Robotics: Principles and Practice

Module 5: Robot Vision

Lecture 1: Computer vision; optics and sensors; image acquisition; image representation

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Computer Vision

Computer Vision is concerned with the

- content
- organization, and
- behaviour

of a 3D world

by the automatic analysis of images of that world

Computer Vision

IMAGE → KNOWLEDGE

Extract descriptions of the world from images

Descriptions of what kind? qualitative vs. quantitative

- Geometric: shape and position of object or distances in 3D world
- Semantic: what objects do I see?
- Dynamic: scene changes, object velocities, human actions, …

Credit: Francesca Odone, University of Genova

Computer Vision

Recognizing objects from images . . .

. . . may be difficult!

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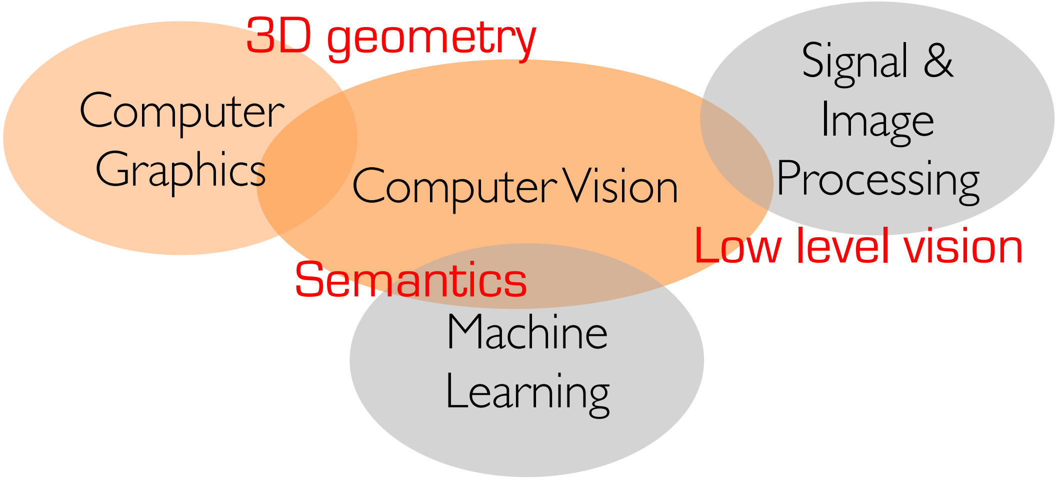
Credit: Alessandro Saffiotti, University of Örebro

Computer Vision



An incomplete view of related disciplines

Credit: Francesca Odone, University of Genova

Computer Vision

- The image is two-dimensional
- We lose information in the projection process, i.e., in passing from a 3D world to a 2D image
- The images are digital images
  - they are a discrete representation (i.e. they have distinct values at regularly sampled points)
  - they are a quantised representation (i.e. each value is an integer value)

Computer Vision

Image formation system

- part illumination
- sensing element
- associated optics

is critical to the successful deployment of industrial systems

Computer Vision

The task of the image acquisition and processing sub-system is

- to convert this signal into a digital image

- to manipulate the resultant image to facilitate the subsequent extraction of information

Computer Vision

The image analysis phase is concerned with the extraction of explicit information regarding the contents of the image (*e.g.* object category, identity, position, size, orientation)

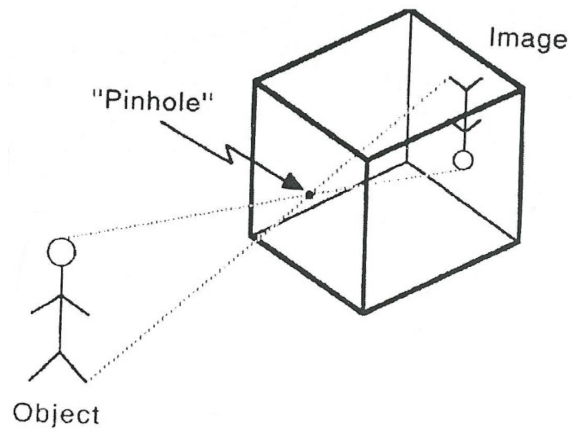
There is a fundamental difference between image processing and image analysis

