as scheduled
Exam	40 marks	16	exam week as per schedule
Total	100 marks	50	The mark must be ≥50 to pass the subject

Assignments

- There will be three programming assignments
- When an assignment is released, download the assignment description from the web site. Read carefully the specifications and make sure you understand what you are required to do
- There is no requirement to carry out assignments in the laboratories. You may work at home to develop solutions
- Your completed solutions must be submitted electronically. The submission process will be explained in every assignment specification
- Late assignments **will not be accepted** without a granted special consideration
- Exact time after which the submitted assignment will not be accepted by the system will be indicated in every assignment specification

Development environment

- Programming languages: C, C++ (standards ANSI C, ANSI C++)
- Compiler: Microsoft Visual C++
- IDE: Microsoft Visual Studio (Express Edition)
- Library: Open CV

  `opencv.org` – downloads, books, forums, online documentation

You need to install and configure this development environment on your PC or laptop to work on assignments.

Subject Materials

- Lecture notes:

  The lecture notes will be available on the subject web site.

- Recommended books:

  - D. Forsyth, J. Ponce. *Computer Vision: a Modern Approach*, Prentice Hall, 2nd edition, 2012

  - G. Bradski, A. Kaehler. *Learning OpenCV*, 2008.

  - R. Laganlere. *OpenCV 2 Computer Vision Application Programming Cookbook*

  - R. Szeliski, *Computer Vision: Algorithms and Applications*, 2010.

Consultation Times

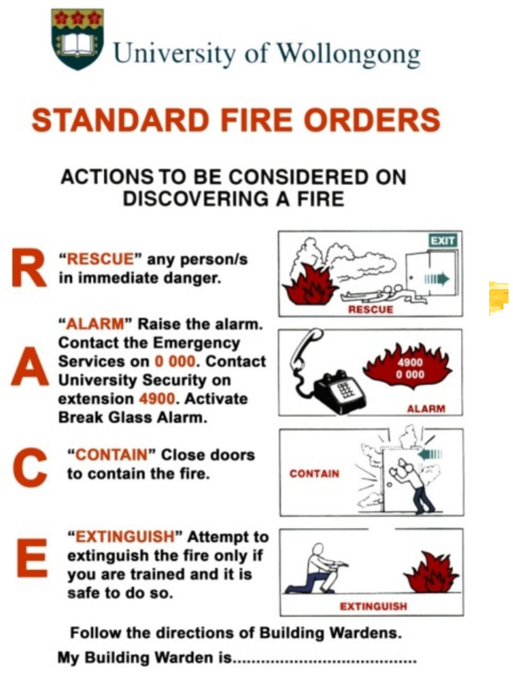
- Dr Igor Kharitonenko

Thursday	13:30 – 15:30
Friday	11:30 – 13:30

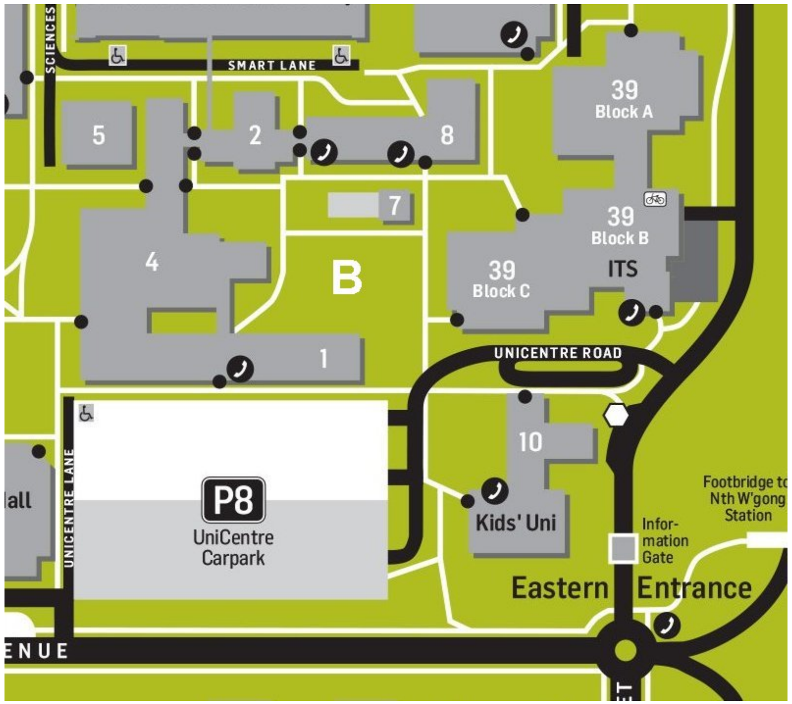
- Prof. Philip Ogunbona

Monday	10:30 – 12:30
Tuesday	14:30 – 16:30

Emergency Evacuation Procedure



- Turn off any electrical equipment
- Leave the building immediately via the nearest exit
- Don't use lifts
- Obey all directions from wardens
- Do not re-enter the building until advised



