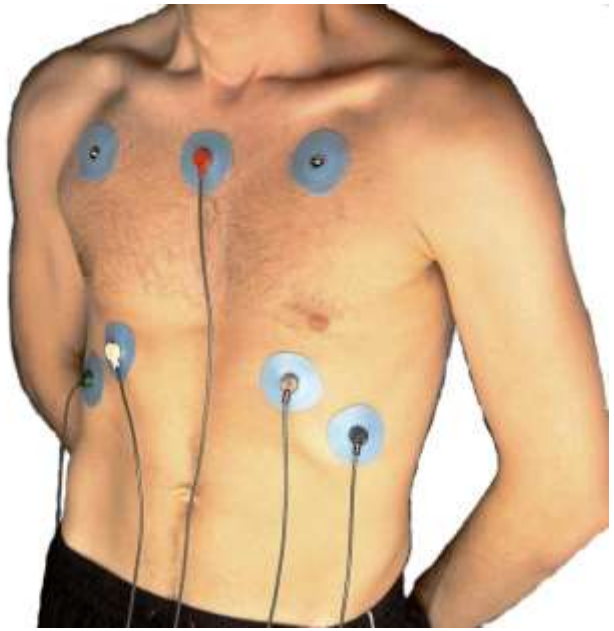
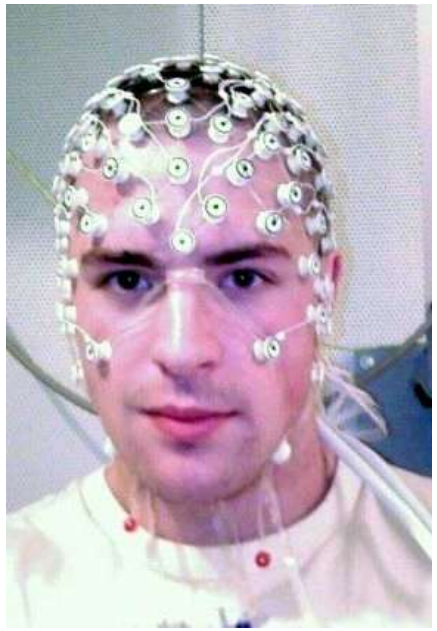
Looking into the body non-invasively.

A medical procedure is defined as *non-invasive* when no break in the skin is created and there is no contact with the mucosa, or skin break, or internal body cavity beyond a natural or artificial body orifice. : Non-invasive procedure - Wikipedia



Biopotential: electrical signal

14101766166_c78919676e_b.jpg (850×760) (staticflickr.com)



Biopotential: electrical signal

EEG_cap.jpg (289×423) (wikimedia.org)

Sound signal

Finding the Error Activity: Infant Apical Pulse – Answer – Vital Sign Measurement Across the Lifespan – 1st Canadian edition (pressbooks.pub)

Looking into the body non-invasively.

https://en.wikipedia.org/wiki/CT_scan

https://en.wikipedia.org/wiki/Ultrasound

https://en.wikipedia.org/wiki/Magnetic_resonance_imaging

NIR IMAGING

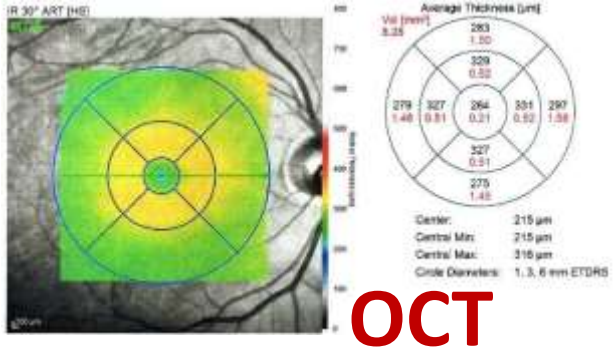
https://www.wikiwand.com/en/Near-infrared_spectroscopy

https://en.wikipedia.org/wiki/Photoacoustic_imaging

PHOTO ACOUSTIC IMAGING

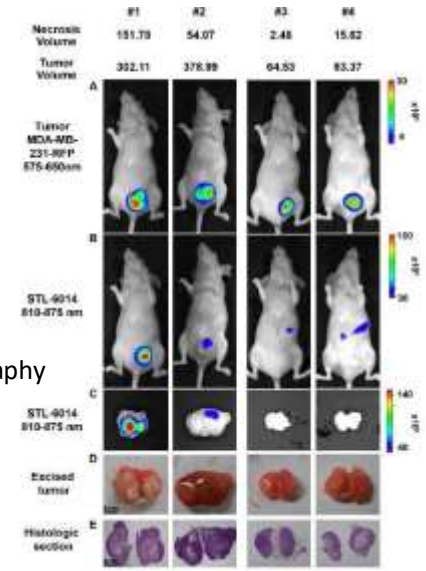
https://en.wikipedia.org/wiki/Positron_emission_tomography