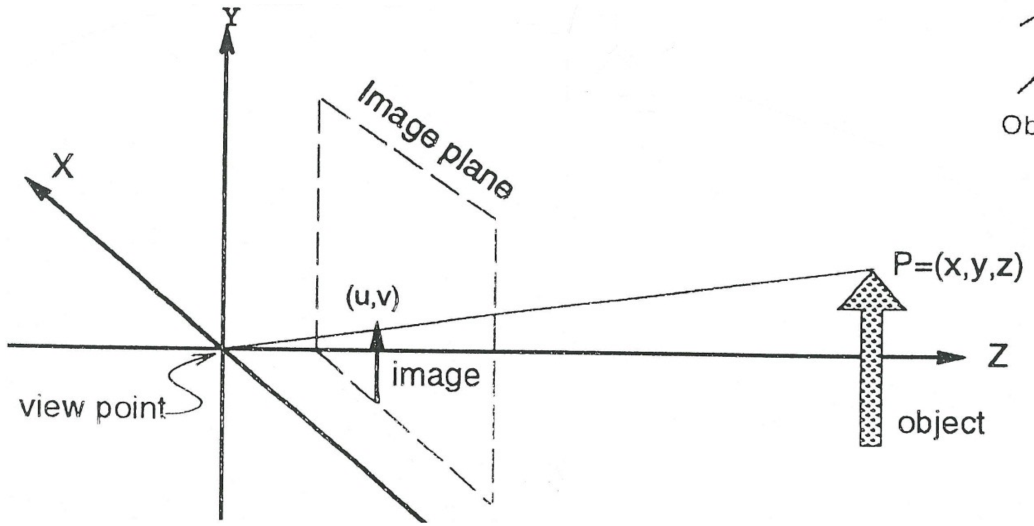
- Image Processing facilitates transformations of images to (hopefully, more useful) images
- Image Analysis facilitates the transformation from an image to explicit (symbolic) information

Optics and Sensors

Optics

- Perspective Projection
- Pin-hole model of a camera





Basic model of imaging process

Optics

Lenses are required to focus part of the visual environment onto the image sensor

Lenses are defined by:

- their Focal Length (quoted in millimetres)
- their Aperture (the f number)

These parameters determine the performance of the lens in terms of light gathering power and magnification, and it often has a bearing on its physical size

Optics

The focal length of a lens is a guide to the magnification it effects and its field of view

Selecting the focal length which is appropriate to a particular application is simply a matter of applying the basic lens equation

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$

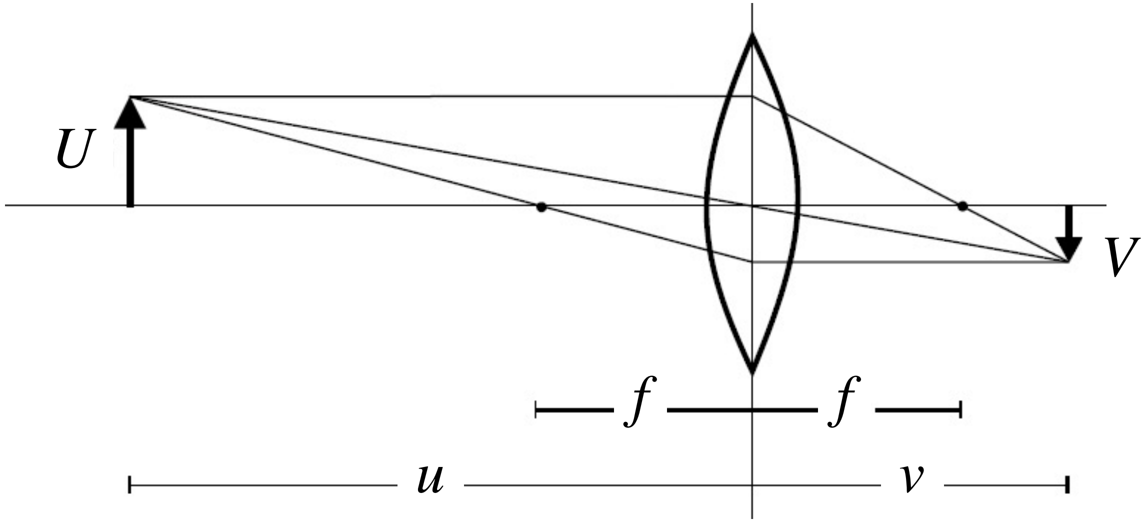
where

- v is the distance from the lens to the image
- u is the distance from the lens to the object
- f is the focal length

Optics

Gaussian lens equations: $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$ and $\frac{V}{U} = \frac{v}{u}$