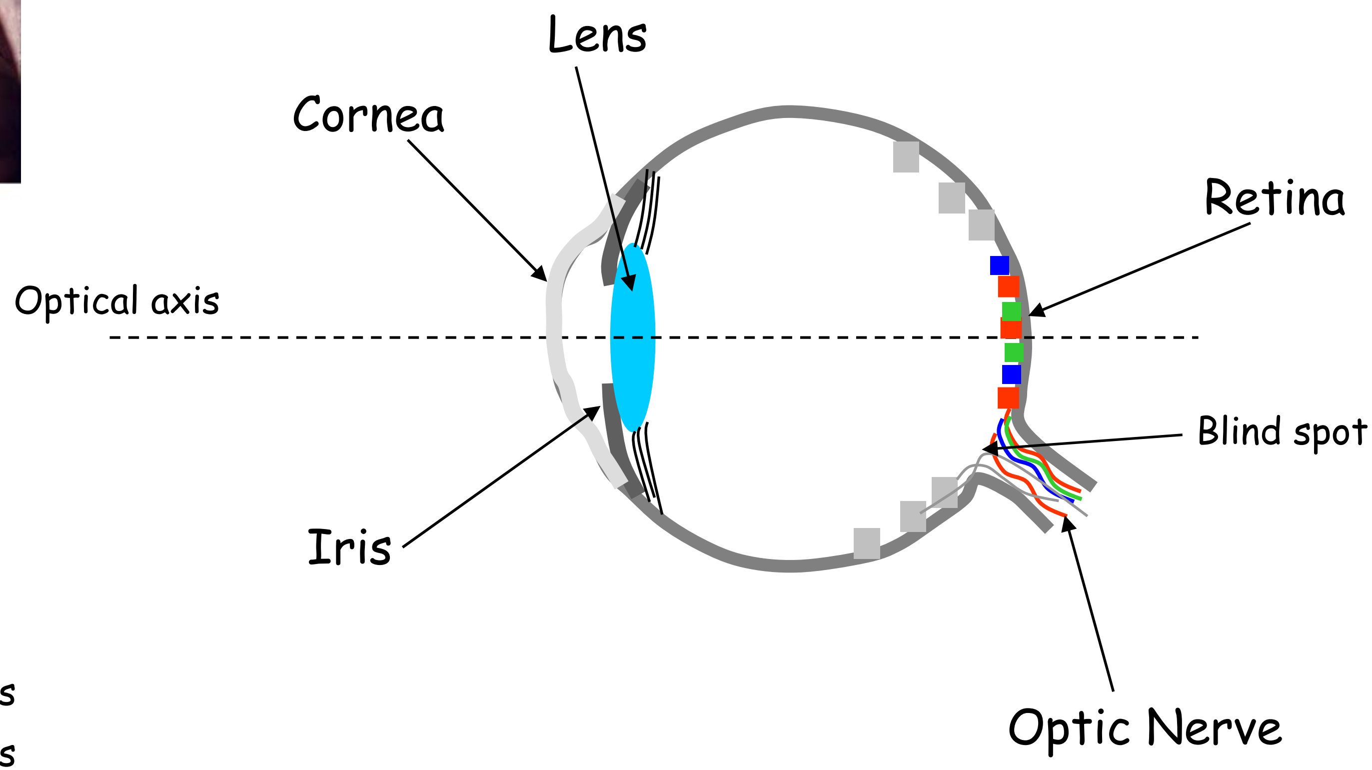
Assembly area

The Senses

delivers more than 80% of the information

The Nature of Vision

Fig. 1. View of the human eye



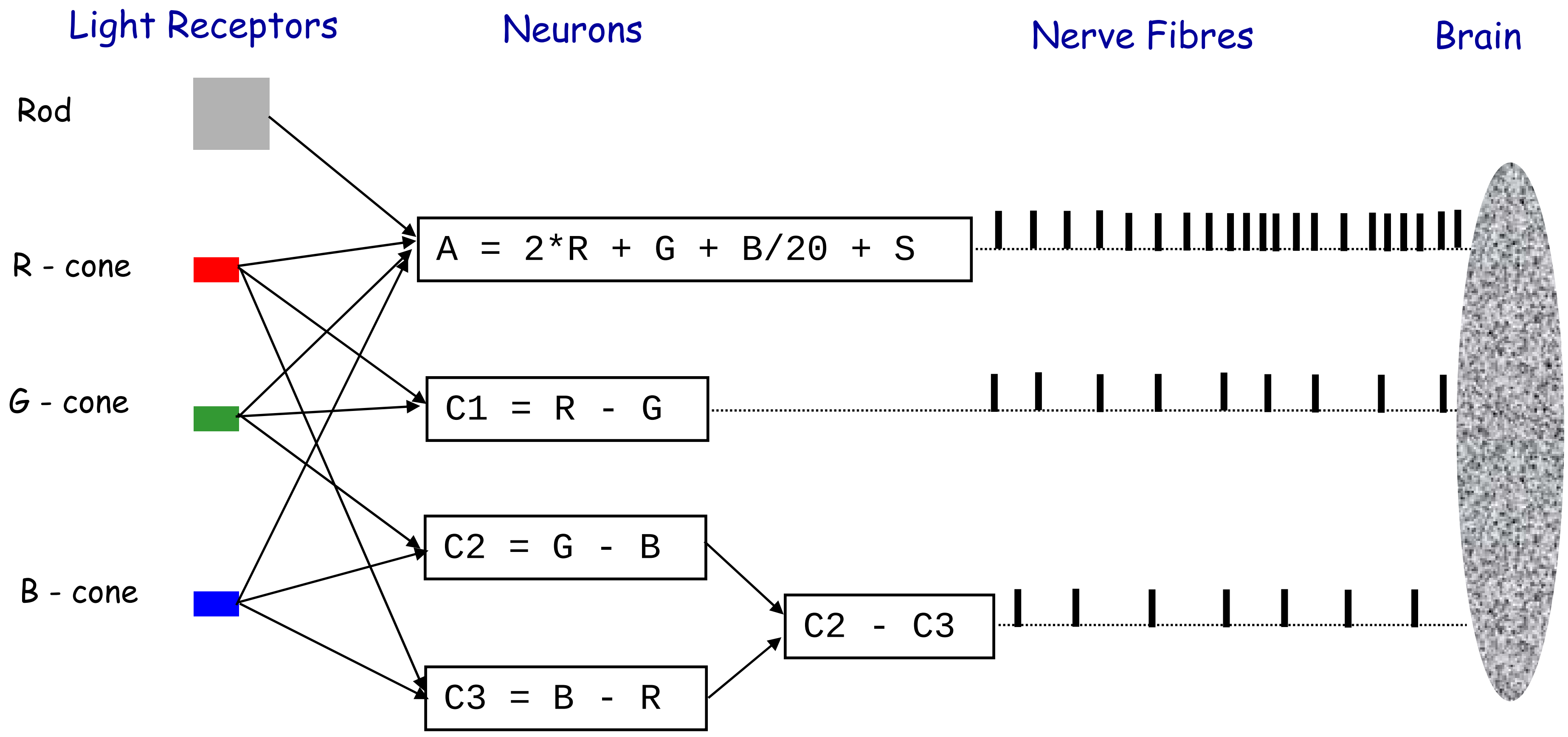
R - cones

G - cones

B - cones

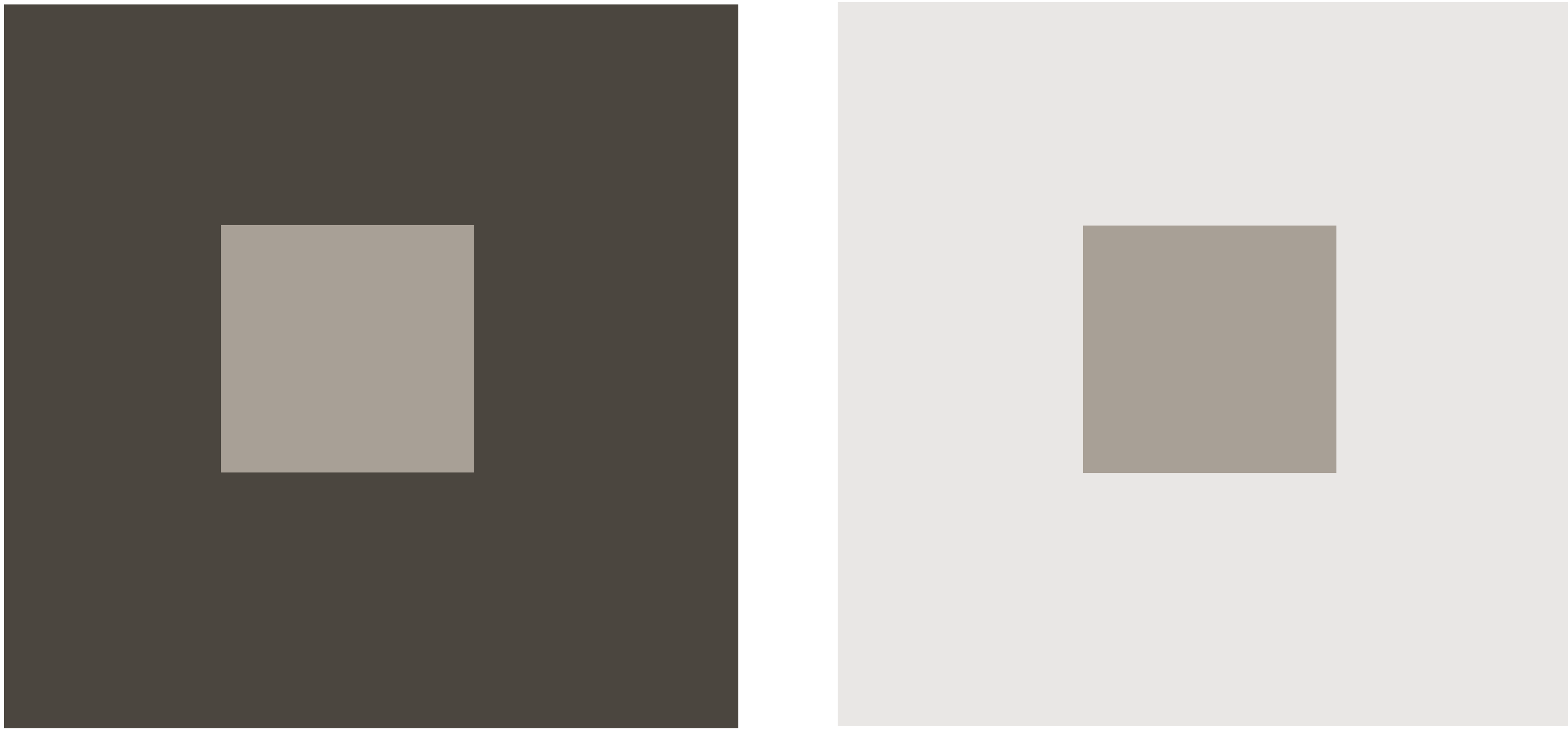
rods

Visual Data Transmission

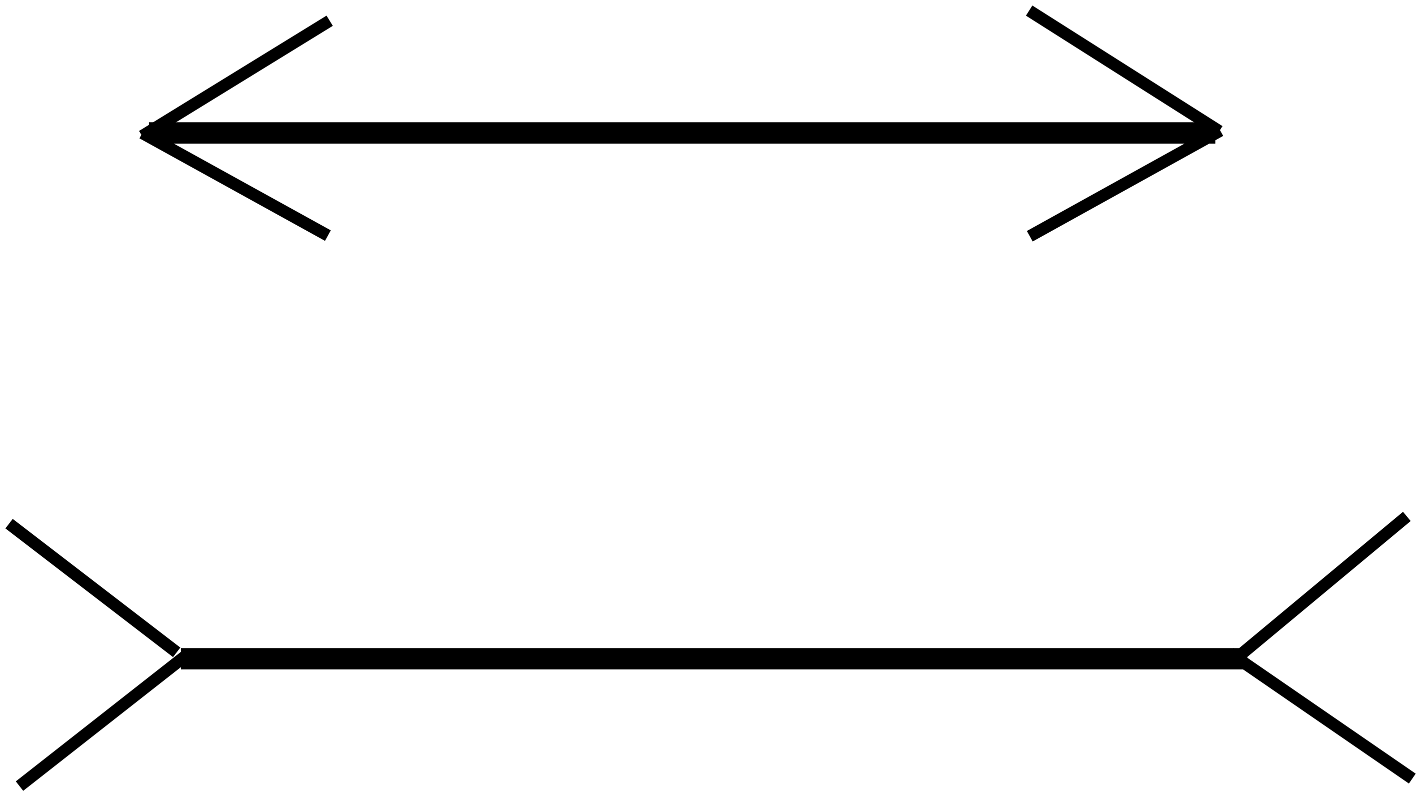


There are four types of receptors and only three types of nerve fibres

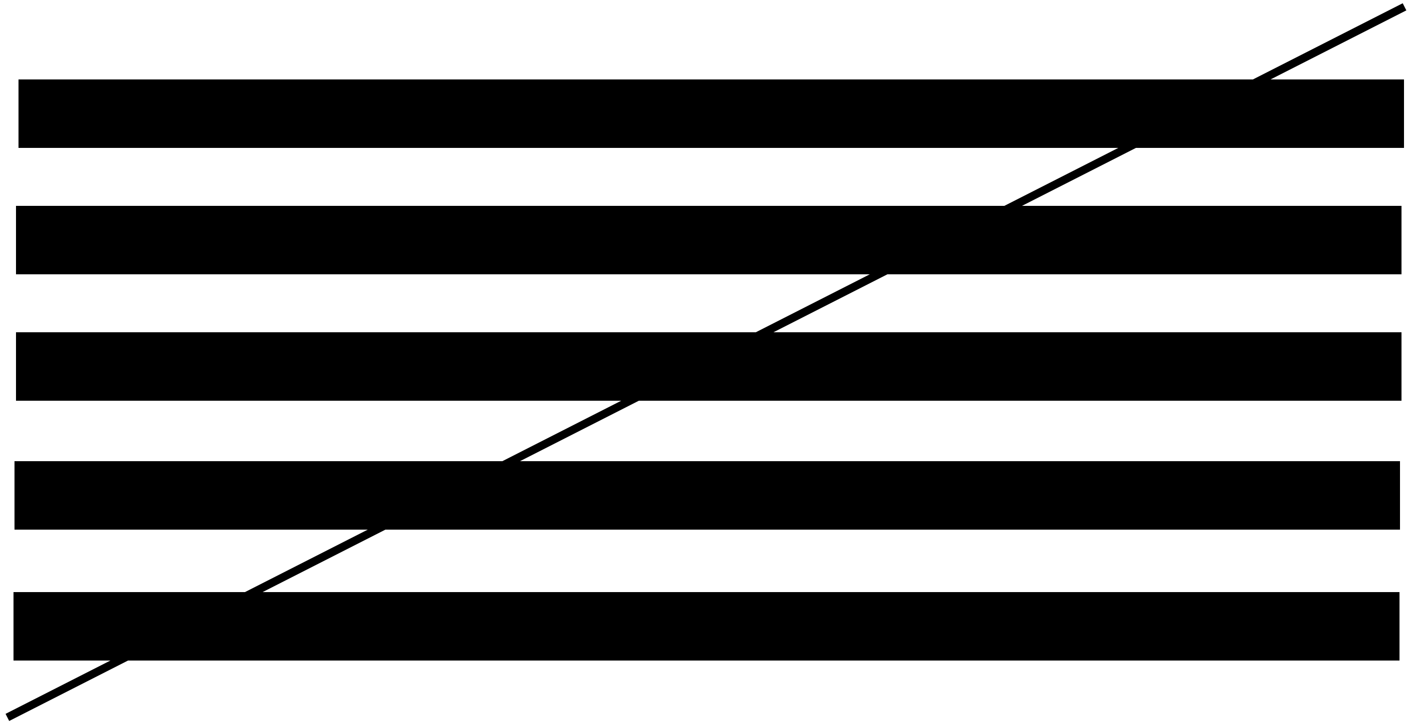
Optical Illusions



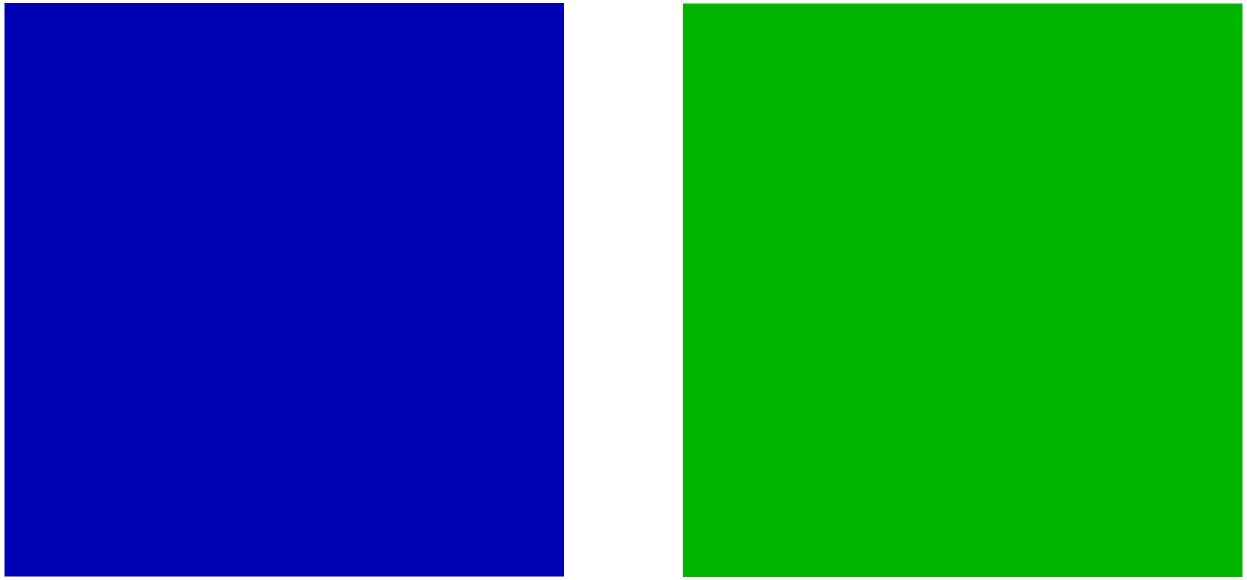
Optical Illusions



Optical Illusions



Optical Illusions



Blind Spots

Blind Spot

Print out this page. Close the right eye. Look at the blue circle from various distances until the green circle disappear