PET SCAN



OCT

https://en.wikipedia.org/wiki/Optical_coherence_tomography



FLOURESCENCE IMAGING

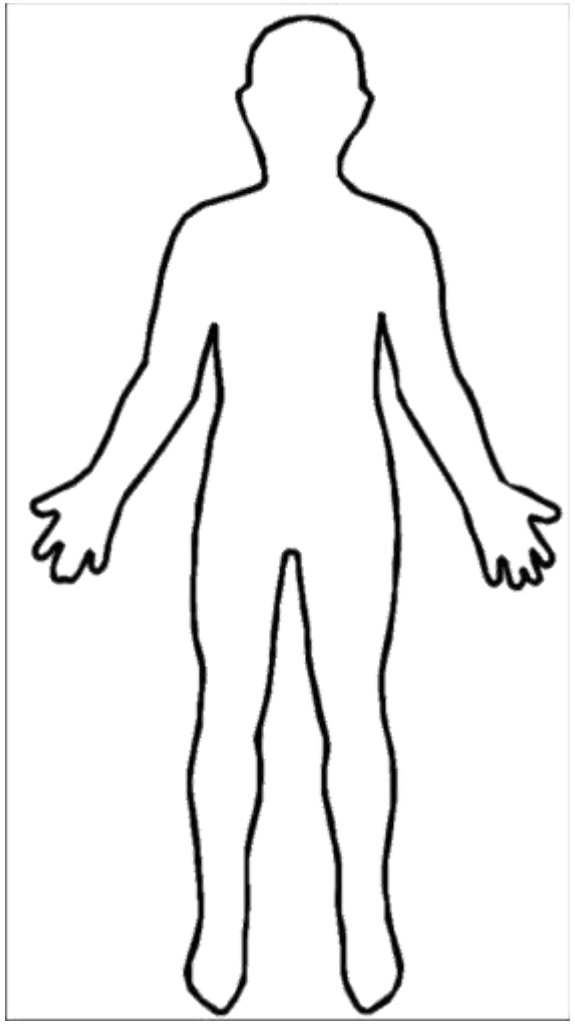
https://commons.wikimedia.org/wiki/File:Fluorescence_Imaging_07.jpg

- **Different imaging modalities have different underlying physical principles.**
- **Look for common features of each imaging modalities.**
- **A common platform or theory to many imaging modalities.**

Looking into the body non-invasively.

Measure externally irradiated Probing signals after interacting with the body.
Eg: X Ray, CT, Ultrasound MRI, NIRS, OCT etc

https://en.wikipedia.org/wiki/Ultrasound



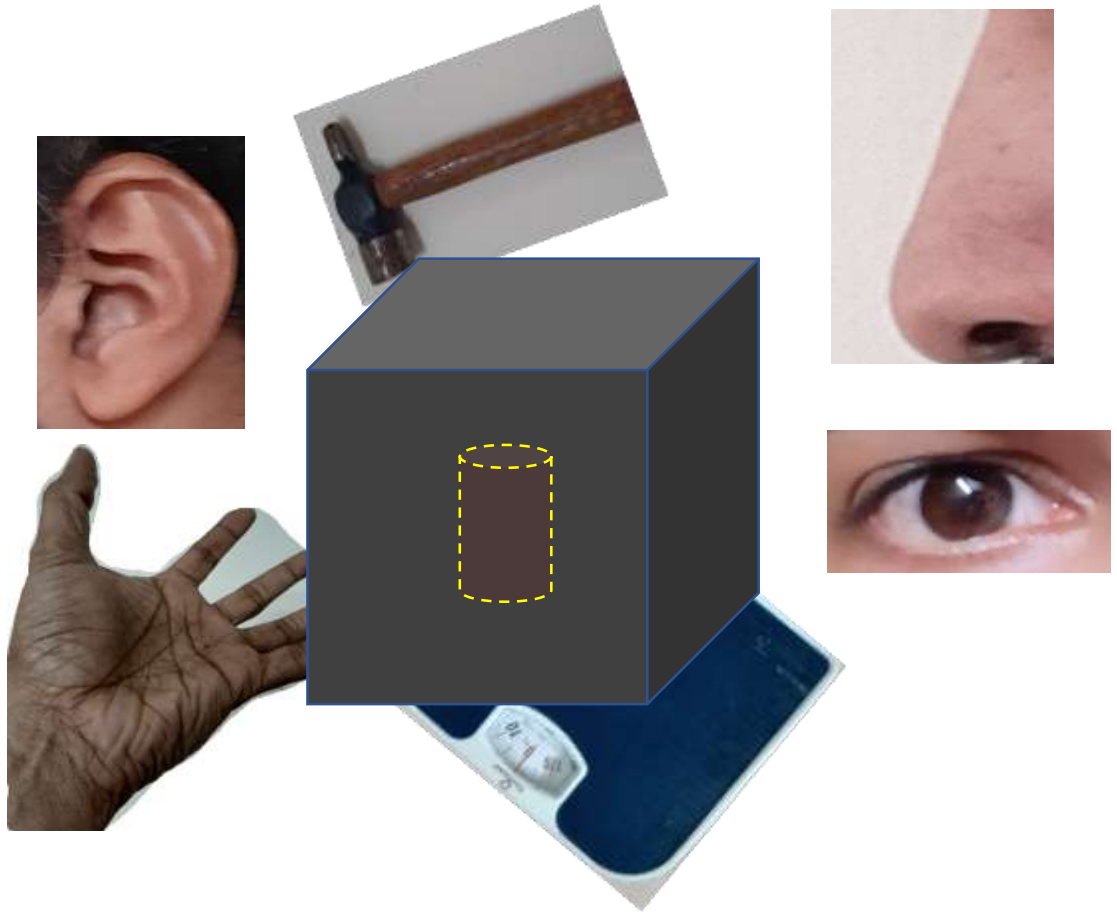
human body wiki - Bing images

Measure Bio Signals emanating from the body:
Eg: ECG, EEG, EMG, EKG, Phonocardiography, body temperature etc.