Focal length: $f = \frac{uV}{U + V}$



Optics

Noting the Magnification Factor M is

$$M = \frac{image\_size}{object\_size} \quad \frac{V}{U}$$

Optics

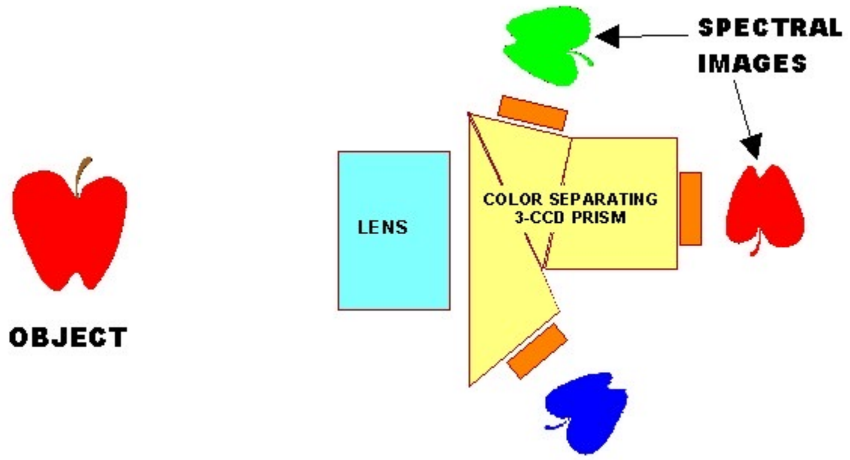
Thus

$$f = \frac{uM}{M+1}$$

Hence if we know the required magnification factor and the distance from the object to the lens, we can compute the required focal length.

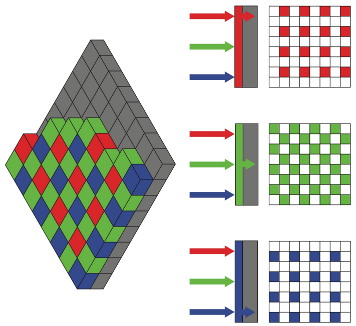
Sensors

3-Chip Colour Camera



1-Chip Colour Camera

(Bayer filter)



C. Bartneck, T. Belpaeme, F. Eyssel, T. Kanda, M. Keijsers, S. Šabanović, Human-Robot Interaction – An Introduction, Cambridge University Press, 2020

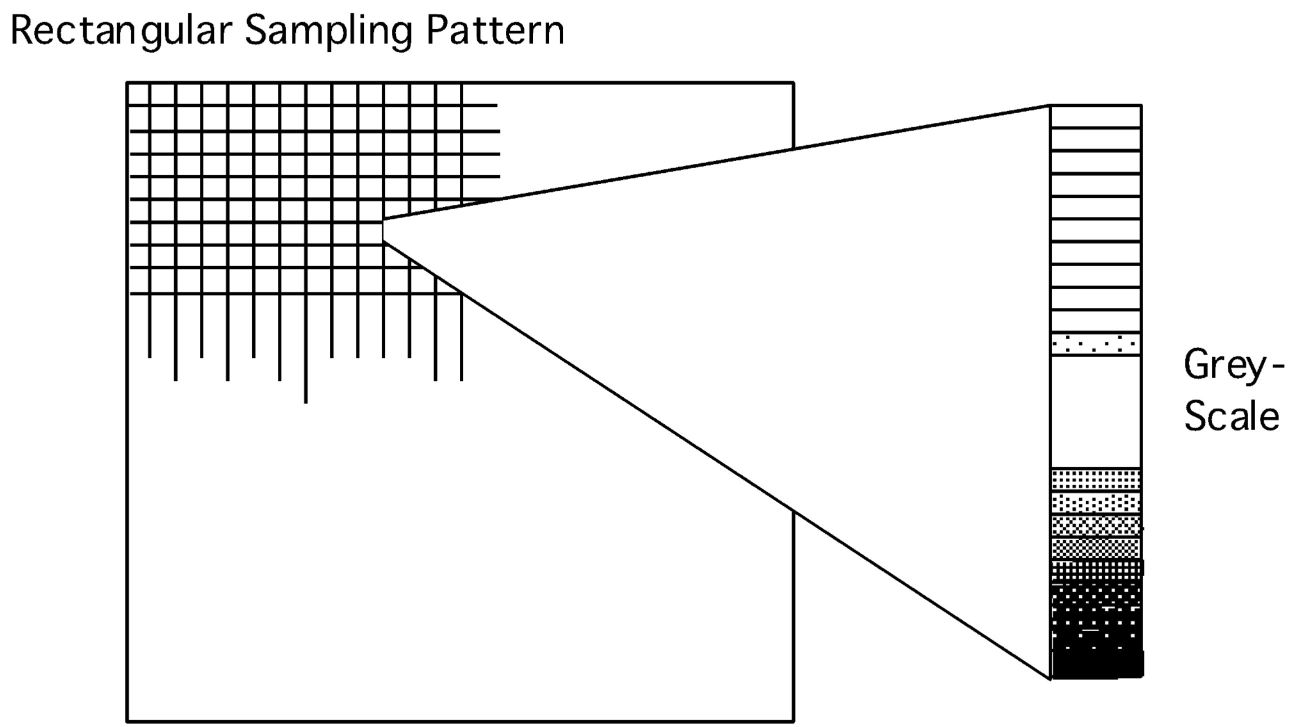
Image Acquisition
and
Image Representation