Summary

- Human Vision is a very complex multistage process
- Human Vision is optimised (may be by evolution) to provide reasonable reaction time in daily life
- Human Vision keeps focus on objects of interest ignoring other details
- Human Vision is not the ultimate visual system It has poor performance in measurement of parameters and may lead to incorrect conclusions
- Efficiency of Human Vision declines due to fatigue

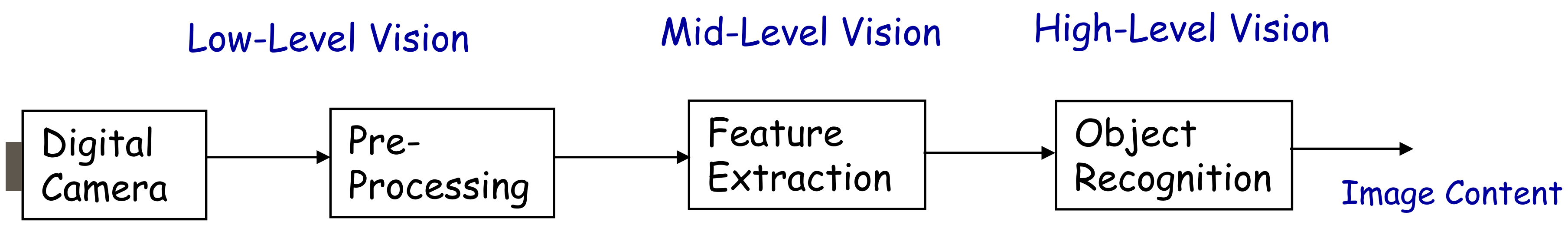
Examples of Industrial Applications

- Paint Colour Matching
- Video Surveillance
- Intelligent Cruise Control
- Automatic Parking
- Automatic Assembly Lines
- Automatic Visual Inspection
- Target Detection and Tracking