Finding the Error Activity: Infant Apical Pulse – Answer – Vital Sign Measurement Across the Lifespan – 1st Canadian edition (pressbooks.pub)

Hari M Varma, BSBE, IIT Bombay (harivarma@iitb.ac.in)

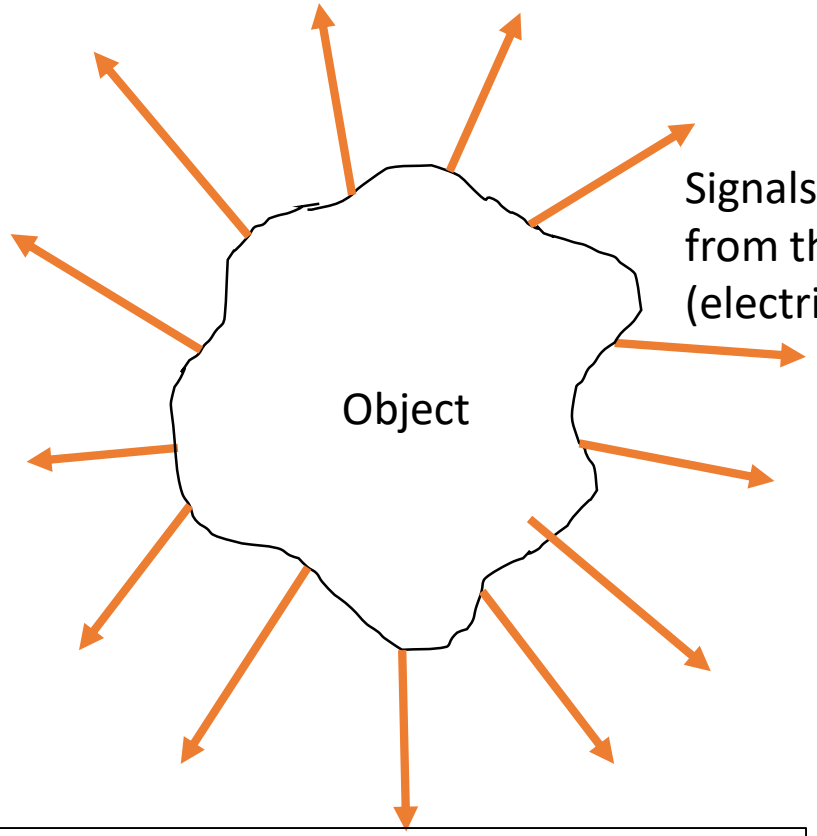
Looking at the body : A black box approach



A BLACK BOX WITH A HIDDEN OBJECT

Hari M Varma, BSBE, IIT Bombay (harivarma@iitb.ac.in)

Signals originating from body and signals created by probing waves

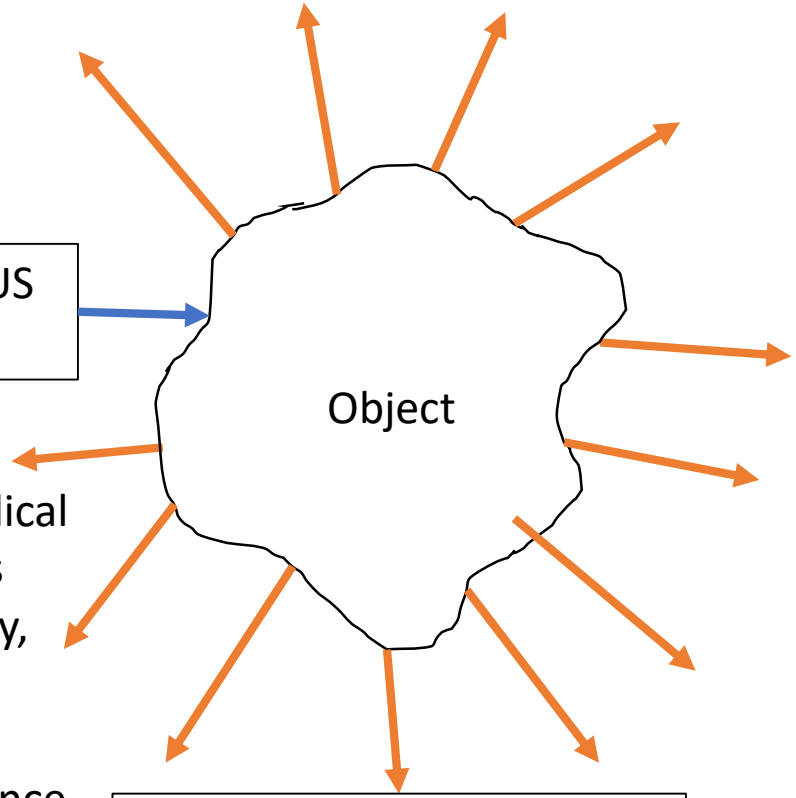


Signals originating from the body (electrical, sound etc)

Measurement (eg: ECG, EEG..)

Quantification of the physiological status. (eg : condition of the heart)

Probing wave (eg: US or any EM wave)



Examples

All non invasive medical diagnostics methods

- CT mammography, Tomography etc
- Pulse oxymeter
- Electrical impedance tomography
- MRI
- Ultrasound
- Near Infrared Spectrsocpy etc..

Measurement of probing wave after interacting with the object

Quantification of the physiological or anatomical status

Forward and inverse problem

Signals from the body

Forward Model/Problem

A physical/mathematical model explaining how signal is originated and then propagated through the object.

Eg: how Neuron action potential is originated and then manifest as EEG at the body surface

Measurement Model

A physically realizable measurement of the signals from the object at appropriate places in the surface of the body.

Inverse Model/Problem

Given the forward model and the measurement model, find the object property.

(eg: physiological status of the heart or functional activation studies using EEG etc.)

Probing signals coming out from the body after interaction

Forward Model/Problem

A physical/mathematical model explaining how probing wave interacts with the object.