Image Acquisition

Digital images represent the reflectance function of a scene but they do so in a sampled and quantised form

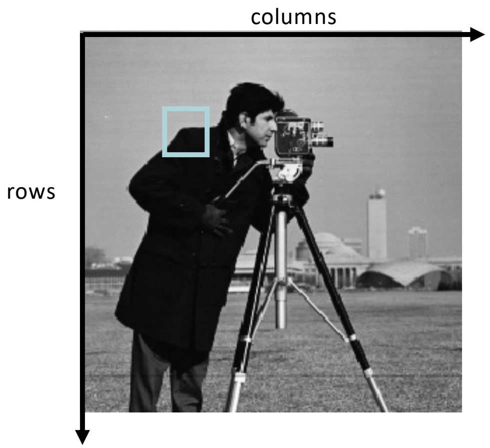
Each quantized integer value is known as a pixel and is the smallest discrete accessible sub-section of a digital image.

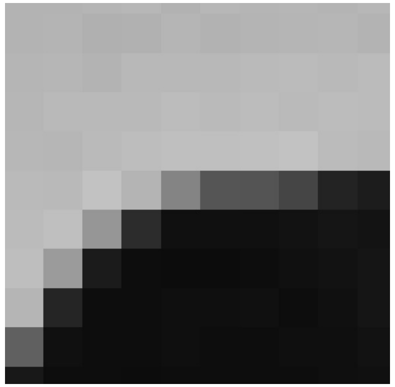
Image Acquisition



Sampling and Quantisation

Image Acquisition





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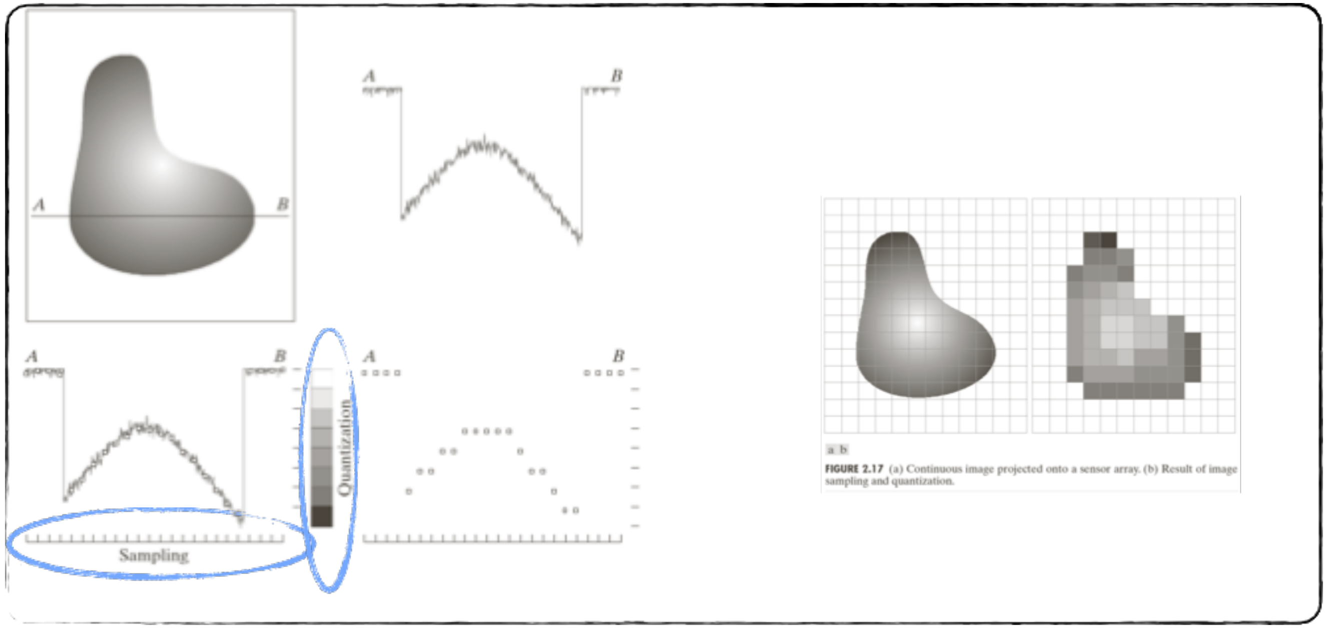
Credit: Francesca Odone, University of Genova

