ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

Introduction to computational imaging

Computational imaging
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Image processing, Computer Vision and Computer Graphics

Image Processing:
Image Processing is the field of enhancing the images by tuning many parameter and features of the images. So Image Processing is the subset of Computer Vision.
Here, transformations are applied to an input image and the resultant output image is returned.
Some of these transformations are- sharpening, smoothing, stretching etc.
Now, as both the fields deal with working in visuals, i.e., images and videos,
there seems to be lot of confusion about the difference about these fields of computer science.

Computer Vision:
In Computer Vision, computers or machines are made to gain high-level understanding from the input digital images or videos with the purpose of automating tasks that the human visual system can do. It uses many techniques and Image Processing is just one of them.

Computer graphics are introduced as drawings or any type of sketch that can represent some meaningful information in the form of pictures. Computer graphics is used widely in the software and computer field when there is a set of images that needs to be created or manipulated such as in digital films, the entertainment industry, or digital photography.

Image processing and Computer Vision

Image Processing	Computer Vision
Image processing is mainly focused on processing the raw input images to enhance them or preparing them to do other tasks	Computer vision is focused on extracting information from the input images or videos to have a proper understanding of them to predict the visual input like human brain.
Image processing uses methods like Anisotropic diffusion, Hidden Markov models, Independent component analysis, Different Filtering etc.	Image processing is one of the methods that is used for computer vision along with other Machine learning techniques, CNN etc.
Image Processing is a subset of Computer Vision.	Computer Vision is a superset of Image Processing.
Examples of some Image Processing applications are- Rescaling image (Digital Zoom), Correcting illumination, Changing tones etc.	Examples of some Computer Vision applications are- Object detection, Face detection, Hand writing recognition etc.

Image processing and Computer Vision

	Computer Vision	Image Processing
Goals	Extracting insights from images and videos.	Manipulating visual aspects of images.
Input/Out-put	Input can be both image and video. Output can be an interpretation, which is often non-visual.	Input and output are both images.
Scope	More comprehensive.	Low-level operations that affect pixels within an image.
Methods	Complex algorithms and techniques.	More straightforward operations.
Common Applica-tions	Autonomous vehicles, robotics, augmented reality, etc.	Image editing software (like Photoshop), medical imaging enhancements, etc.

Image processing and Computer graphics

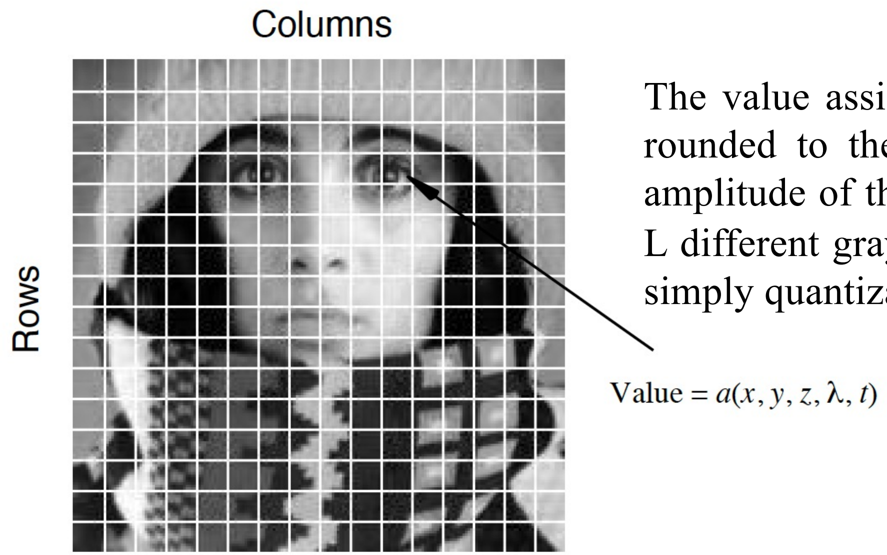
Computer Graphics	Image Processing
It focuses on the generation and manipulation of images for visual output.	Image processing focuses on analyzing and enhancing the quality and helps to extract information or improve quality.
The primary goal is to create visual content that can be understood by humans, often for informative purposes.	The primary goal is to modify or extract information from digital images, typically through algorithms and techniques.
Computer graphics is used in movies, video games and flight simulators for graphic purposes.	Image processing is used in medical imaging, satellite imaging, facial recognition, editing, etc for better imaging.
Computer graphics produces new images from scratch or modifies existing ones to convey a particular message.	Image processing modifies or enhances existing images, mostly without fundamentally changing their content.

Image processing and Computer graphics

Some examples of computer graphics are Pixar movies, Adobe Photoshop, and video game graphics engines among others.	Some examples of image processing are medical image analysis software, Instagram filters, and face recognition systems.
It often starts with geometric descriptions or models of objects etc.	It begins with digital images captured from various sources such as cameras, scanners, or satellites.
Computer Graphics often requires powerful graphics processing units (GPUs) and rendering hardware.	It can be implemented on standard computing hardware but may require parallel processing units for efficiency.
Can produce highly complex visual scenes with better details and dynamic effects like lighting and shadows.	Outputs are often simpler, focusing on enhancing or analyzing specific aspects of an image, such as contrast or texture.