Eg: how X-rays interacts with human body (Beer Lamberts Law)

Measurement Model

A physically realizable measurement of the probing wave after interacting with the object.

Inverse Model/Problem

Given the forward model and the measurement model, find the object property. (eg: the absorption coefficient of the tissue as a 3D map in CT scan.)

Origin of signals from the body : the forward model.

- Origin of Bio electric potentials : membrane potential and action potential
- Neuron : signalling and origin of EEG
- Cardiac system : working of heart and origin of ECG.
- Emphasis on the engineering concepts in above phenomenon's :

How body interacts with probing signals applied externally (non- invasively) : imaging problem

- X ray propagation inside the human body : Beers Lamberts Law.
- Concept of computed tomography to create three dimensional anatomical images.
- Image reconstruction method (INVERSE PROBLEMS): simple back projection and its implementation in Matlab.
- Concept of Fourier Transform
- Quick introduction to Magnetic Resonance Imaging.
- Why Fourier Transforms are indispensable tool for CT and MRI ?

INTRODUCTION TO IMAGING USING IMAGES

HARIDWAR

Hari M Varma, BSBE, IIT Bombay (harivarma@iitb.ac.in)

DIFFERENT IMAGING MODALITIES

https://en.wikipedia.org/wiki/CT_scan

CT SCAN

https://en.wikipedia.org/wiki/Ultrasound

ULTRASOUND

https://en.wikipedia.org/wiki/Magnetic_resonance_imaging

MRI

NIR IMAGING

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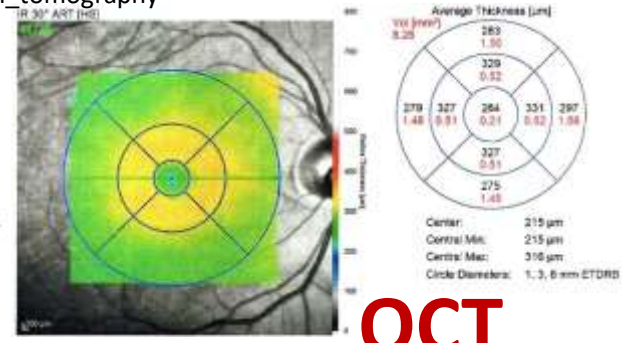
PET SCAN

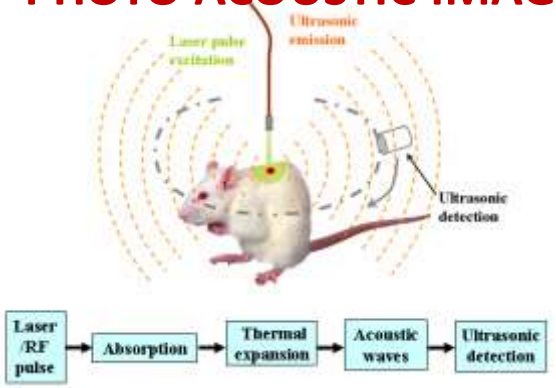


OCT

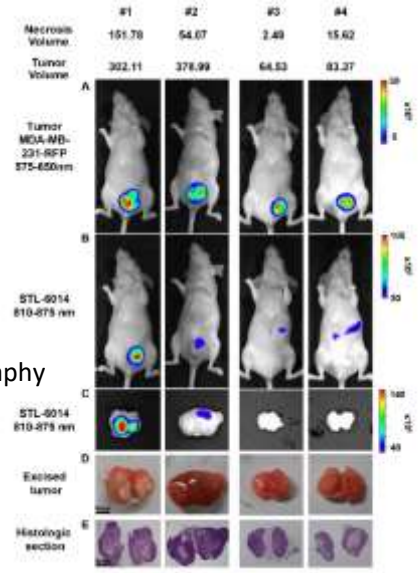
https://en.wikipedia.org/wiki/Optical_coherence_tomography

https://en.wikipedia.org/wiki/Photoacoustic_imaging

PHOTO ACOUSTIC IMAGING



- **Different imaging modalities have different underlying physical principles.**
- **Look for common features of each imaging modalities.**
- **A common platform or theory to many imaging modalities.**