Image Acquisition



Credit: Francesca Odone, University of Genova

Image Acquisition

Dynamic range

Total number of distinctive values occurring in the image

- it is limited by the number of bit per pixel we may want to use
- it is also limited by the physical dynamic range of the sensor

this is related to the quantization process...

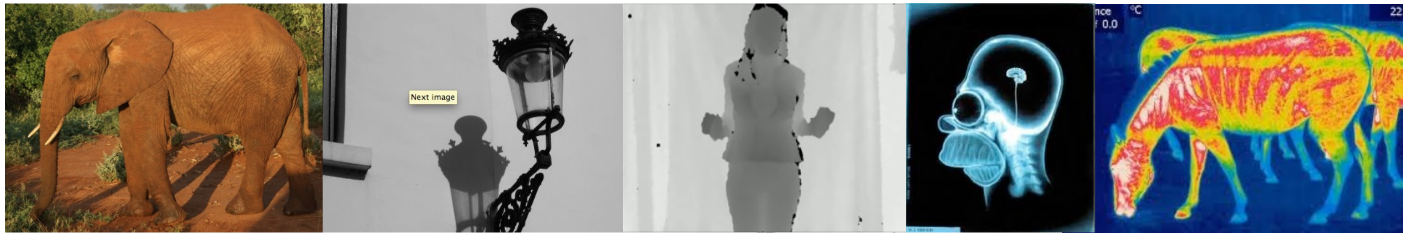
- To represent black-white images 1 bit is sufficient
- Grey level images: usually associate a byte to a pixel 2^8=256 gray levels
- Color images: usually 1 byte per channel ("millions of color")

Credit: Francesca Odone, University of Genova

Image Representation

Pixel content depends on the image type

- Gray level pictorial digital images ("black and white photos"): intensity
- Color pictorial digital images: color (modeled as triplets, eg RGB)
- Range images: depth information
- Medical images: radiation absorbance level
- Thermal images: heat



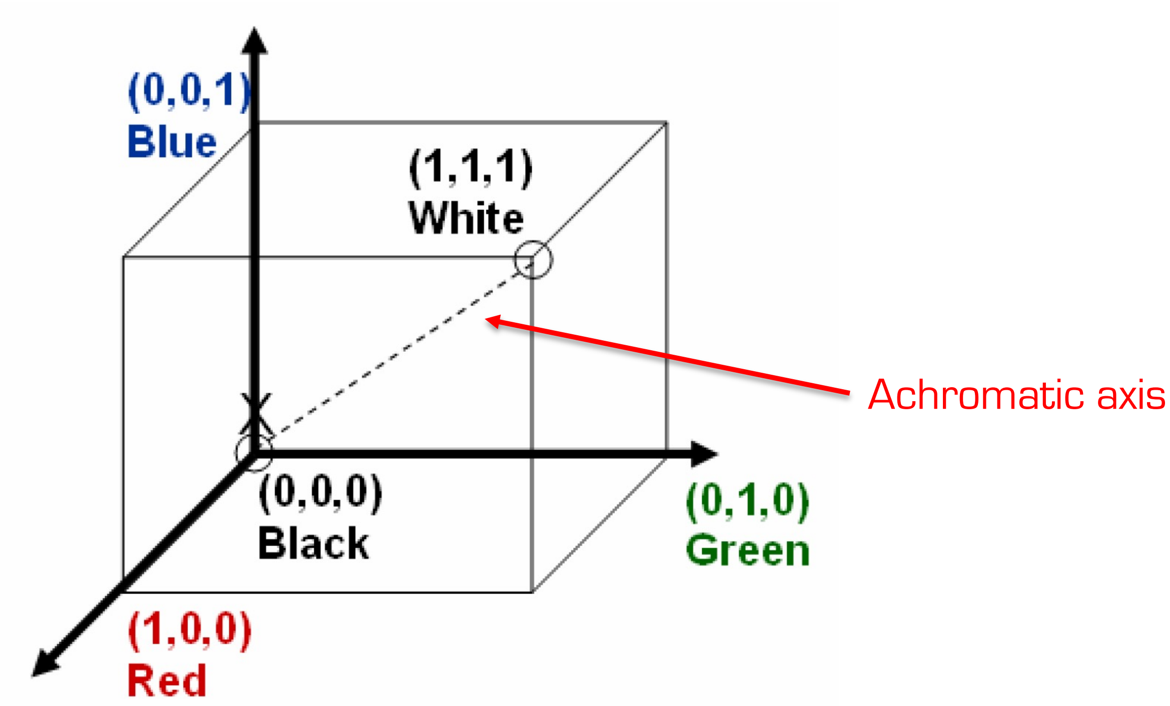
Credit: Francesca Odone, University of Genova