Human Vision may not be the best model for many industrial applications

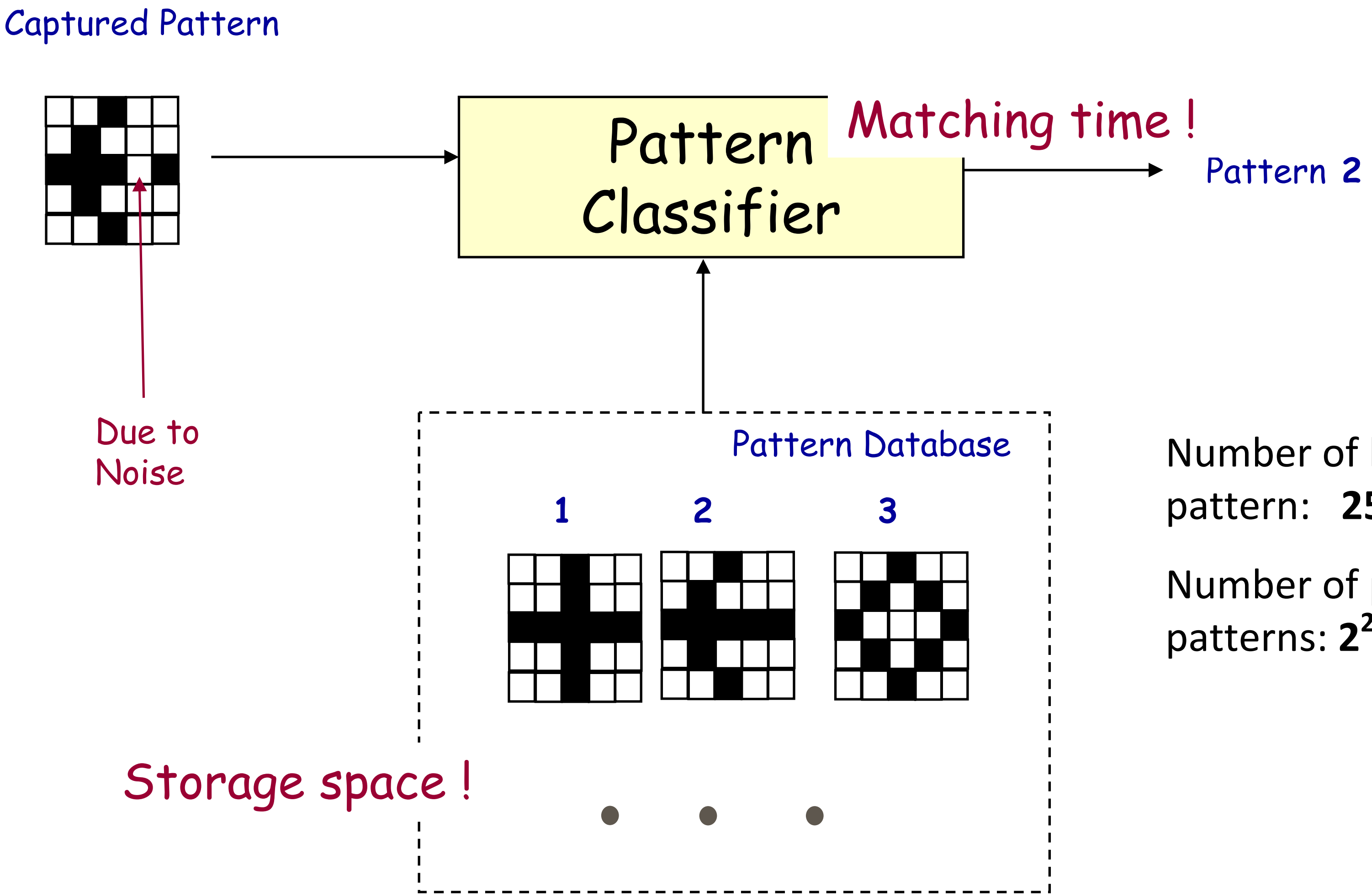
Machine Vision Concept

- Machine Vision is the process where a digital computer automatically controls the process of image capturing and image analysis to understand content of the image



- Guiding principle: *If the eye can do it, so should the machine*
- This structure and computer vision algorithms do not mimic the human vision. However, they may utilise relevant discoveries in biological studies.

Semiconductor Market Technical Challenges



Number of bits per pattern: **25**

Number of possible patterns: $\mathbf{2^{25} = 33.5}$ M

Semiconductor Market Technical Challenges

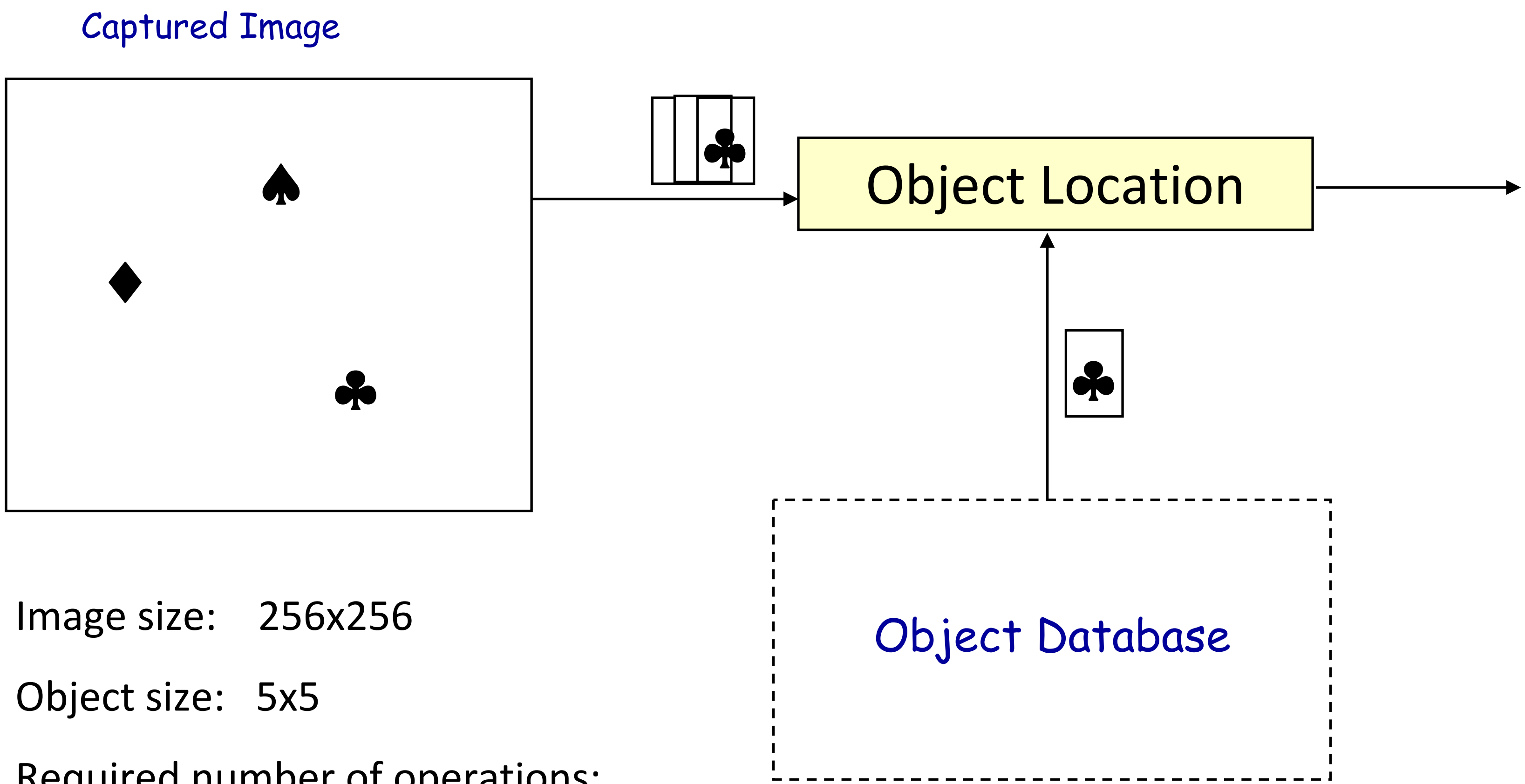


Image size: 256x256

Object size: 5x5

Required number of operations:
$5^2 * 256^2 = 1.6M$

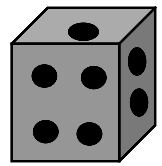
Review of Math

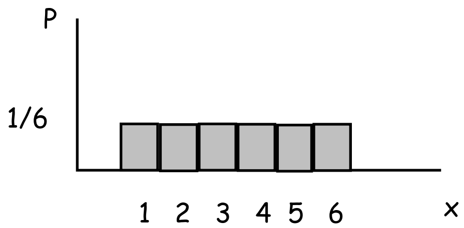
Probability

- Some events are random and cannot be described with certainty

Rolling a dice can equally result in any number x from 1 to 6.