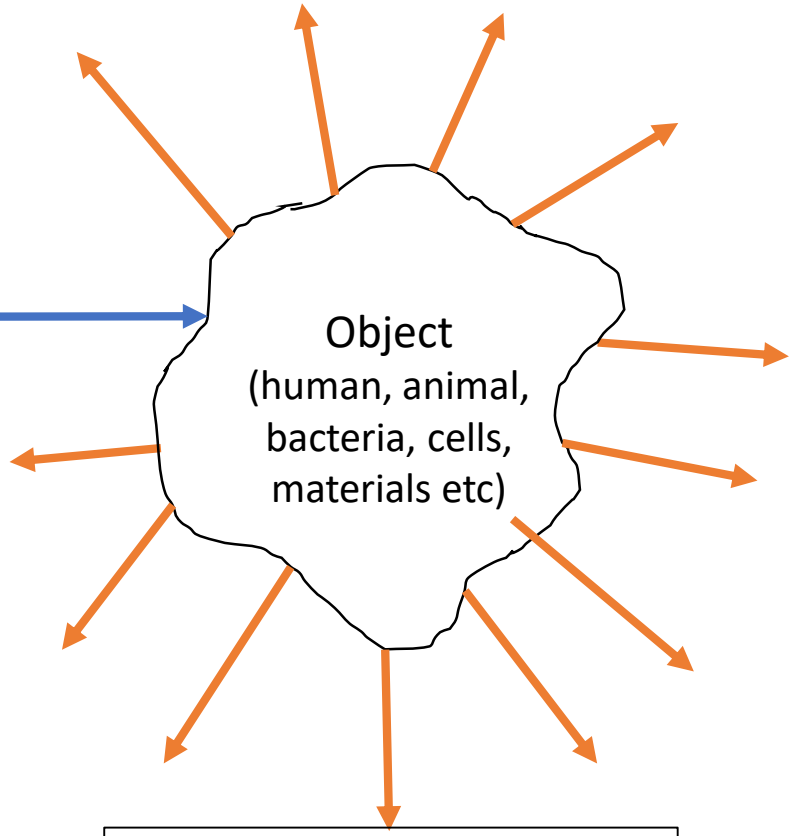


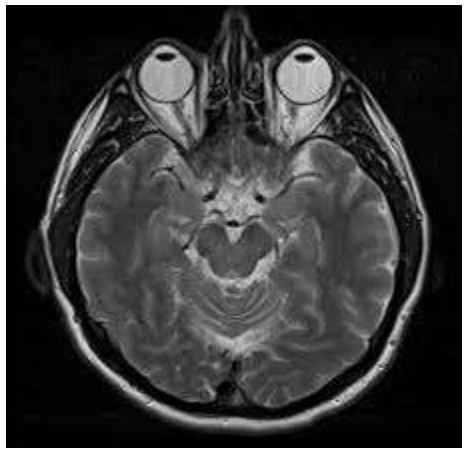
FLOURESCENCE IMAGING

https://commons.wikimedia.org/wiki/File:Fluorescence_Imaging_07.jpg

What is an Image ???

Probing wave (eg: US or any EM wave)



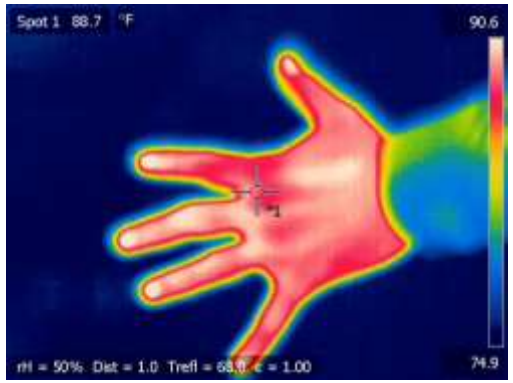


MRI image: PD image or T1 or T2 relaxation image etc

https://commons.wikimedia.org/wiki/File:MRI_Head_Brain_Normal.jpg

Appropriate (matching to probing wave) detectors

Image of the object property

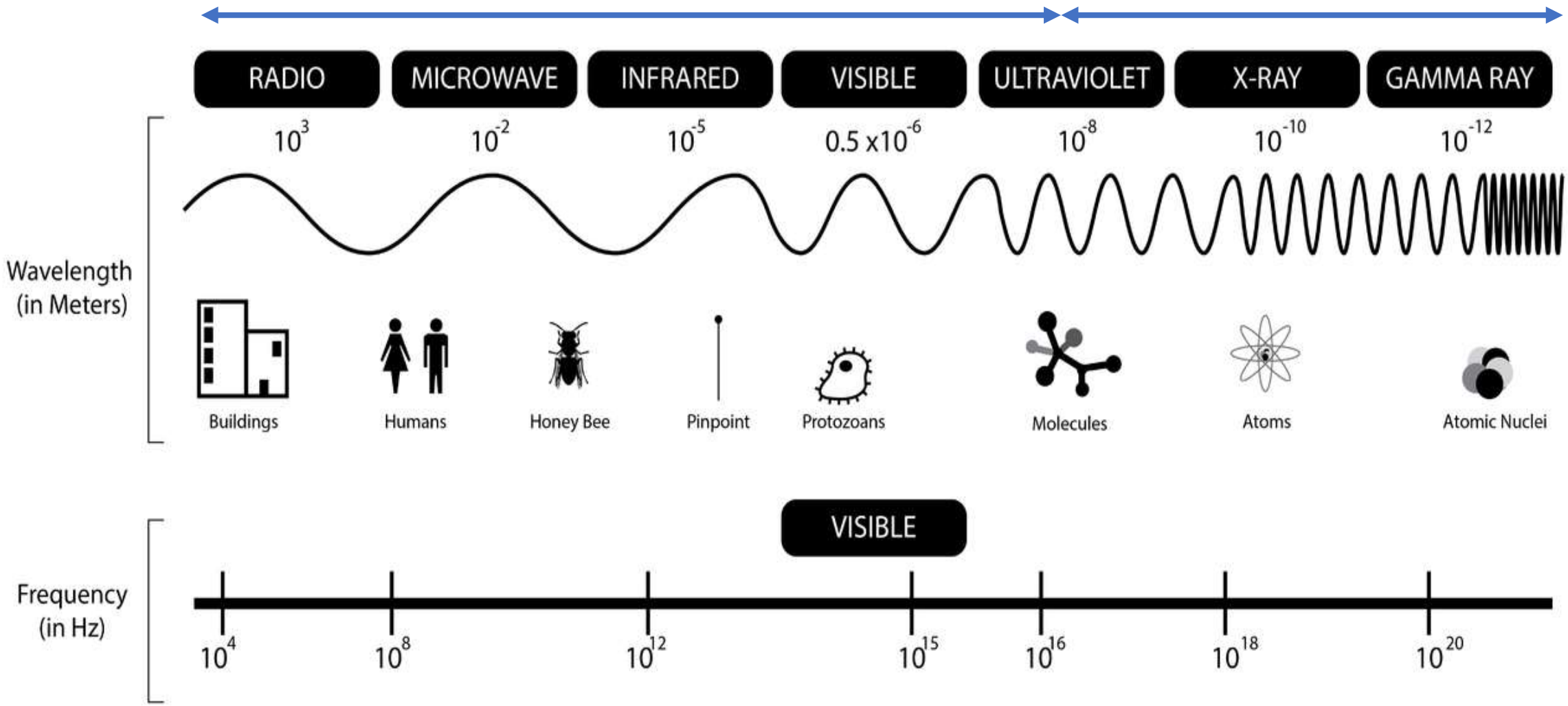


Thermal imaging :Long infrared range emanating from body.