The digital Image

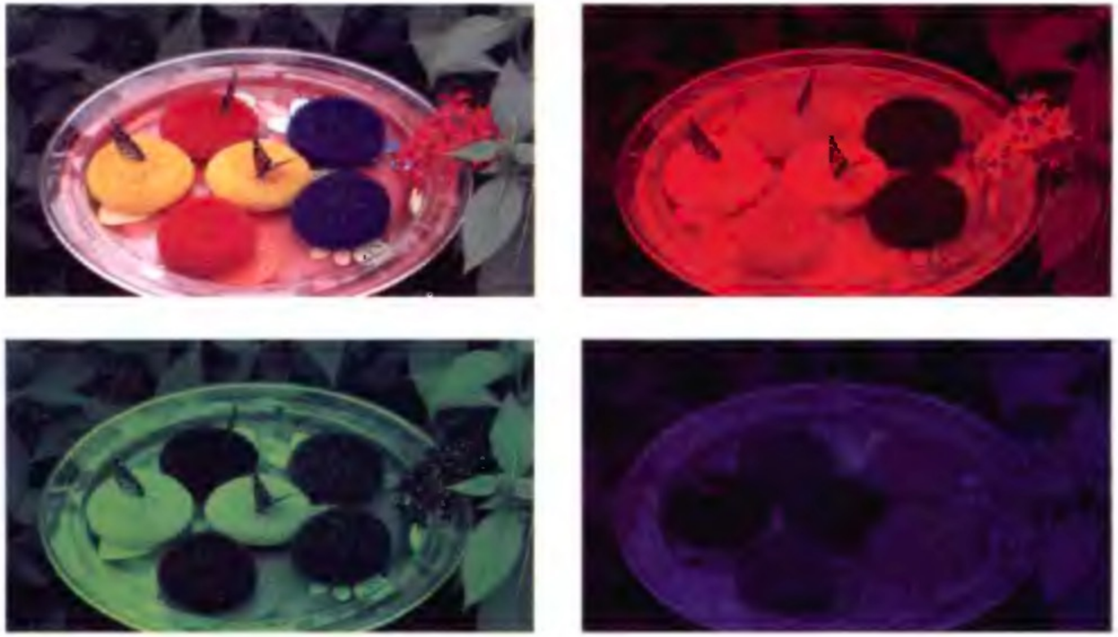
- A continuous (or analogue) image is a function $f : \Omega \subset R^2 \to R$
- A discrete image A is a matrix of size M xN obtained by discretinzing the function f.
- The intersection between a row and a column is called pixel.



The value assigned to every pixel is the average brightness in the pixel rounded to the nearest integer value. The process of representing the amplitude of the 2D signal at a given coordinate as an integer value with L different gray levels is usually referred to as amplitude quantization or simply quantization.

The digital Image

Color image and RGB channels.



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The Image

- In the case of color images three values are associated to each pixel, for example in the R(red)G(green)B(blue) scale.

- Many techniques developed for the single channel image are repeated on the three channels .

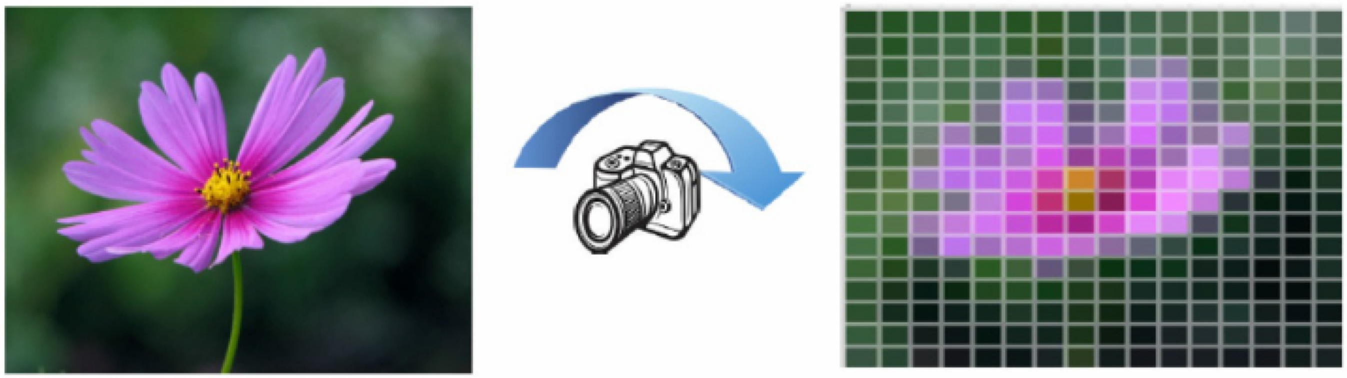


Image manipulation

Different manipulating operations can be performed on the images, such as:

- Transforming the color space

Image manipulation

- Applying ffine transformations

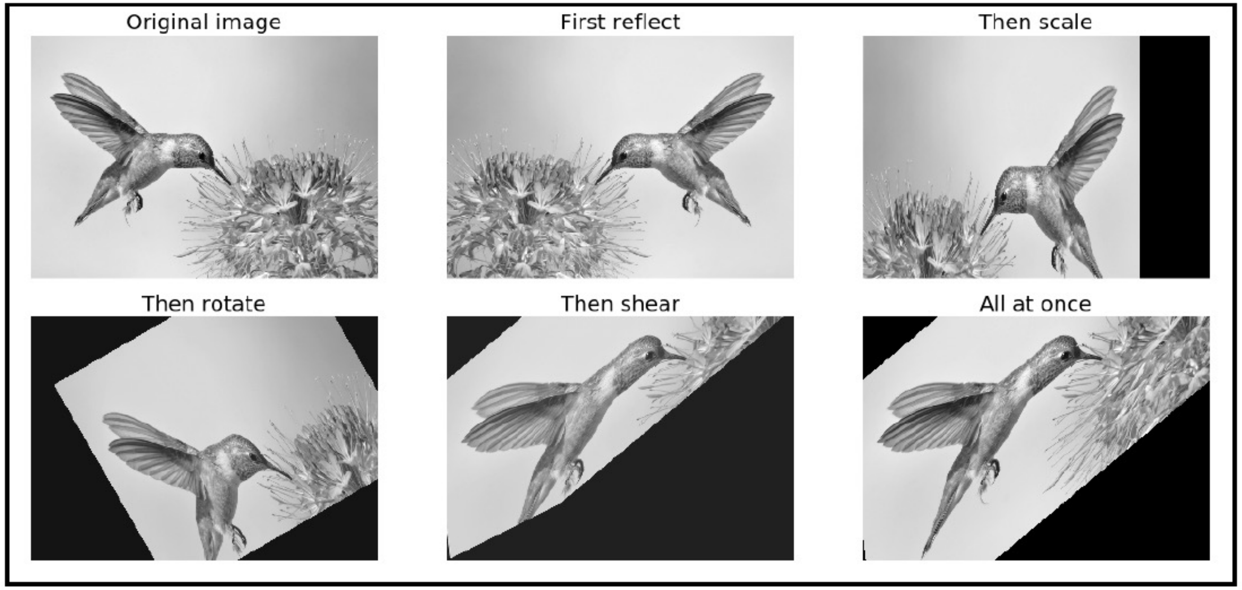


Image manipulation

- Create cartoonized images

Image manipulation

- Object detection using colors in HSV

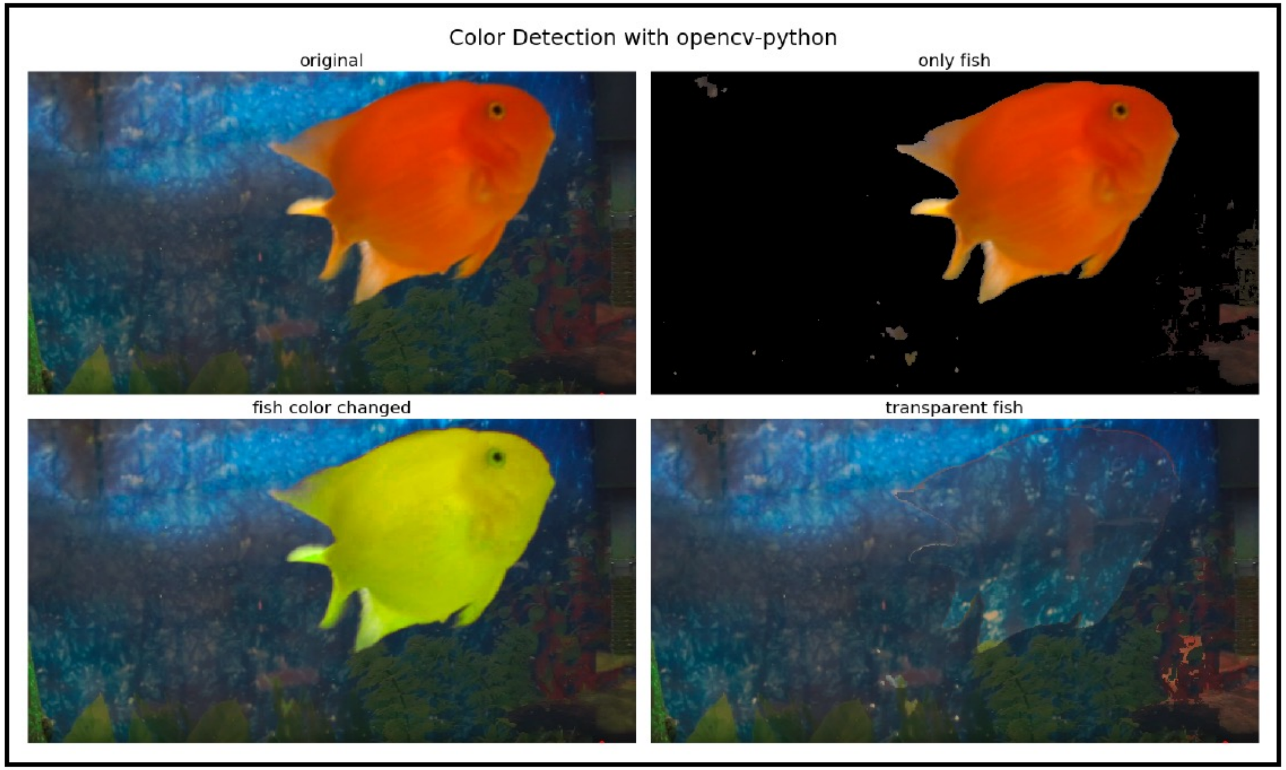


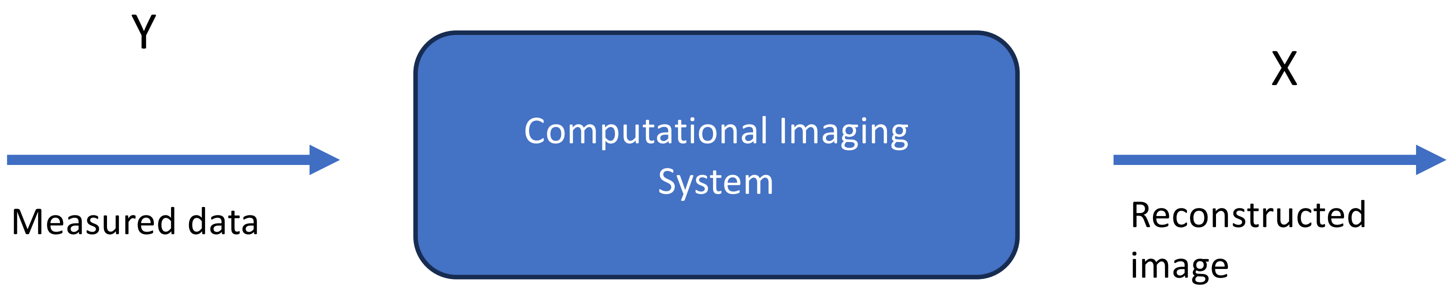
Image manipulation

- ……

Bibliography

- Sandipan Day, Python Image Processing Cookbook
- Gonzales, Woods, Digita Image Processing.
- …..

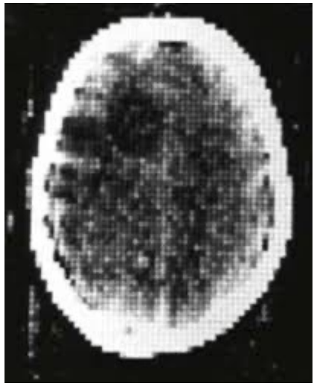
What is computational imaging?



Computational Imaging