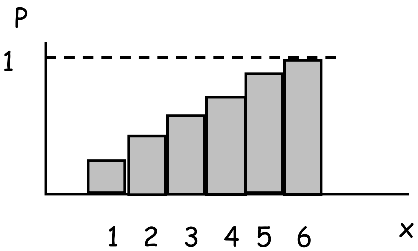
Pr(1) = Pr(2) = Pr(3) = … Pr(6) = 1/6





Probability Density Function p(x) = Pr(x)

What is the probability that the number x will be less than or equal to N, where $N \in \{1, 2, \ldots 6\}$



Probability Distribution Function P(x) = Pr(x ≤ N)

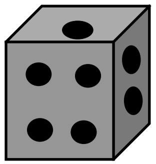
P(1) = Pr(1) = 1/6

P(2) = Pr(1 or 2) = 1/6 + 1/6 = 1/3

Review of Math

- The complement of an event

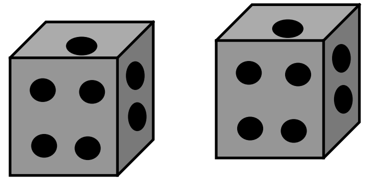
What is the probability that the dice is not result in 4 ?



P(not 4) = 1 – P(4) = 1 – 1/6 = 5/6

Review of Math

- Independent events



What is the probability that both dices result in 1 ?

$Pr(1 \text{ and } 1) = Pr_A(1) * Pr_B(1) = 1/6 * 1/6 = 1/36$

What is the probability that at least one dice results in 1 ?

$Pr(1 \text{ or } 1) = Pr_A(1) + Pr_B(1) - Pr(1 \text{ and } 1) = 1/3 - 1/36 = 11/36$

What is the probability that the sum is 3 ?

Suitable outcomes are: (1 and 2) or (2 and 1)

$Pr(S=3) = Pr(1\text{and}2) + Pr(2\text{and}1) - Pr(1\text{and}2 \text{ and } 2\text{and}1)$

However, $Pr(1\text{and}2 \text{ and } 2\text{and}1) = 0$, as events 1and2, 2and1 are mutually exclusive. Thus,

$Pr(S=3) = 1/36 + 1/36 - 0 = 2/36 = 1/18$

Review of Math

- Quiz

Two dices are rolled. The probability that the sum is equal to 3 is 1/18.
The probability that the sum is equal to 2 is 1/36
What is the probability that the sum is either 2 or 3 ?

Are the events mutually exclusive ?

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P(S=2 or S=3) = P(S=2) + P(S=3) - 0 = 1/36 + 1/18 = 1/12
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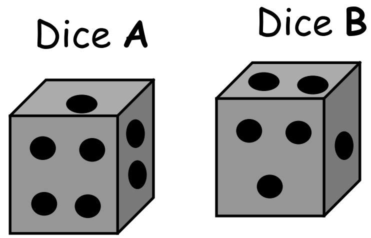
Review of Math

- Quiz



Two dices are rolled.
What is the probability that only one dice will result in 2?

1. Probability that dice A results in 2 is and dice B not:
`P( 2 and (not 2) ) = 1/6 * 5/6 = 5/36`

2. Probability that dice B results in 2 is and dice A not:
`P((not 2) and 2 ) = 5/6 * 1/6 = 5/36`

3. Events 1 and 2 are mutually exclusive. Thus:
`P(only one 2 ) = 5/36 + 5/36 = 10/36`

Review of Math

- Dependent events

Probability of the letter 'p' in English is 0.019
Probability of the letter 'b' in English is 0.015

What is the probability of finding a word that starts with pb... ?
P('pb') = 0.019*0.015 = 0.00029

That gives an incorrect results, because there is no such a word. We used an incorrect assumption.

Letters in words are dependent

P('pb') = P(p)***P('b'|'p')** = 0.019 * 0 = 0

conditional probability

Review of Math

- Quiz

Probability of a rainy day in May is 0.2. If it's raining today, the probability that tomorrow will be raining is 0.6, cloudy 0.3, sunny 0.1.

What is the probability that there will be raining two days ?

Is this correct?

P(rain and rain) = 0.2*0.2 = 0.004

Since the events are dependent,

P(rain and rain) = P(rain)***P(rain|rain)** = 0.2 * 0.6 = 0.12

Review of Math

- Bayes' rule

  Given two dependent events Ea and Eb,

  Pr(Ea|Eb)*Pr(Eb) = Pr(Eb|Ea)*Pr(Ea)

  Thus,

  Pr(Ea|Eb)= (Pr(Eb|Ea)*Pr(Ea)) / Pr(Eb)

- Example: Given probabilities Pr(a) = 0.02, Pr(d)=0.019 Pr(a|d) = 0.015 What is the probability Pr(d|a) ?

  Pr(d|a) = 0.015*0.019/0.02 = 0.014

Review of Math

Bayesian Classifier

Problem: There are several symbols a, b, c, d encoded and transmitted through a wireless network by a remote device. Due to various channel errors a workstation can receive corrupted symbols `a, b, c, d, e, f,g, h`. If a symbol g is received, what was actually send `a, b, c` or d?

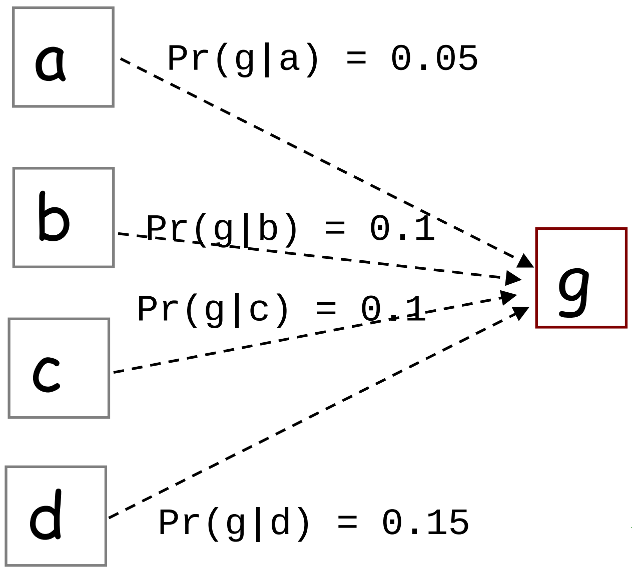
is the same for all expressions

`Pr(a) = 0.3`

`Pr(b) = 0.2`

`Pr(c) = 0.1`

`Pr(d) = 0.4`



`Pr(a|g) = 0.3*0.05/Pr(g) = 0.015`

`Pr(b|g) = 0.2*0.1/Pr(g) = 0.02`

`Pr(c|g) = 0.1*0.1/Pr(g) = 0.01`

`Pr(d|g) = 0.4*0.15/Pr(g) = 0.06`

Review of Math

Statistics

Some sequences of numbers, data sets, processes cannot be described precisely

Example: Outside daily temperature during a month, share prices, speed of traffic

Random sequences can be characterised by several parameters

Given sequence $x = (x_1, x_2, x_3, \dots x_n)$ of n random numbers

The mean: $\bar{x} = \frac{1}{n} * \sum x_i$

The average deviation: $dev = \frac{1}{n} * \sum | x_i - \bar{x} |$

The standard deviation: $\sigma = \sqrt{\frac{1}{n} * \sum (x_i - \bar{x})^2}$

Review of Math

Statistics

Problem: Given two sequences of n random numbers

$x = (x_1, x_2, x_3, \ldots x_n)$

and

$y = (y_1, y_2, y_3, \ldots y_n)$

How to characterise the degree of relationship between the sequences?