https://commons.wikimedia.org/wiki/File:Thermal_image_-_hand_-_1.jpg

Visible light from sun (reflected, transmitted, absorbed , scattered etc from the objects) picked by an eye or a camera. [Dal Lake: Kashmir]

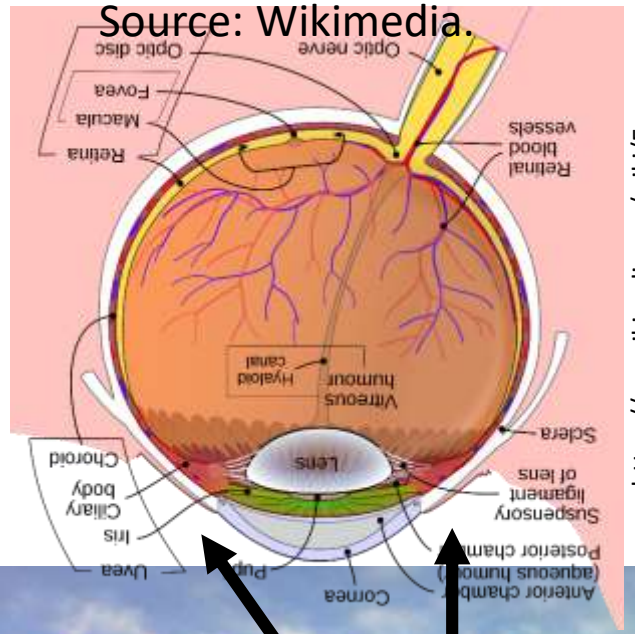
ELECTROMAGNETIC SPECTRUM



Source: https://commons.wikimedia.org/wiki/File:BW_EM_spectrum.png

IMAGE , IMAGING AND IMAGE PROCESSING

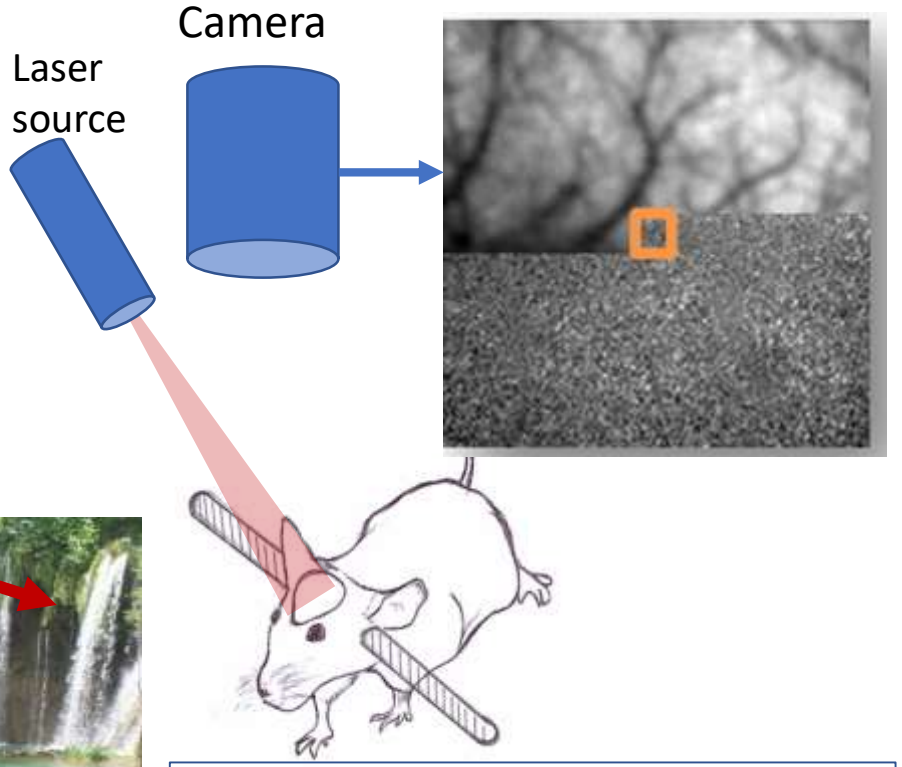
Source: Wikimedia.