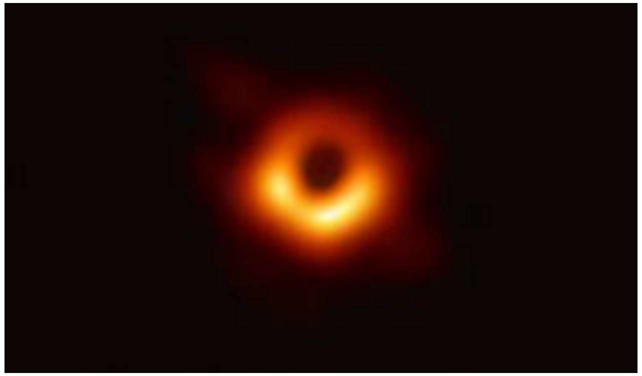
1. **1971**. The first X-ray Computed tomography machine is installed in the Atkinsons Morley Hospital, Wimbledon, Great Britain.

The CT generated images were obtained by a specially designed algorithm, since no viable method existed.



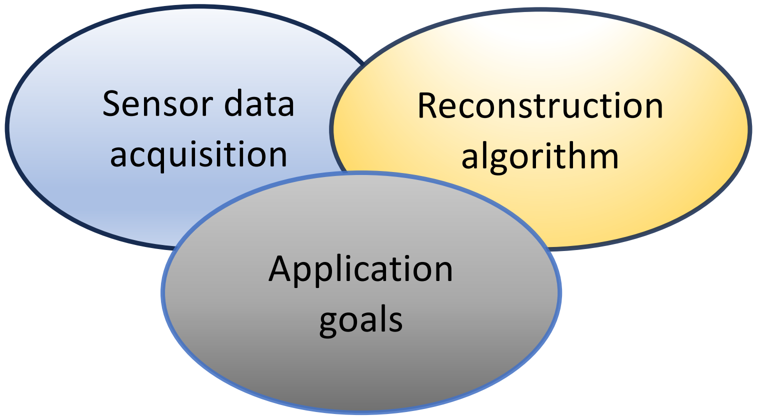
Computational Imaging

2. April 10, 2019. The first image of a black hole by means of the Event Horizon telescope.
The image was constructed from enormous quantities of data collected alla around the world
With an algorithmic computation.