Correlation coefficient:

$$r = \frac{\Sigma(x_i - \bar{x}) * (y_i - \bar{y})}{\sqrt{\Sigma(x_i - \bar{x})^2} * \sqrt{\Sigma(y_i - \bar{y})^2}}$$

$r \approx 1$ indicates strong statistical relationship

$r \approx 0$ indicates statistical independence

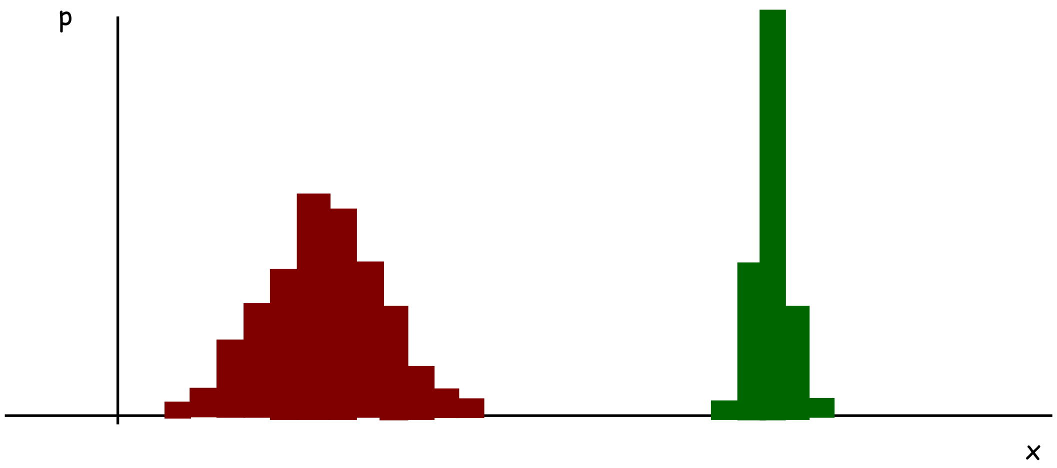
Review of Math

Quiz

Problem: Given two probability density functions of two random sequences

Which random sequence has a smaller mean value?

Which random sequence has a smaller deviation?



$$\bar{x} = \sum p_i * x_i$$

$$\sigma = \sum p_i * (x_i - \bar{x})^2$$

Review of Math

- Linear Algebra, major definitions

$$\mathbf{A} = \begin{bmatrix} a00 & a01 & a02 & a03 \\ a10 & a11 & a12 & a13 \\ a20 & a21 & a22 & a23 \end{bmatrix}$$

A is a 3x4 matrix with 3 rows and 4 columns

$$\mathbf{B} = [\ 5.1 \quad 0.7 \quad 1.3 \quad 5.3\ ]$$

B is a row vector

$$\mathbf{C} = \begin{bmatrix} 2.1 \\ 5.1 \\ 2.9 \end{bmatrix}$$

C is a column vector

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

I is an identity matrix

$$\mathbf{M} = \begin{bmatrix} m00 & m01 \\ m10 & m11 \end{bmatrix}$$

$$\mathbf{det(M)} = \begin{vmatrix} m00 & m01 \\ m10 & m11 \end{vmatrix} = m00*m11 - m01*m10$$

the determinant of the matrix M

Review of Math

- Major operations with matrices

Multiplication

$1*2 + 3*2 + 2*0 = 8$

$3*0 + 1*2 + 4*1 = 6$

$$\mathbf{C} = \mathbf{A}*\mathbf{B} = \begin{bmatrix} 1 & 3 & 2 \\ 3 & 1 & 4 \\ 2 & 4 & 5 \end{bmatrix} * \begin{bmatrix} 2 & 1 & 0 \\ 2 & 1 & 2 \\ 0 & 4 & 1 \end{bmatrix} = \begin{bmatrix} 8 & . & . \\ . & . & 6 \\ . & . & . \end{bmatrix}$$

- The number of columns of **A** must be equal to the number of rows of **B**

Addition

$$\mathbf{C} = \mathbf{A}+\mathbf{B} = \begin{bmatrix} 1 & 3 & 2 \\ 3 & 1 & 4 \\ 2 & 4 & 5 \end{bmatrix} + \begin{bmatrix} 2 & 1 & 0 \\ 2 & 1 & 2 \\ 0 & 4 & 1 \end{bmatrix} = \begin{bmatrix} 3 & . & . \\ . & . & 6 \\ . & 8 & . \end{bmatrix}$$

- Both dimensions of **A** and **B** must match

Review of Math

- Major operations with matrices

Transposition

$$A = \begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \\ 7 & 8 & 9 \end{bmatrix} \qquad A^T = \begin{bmatrix} 1 & 4 & 7 \\ 2 & 5 & 8 \\ 3 & 6 & 9 \end{bmatrix}$$

Inversion

Let **A** be a square **NxN** matrix. If there exist an **NxN** matrix **B** such that

$A*B = I$, the matrix **B** is called an inverse of **A** and denoted A^{-1}

$$A*A^{-1} = A^{-1}*A = I$$

Review of Math

- Major properties of matrix operations

$A + B = B + A$

$A * B \neq B * A$ $\quad$ $A*B = A*I*B$

$(A*B)^T = B^T * A^T$

$(A*B)^{-1} = B^{-1} * A^{-1}$ $\quad$ $(A^{-1})^{-1} = A$

If $A*A^T = A^T*A = I$, the matrix A is called orthogonal

If A is orthogonal, then $A^{-1} = A^T$

Review of Math

Vectors

The Dot Product

The dot product of two vectors $\mathbf{A} = [\ a_0 \quad a_1 \quad a_2\ ]$ and $\mathbf{B} = \begin{bmatrix} b_0 \\ b_1 \\ b_2 \end{bmatrix}$

$\mathbf{A}*\mathbf{B} = a_0*b_0 + a_1*b_1 + a_2*b_2 = c$

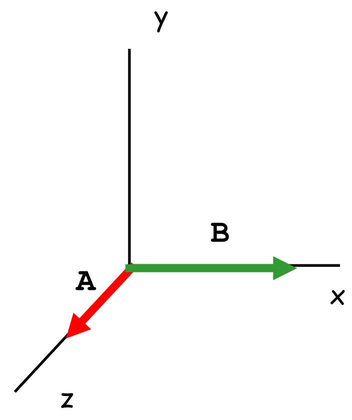
Orthogonal Vectors

If the dot product of two vectors $\mathbf{A}$ and $\mathbf{B}$

$\mathbf{A}*\mathbf{B} = 0$, the vectors are orthogonal

Example: $\mathbf{A} = [\ 0\ 0\ 2]$ $\mathbf{B}^T = [\ 3\ 0\ 0\ ]$

$\mathbf{A}*\mathbf{B} = 0$



Review of Math

- **Quiz**

$$A = \begin{bmatrix} 1 & 2 & 3 \\ 2 & 1 & 2 \\ 3 & 0 & 1 \end{bmatrix} \qquad B = \begin{bmatrix} 1 \\ 1 \\ 2 \end{bmatrix} \qquad C = \begin{bmatrix} 2 & 1 & 2 \end{bmatrix}$$

Calculate

$$B^T = \begin{bmatrix} 1 & 1 & 2 \end{bmatrix}$$

$$A*B = \begin{bmatrix} 9 \\ 7 \\ 5 \end{bmatrix}$$

$$C*B = \begin{bmatrix} 2 & 1 & 2 \end{bmatrix} * \begin{bmatrix} 1 \\ 1 \\ 2 \end{bmatrix} = [7]$$

Review of Math

- Linear Transformations

Linear transformation is a matrix operation

$\mathbf{Y} = \mathbf{T}^*\mathbf{X}$

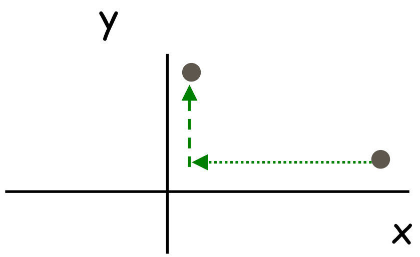
that maps vector $\mathbf{X}$ onto vector $\mathbf{Y}$

Let $\mathbf{G}$ be a column vector that represents coordinated of a point in 2D space. $\mathbf{G}^T = [\ x_0\ \ y_0\ ]$

Translate the point to a new location $x_1,\ y_1$ by using displacement d_x and d_y

$$x_1 = x_0 + d_x$$

$$y_1 = y_0 + d_y$$



This transformation can be represented in a matrix form using a transformation matrix $\mathbf{D}$

$$\begin{bmatrix} x_1 \\ y_1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & d_x \\ 0 & 1 & d_y \end{bmatrix} * \begin{bmatrix} x_0 \\ y_0 \\ 1 \end{bmatrix}$$

Review of Math

Linear Transformations

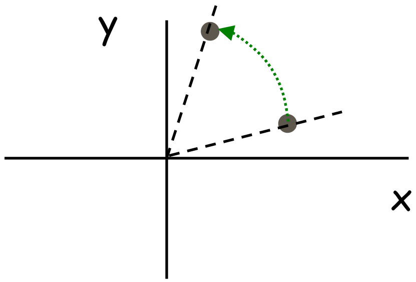
Let **G** be a column vector that represents coordinated of a point in 2D space. $G^T = [\ x_0\ \ y_0\ ]$