Colour Spaces

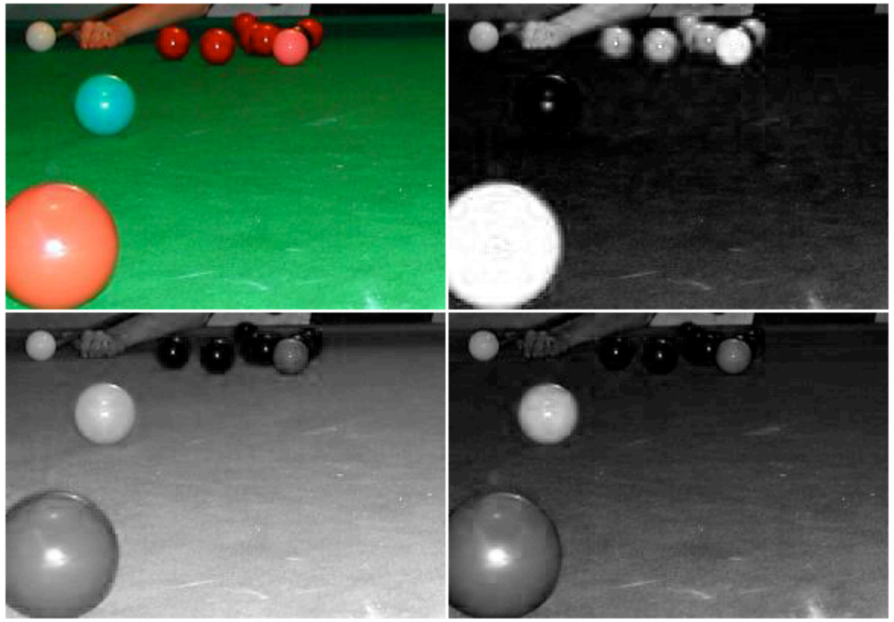
There are many colour representations

RGB	Red, Green, Blue
CMY	Cyan, Magenta, Yellow
YUV	Luminance (Y), Blue minus Luminance (U), Red minus Luminance (V)
YCrCb	Scaled version of YUV
CIE XYZ	Standard reference colour space based on the response of human eye
CIE L*u*V*	Perceptually uniform colour space
CIE L*a*b*	Device independent colour space (all colours perceived by humans)
HSV	Hue, Saturation, Value
HLS	Hue, Luminance, Saturation
HSI	Hue, Saturation, Intensity