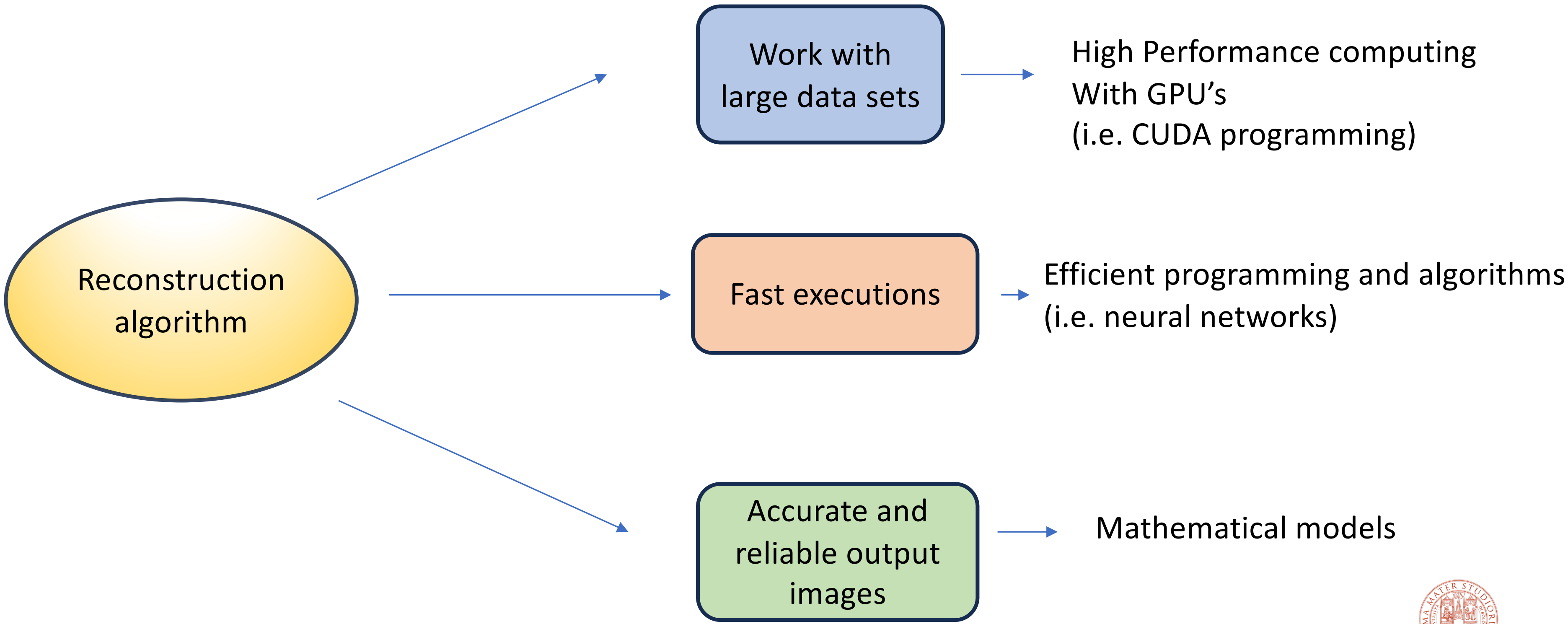


Computational Imaging

- Computational algorithms are essential to convert data to images.
- Contrary to popular believes, sensors almost never directly generate usable images.
- Real imaging systems require that raw sensors date be processed using algorithms to form the resulting images.



Why a math course on Computational Imaging in the Computer Science LM?



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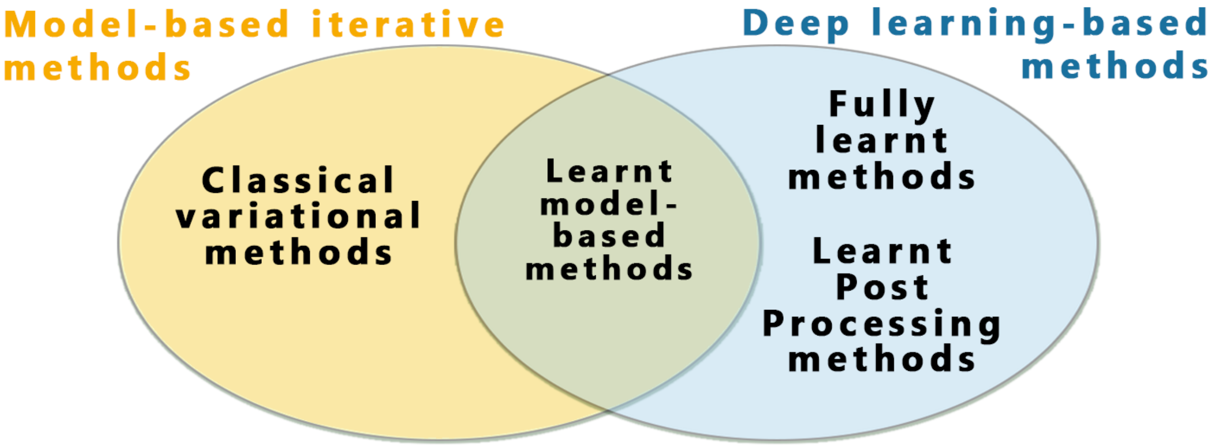
Computational Imaging

Reconstruction algorithms



Organization of the CI course

Module I:

- Introduction to computational imaging (CI)
- CI as inverse problem
- Model-based reconstruction methods

Module II:

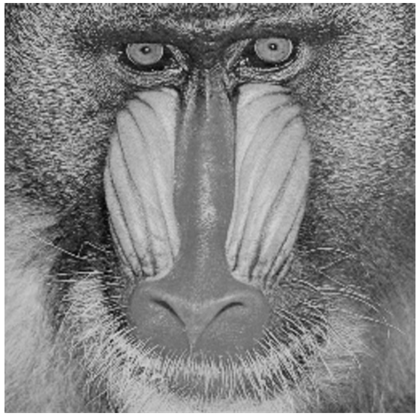
- Introduction to different types of neural networks in imaging
- Deep learning based reconstruction methods
- Learnt model based reconstruction methods (a mention)

Both with examples python programs.