Rotate the point by an angle α about the origin

$$x_1 = \cos\alpha * x_0 + \sin\alpha * y_0$$

$$y_1 = -\sin\alpha * x_0 + \cos\alpha * y_0$$

This transformation can be represented in a matrix form using a transformation matrix **R**



$$\begin{bmatrix} x_1 \\ y_1 \end{bmatrix} = \begin{bmatrix} \cos\alpha & \sin\alpha & 0 \\ -\sin\alpha & \cos\alpha & 0 \end{bmatrix} * \begin{bmatrix} x_0 \\ y_0 \\ 1 \end{bmatrix}$$

Review of Math

Linear Transformations

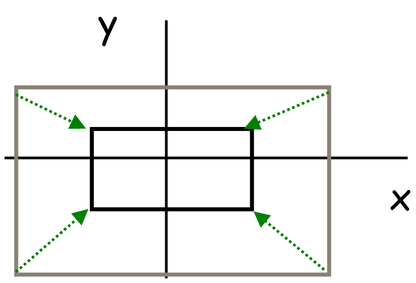
Let G be a column vector that represents coordinated of a point in 2D space. $G^T = [\ x_0\ \ y_0\ ]$

Change the scale of the space by s_x and s_y respectively

$$x_1 = s_x * x_0$$

$$y_1 = s_y * y_0$$

This transformation can be represented in a matrix form using a transformation matrix **S**



$$\begin{bmatrix} x_1 \\ y_1 \end{bmatrix} = \begin{bmatrix} s_x & 0 & 0 \\ 0 & s_y & 0 \end{bmatrix} * \begin{bmatrix} x_0 \\ y_0 \\ 1 \end{bmatrix}$$

Review of Math

Linear Transformations

Multiple transformations can be combined into one equitation as a product of transformation matrices

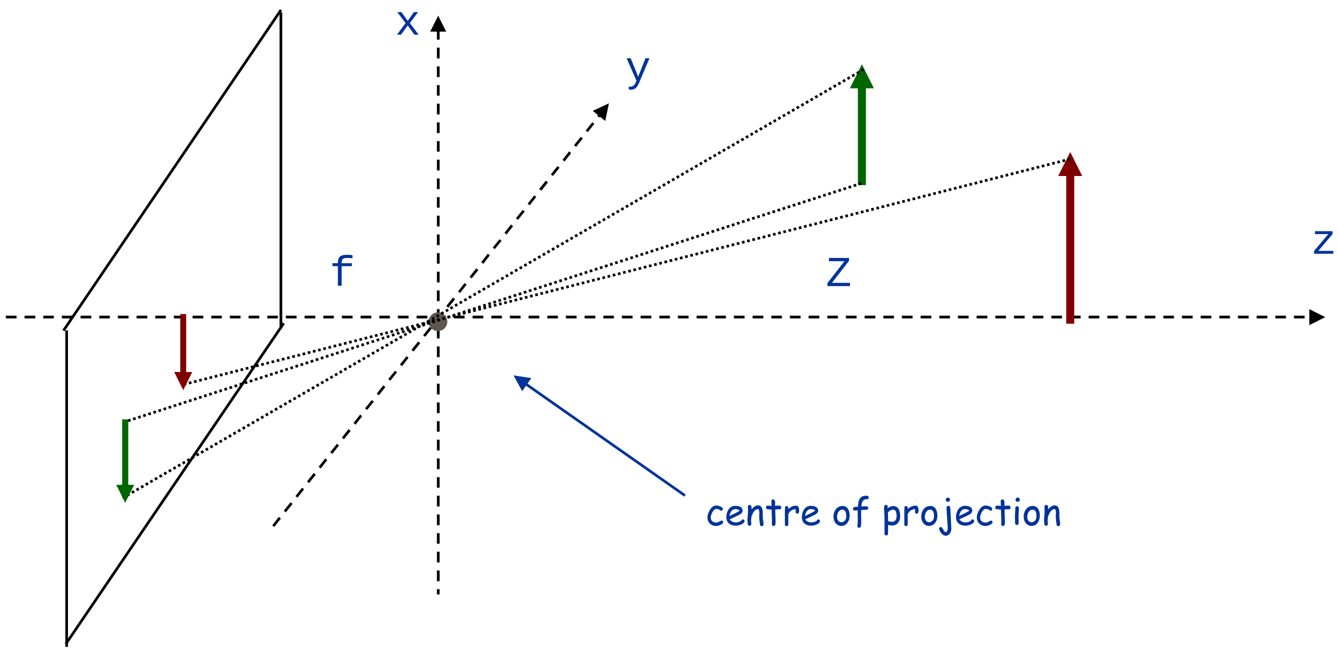
Example: Move a point G_0 with coordinates x_0, y_0 to a new location G_1 with coordinates x_1, y_1 by translating it , rotating and changing scale

$$G_1 = S*R*D*G_0$$

$$G_1 = \begin{bmatrix} s_x & 0 & 0 \\ 0 & s_y & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos\alpha & \sin\alpha & 0 \\ -\sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & d_x \\ 0 & 1 & d_y \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_0 \\ y_0 \\ 1 \end{bmatrix}$$

Review of Math

- Perspective Projection

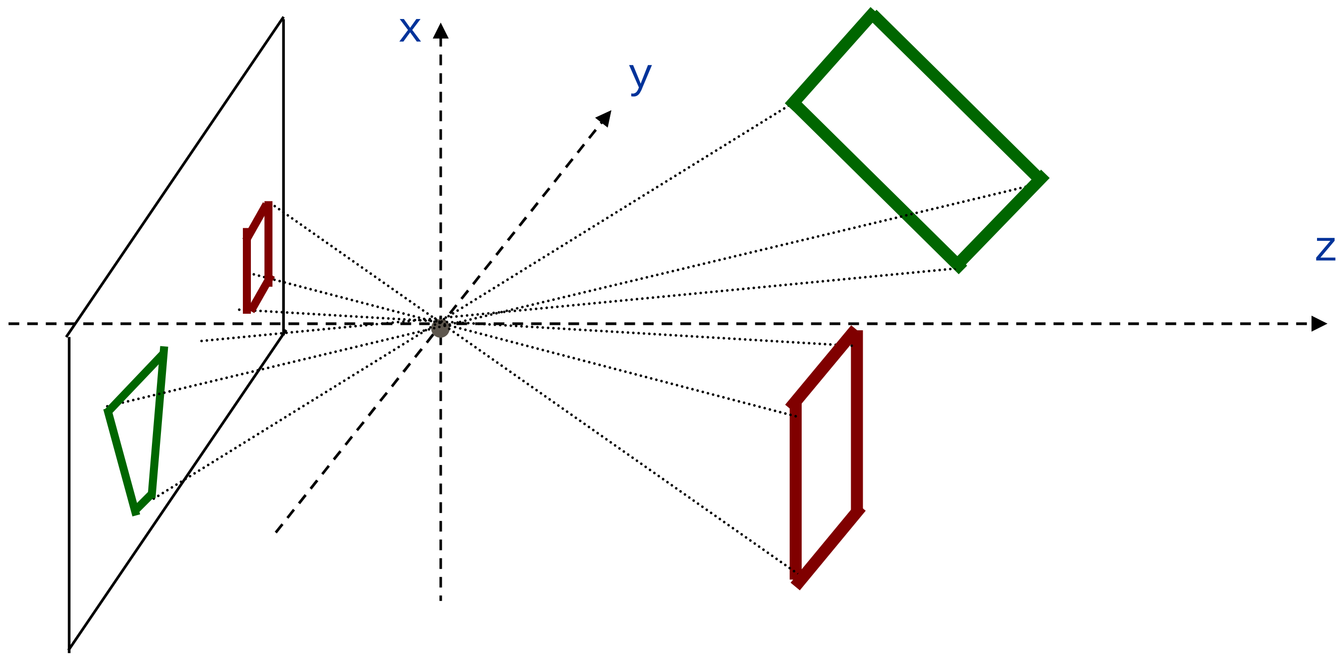


$x_1 = f/Z * x_0$

$y_1 = f/Z * y_0$

Review of Math

- Perspective Projection preserves parallel lines only when they are parallel to the projection plane



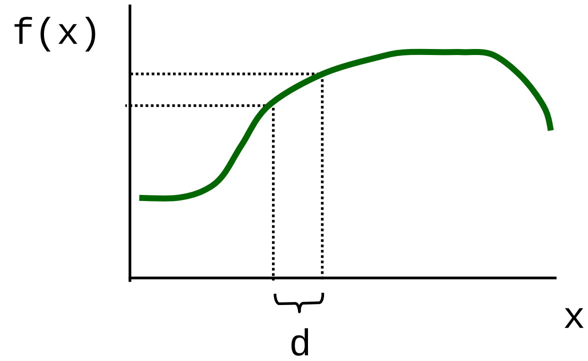
Review of Math

Differentiation and the derivative

The derivative of a function f(x) indicates how the function changes when x changes