Colour Spaces



Colour Spaces

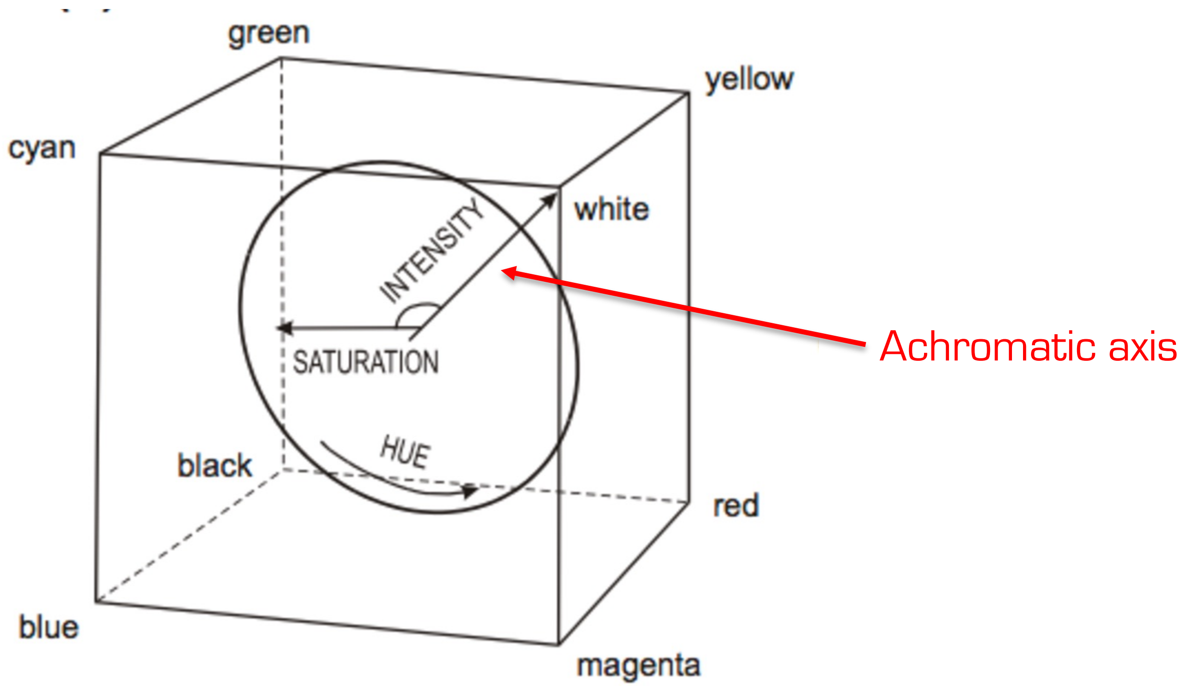


Red Green Blue images

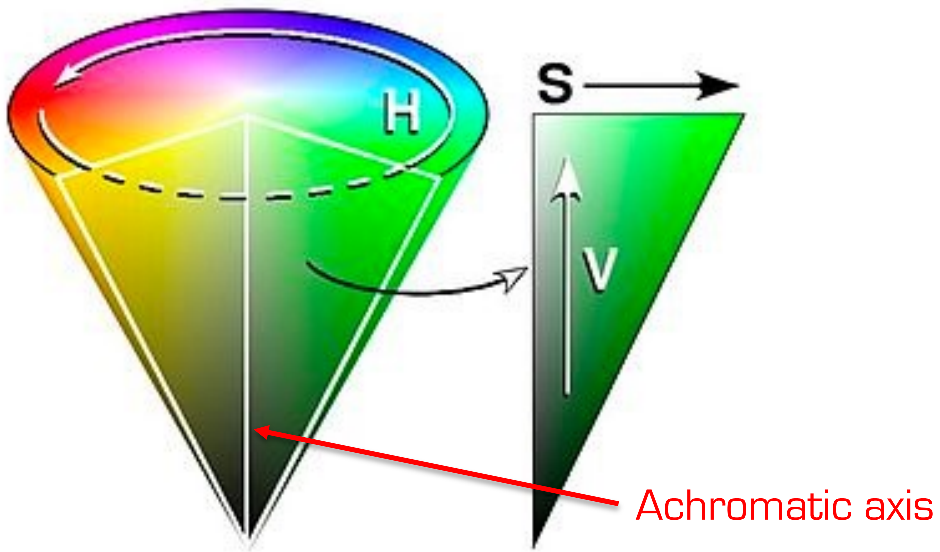
Red (~ 700nm)
Green (~ 546nm)
Blue (~ 436nm)

Credit: Kenneth Dawson-Howe, A Practical Introduction to Computer Vision with OpenCV, © Wiley & Sons Inc. 2014