Image processing applications

Examples of image processing applications:

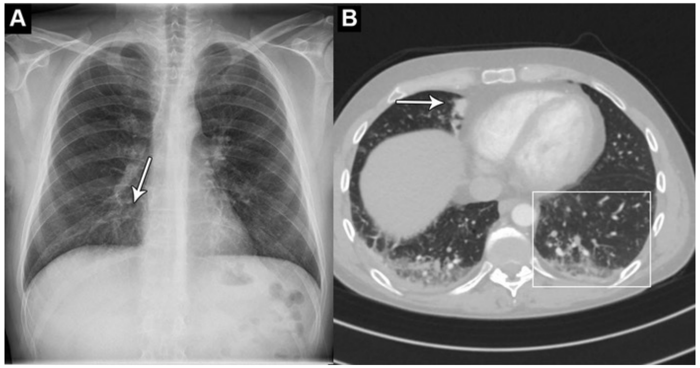
- Digital photography



- Real time videos

Image processing applications

- Medical imaging: transmission tomography (CT), emission tomography (PET), Magnetic Resonance Imaging (MRI), Ultrasound.



X-rays CT images

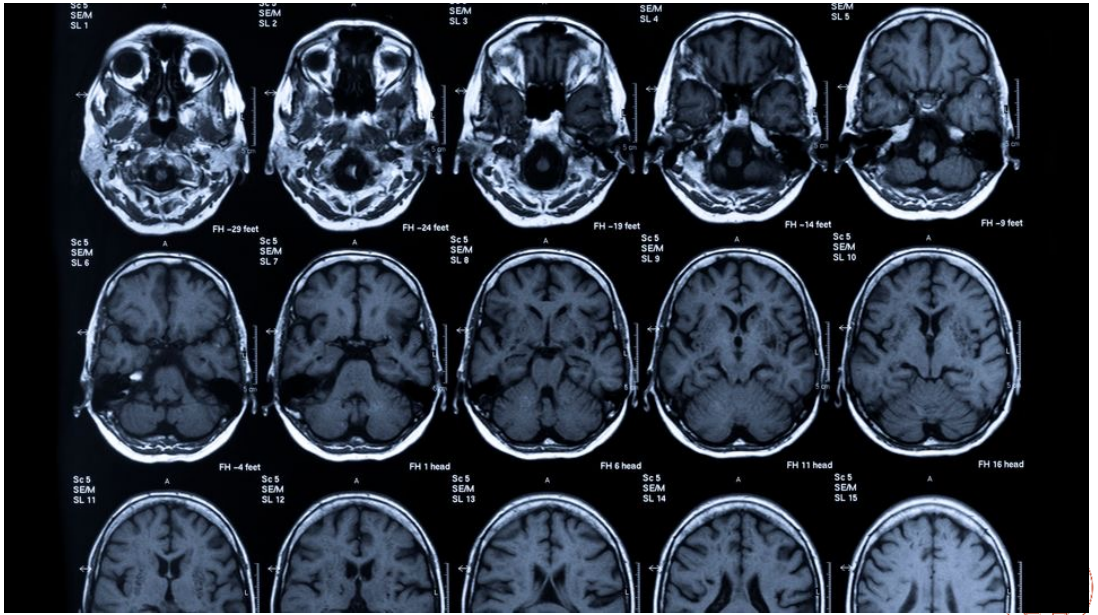
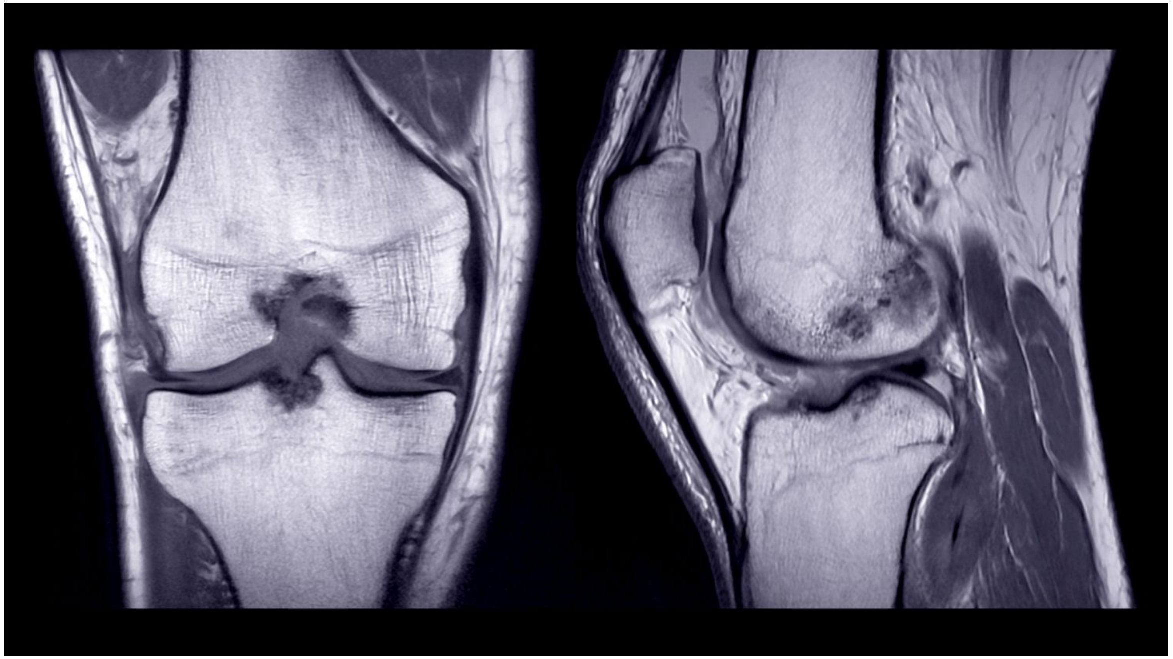