.https://en.wikipedia.org/wiki/Eye

Helsinki, Finland

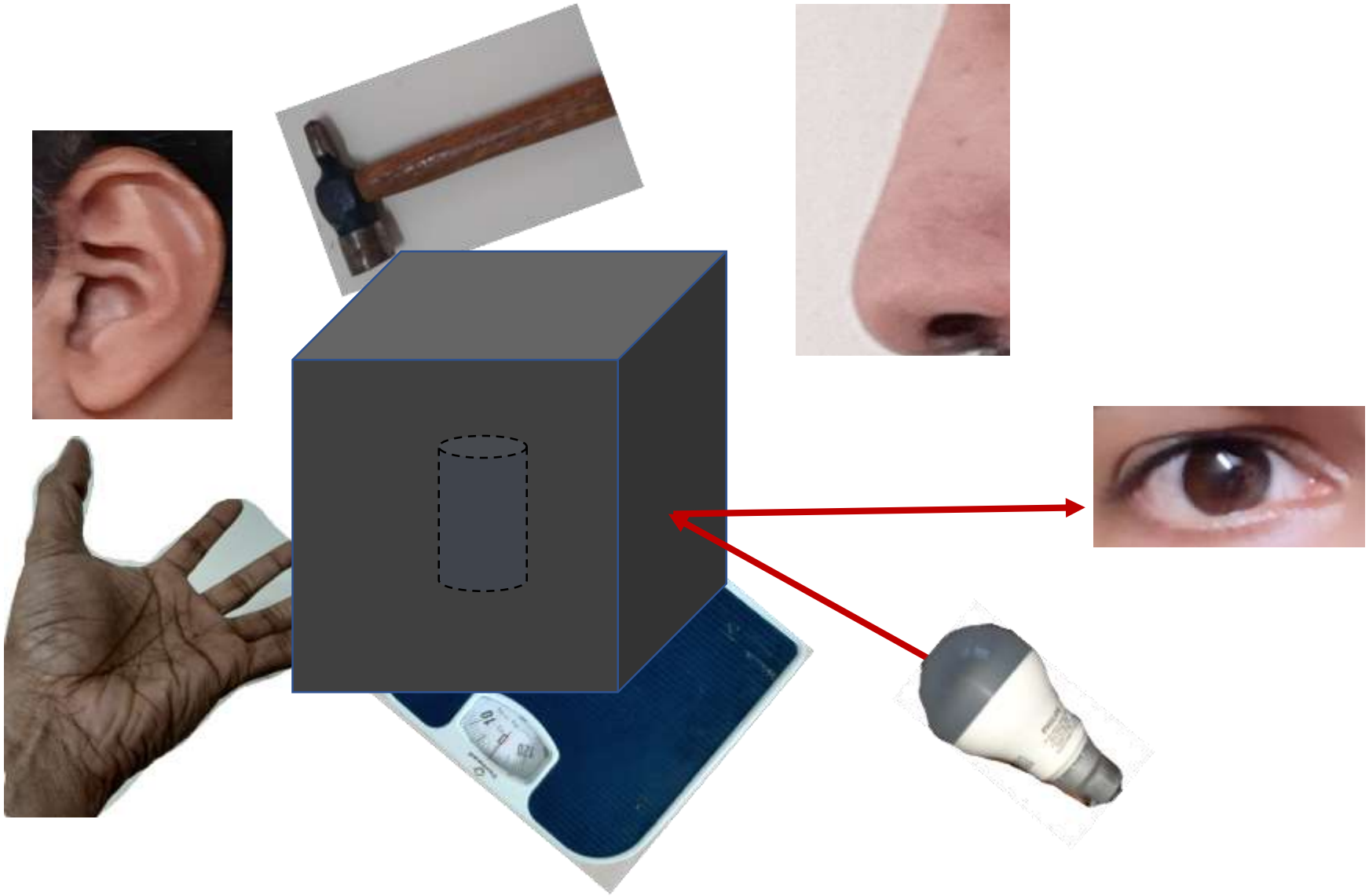
Plitvice National Park, Croatia



D. Briers et. al., J. Biomed. Opt. 18, 066018 (2013).
A. K. Dunn, Ann. Biomed. Engg. 40, 367–377 (2012).
R. Bandyopadhyay et al, Rev. sci. instrum. 76, 2005