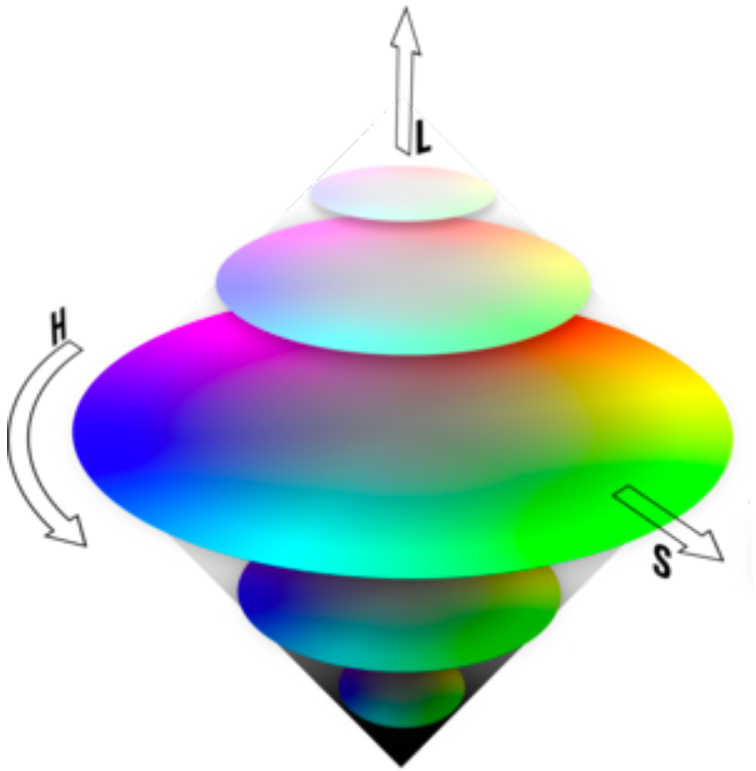
Colour Spaces



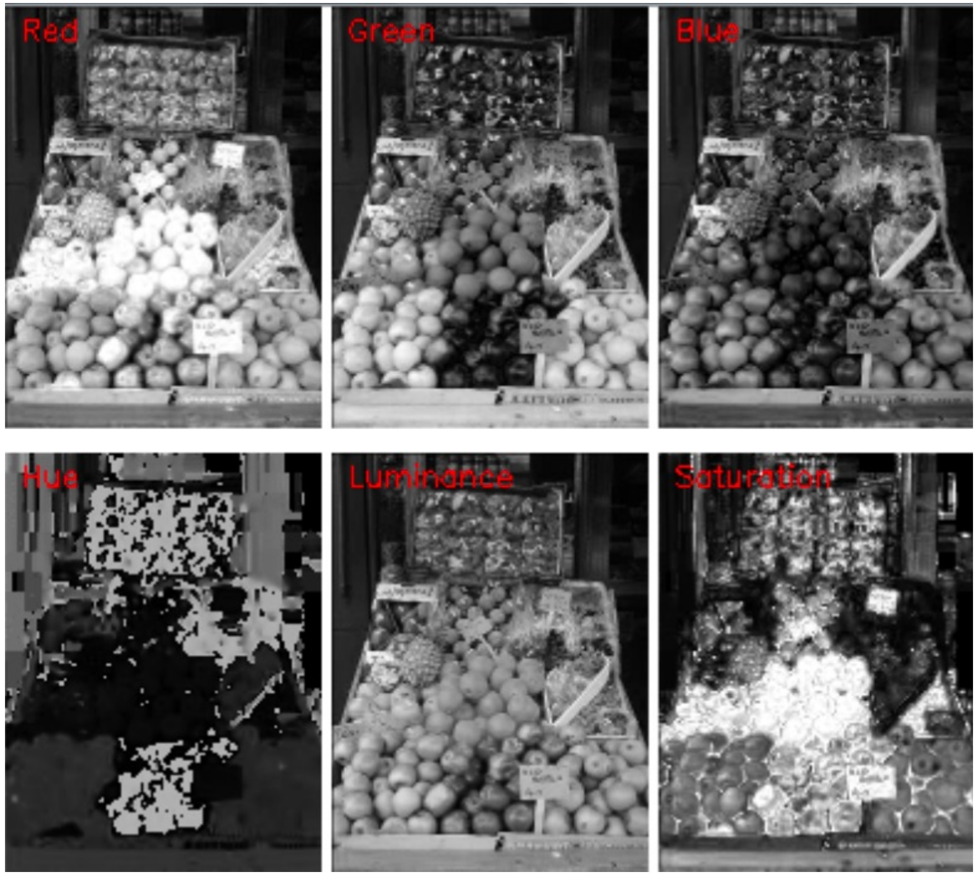
Colour Spaces



Colour Spaces



Colour Spaces



Credit: Kenneth Dawson-Howe, A Practical Introduction to Computer Vision with OpenCV, © Wiley & Sons Inc. 2014

Reading

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

- Section 2.2.3 Optics
- Section 2.3 The digital camera
    - Section 2.3.1 Sampling and aliasing
    - Section 2.3.2 Colour

D. Vernon, *Machine Vision*, 1991.

- Section 2.2.1 Image formation: elementary optics
- Section 2.2.2 Camera sensors
- Section 3.1 Sampling and quantization