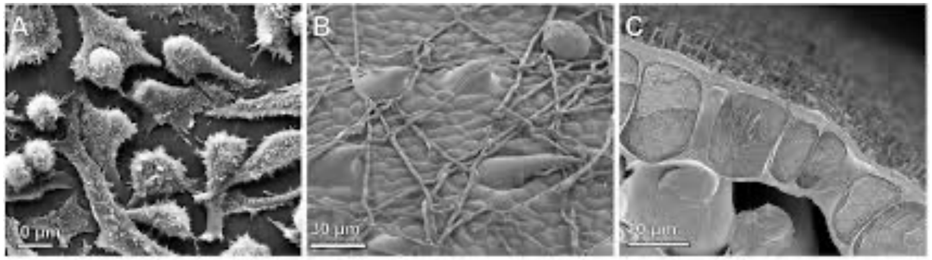
Image processing applications



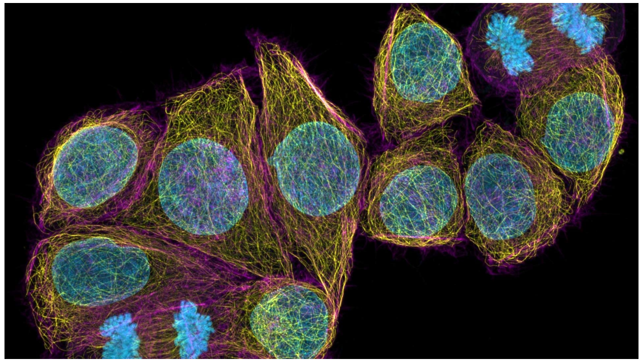
Magnetic Resonance Image

Image processing applications

- Scientific imaging: microscopy images, hyperpectral images thermal images.



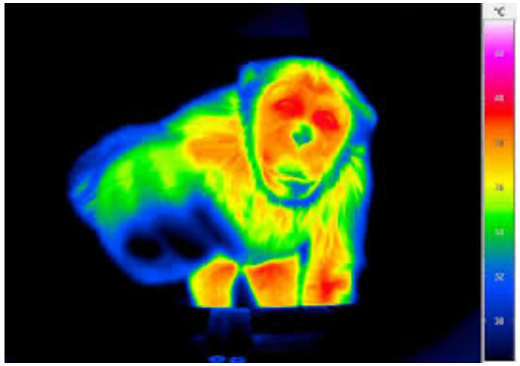
Phase contrast mcroscopy



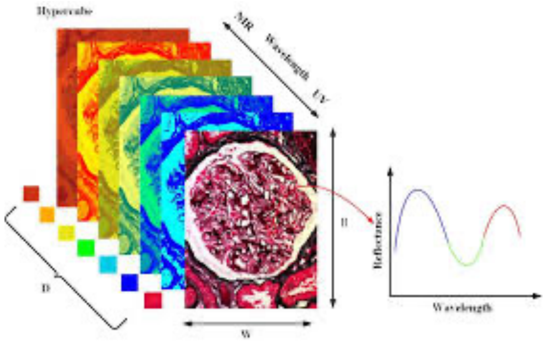
Flourescence microscopy

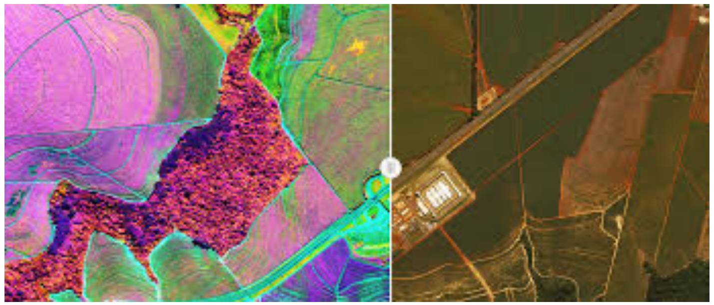
Image processing applications

- Scientific imaging: microscopy images, hyperpectral images, thermal images.