Formal definition:

$$f'(x) = \frac{df(x)}{dx} = \lim_{d \to 0} \frac{f(x+d) - f(x)}{d}$$

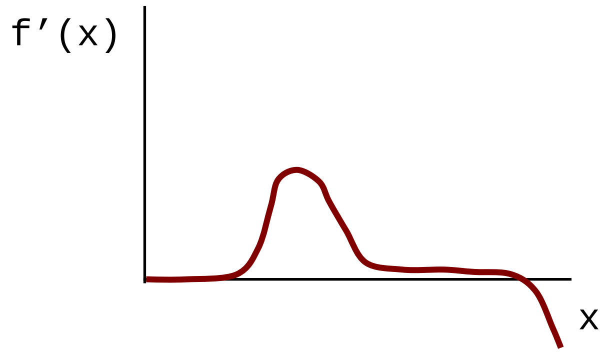


Example:

$f(x) = x^2$ $\quad$ $f'(x) = 2*x$

$f(x) = x^3$ $\quad$ $f'(x) = 3*x^2$

$f(x) = sin(x)$ $\quad$ $f'(x) = cos(x)$



Review of Math

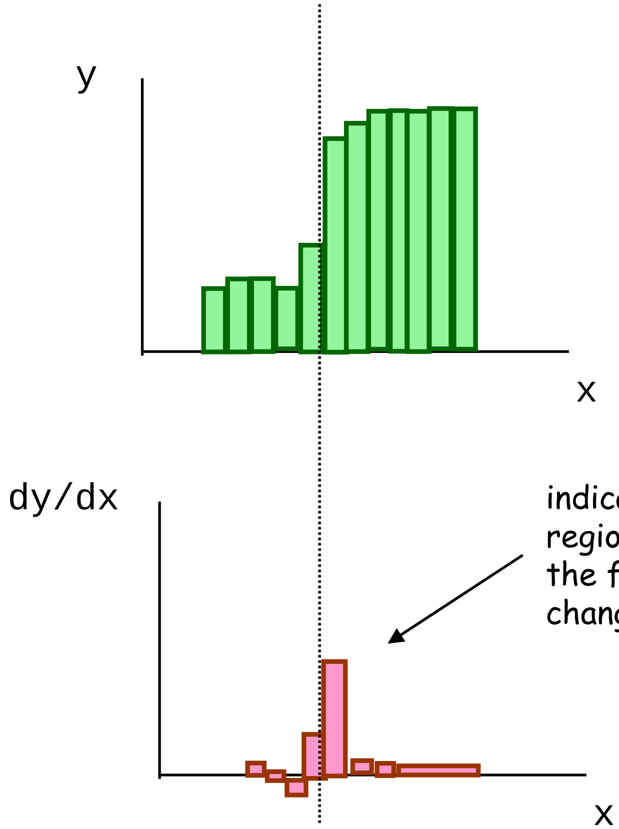
- Numerical differentiation

$$f'(x) = \frac{df(x)}{dx} = \lim_{d \to 0} \frac{f(x+d) - f(x)}{d}$$

$$dy/dx \approx \frac{\text{change in } y}{\text{change in } x}$$

If change in $x = 1$, *then*

$$dy/dx \approx \text{change in } y$$



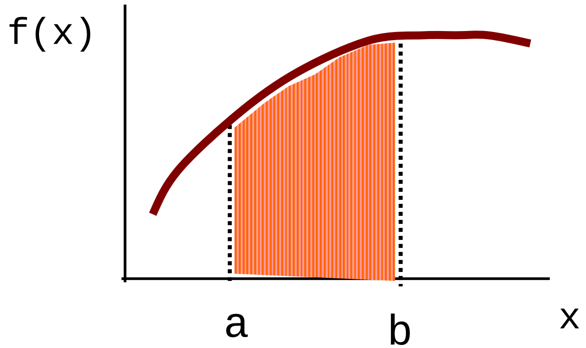
Review of Math

Integration

Given a function f(x) defined on an interval [a,b]

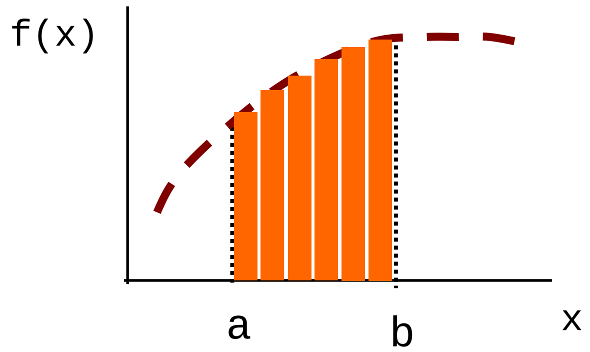
$$\int_a^b f(x)dx$$

is equal to the area of a region bounded by f(x)



Numerical Integration

$$\int_a^b f(x)dx \approx \sum_a^b f_i$$

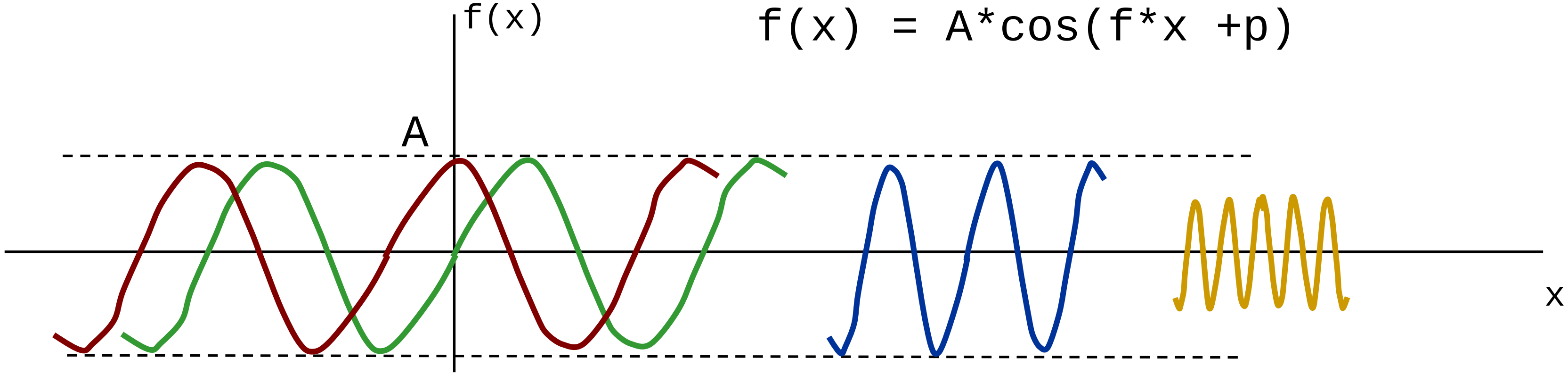


Review of Math

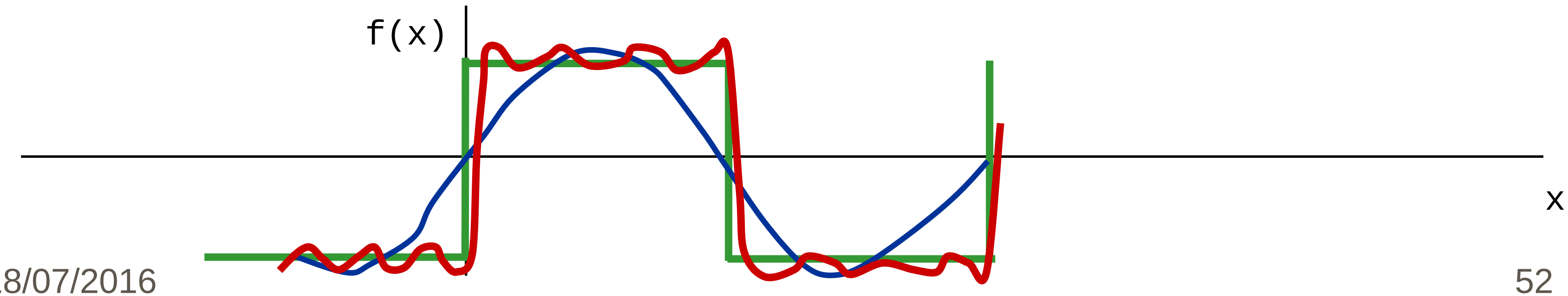
Harmonic Approximation and Spectral Analysis

- Harmonic functions

$$f(x) = A*\sin(f*x + p)$$
$$f(x) = A*\cos(f*x + p)$$



- Any function can be approximated as a sum of harmonic functions of various amplitudes, frequencies and phases $f(x) \approx \Sigma A_i * \sin(f_i * x + p_i)$



Suggested Reading

- D. Forsyth, *Computer Vision. A Modern Approach*

  Chapters

  - 6. An Introduction to Probability
  - 7.3. Spatial Frequency and Fourier Transform