Thermal image



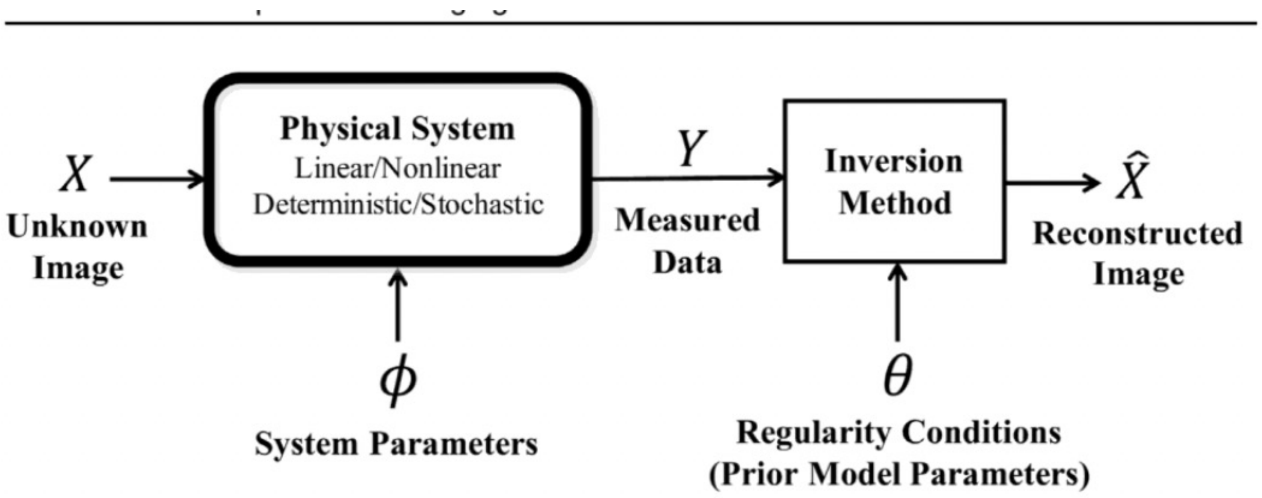


Hyperspectral image

Inverse problems

In this course we will kearn some fundamental tools for the design and implementation of the Reconstruction algorithm.

The reconstruction algorithm necessarily requires the solution of an inverse problem.



Inverse Problems

What is an inverse problem?

Keller: *We call two problems inverse one another if the formulation of the each involves part Or all the formulation of the other.*

The problem that is more extensively studied is usually called ***forward*** (or direct) , the other Is called ***inverse***.

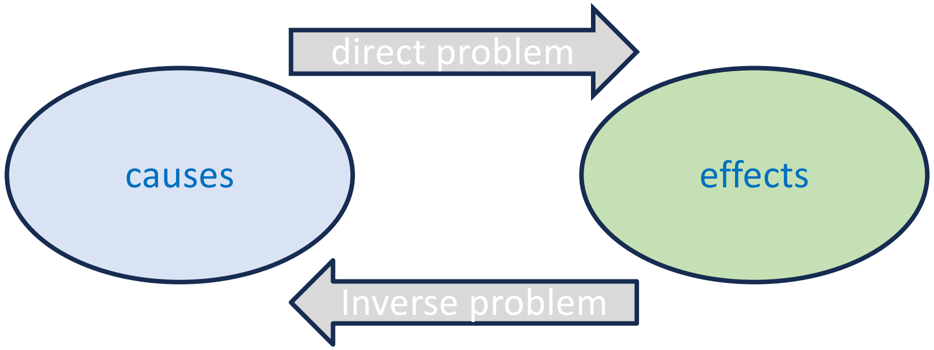
The direct problem is usually oriented along a cause-effect, in the sense that it computes the effect given the cause.

The inverse problem is associated with the reversal of the cause-effect and consists in finding the causes given the effects.

Inverse Problems

In instrumental physics, the direct problem is the measure of the object, obtained by the instrument, whereas the inverse problem consists in determining the object given the measure.

In direct problems usually there is a loss of information from the input to the output.
Hence, in the solution of the inverse problem it is impossible to recover the object exactly,
Due to the information lost in the direct one.



Linear Inverse Imaging Problems

Linear inverse imaging problems are characterized by a linear model describing the relationship Between the measured data y and the unknown object x.

The direct linear model can be expressed as:

$$Ax=y$$

Where A is a matrix representing the linear operator acting on the image x to generate the data y.

Since the unknown object represented as an image, in the prevuois model we suppose
To reshape the image into an array x following a lexicographical order, and the data into an array y.

Linear Inverse Imaging Problems

The data y are usually affected by noise, due to different physical processes.
For the moment, we can consider additive noise so that the final linear model is:

$$Ax = y + e$$

The noise is a random process described by a random variable.

$$\delta$$

Different random processes can corrupt the data y, represented by random variables with different probability distributions.

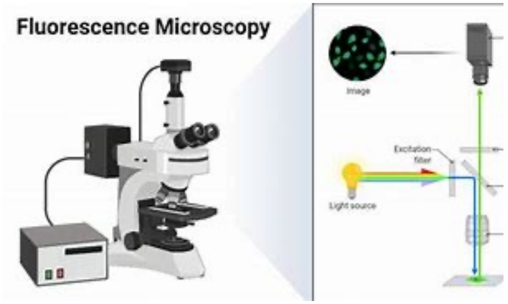
The imaging system

- Optical imaging system

Optical microscopy

Photographic lens

Telescope



Fkuorescence microscopy

Confocal microscopy

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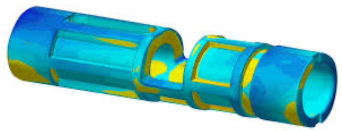
The imaging system

- Medical and industrial imaging system

Total body CT scan

Dental CT scan



Industrial CT scan

Echography system

MR system

The imaging system

- Other imaging systems

Thermal imaging system

Remote sensing imaging system

Hyperspectral imaging system