Eg: Laser Speckle Imaging

NEED OF A COMMON THEORY

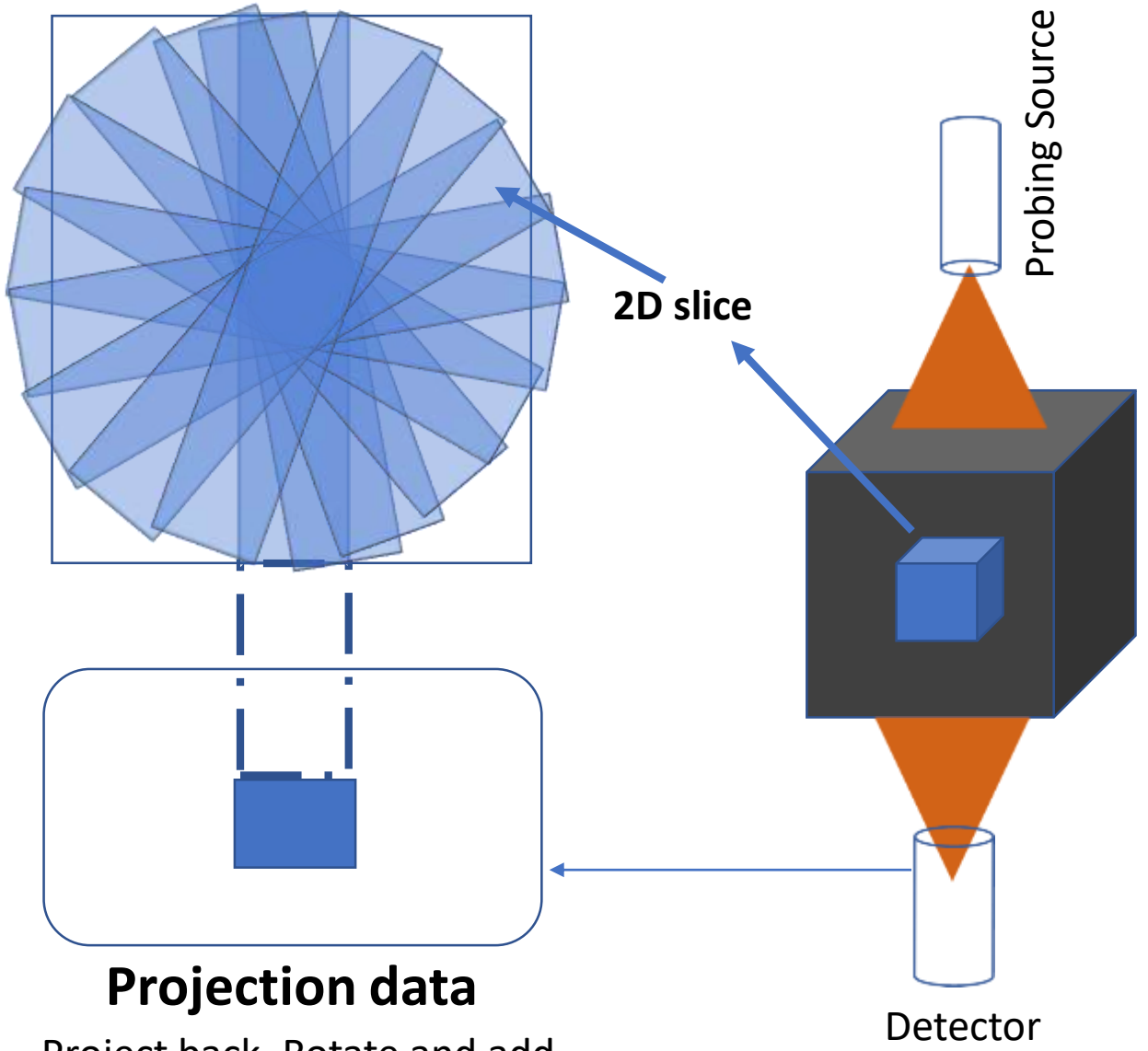


A BLACK BOX WITH A HIDDEN OBJECT

Hari M Varma, BSBE, IIT Bombay
(harivarma@iitb.ac.in)

HOW TO TACKLE THIS PROBLEM

SHADOW OF THE HIDDEN OBJECT:
CAN YOU IDENTIFY PERSON FROM THE SHADOW?
Dali Theatre-Museum, Figueres, Girona, Spain



Project back, Rotate and add.

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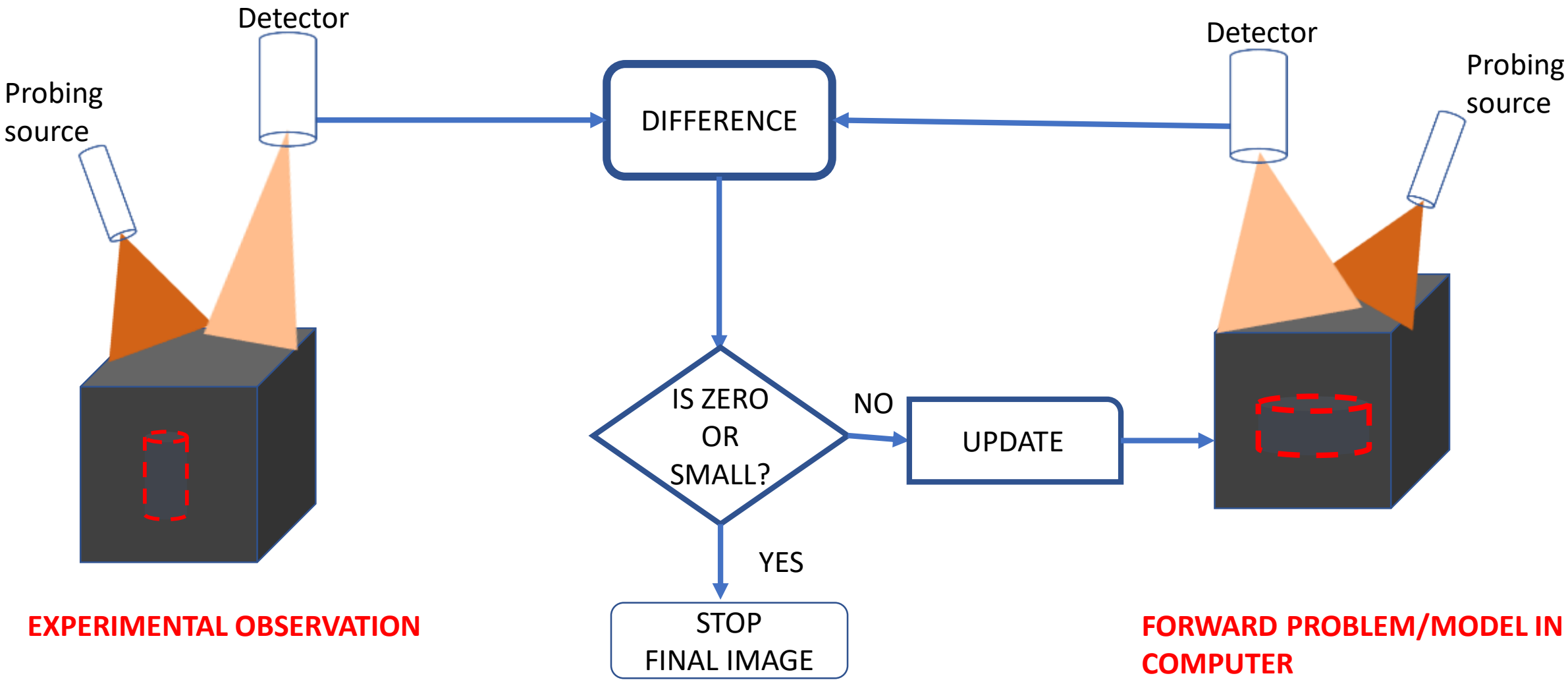
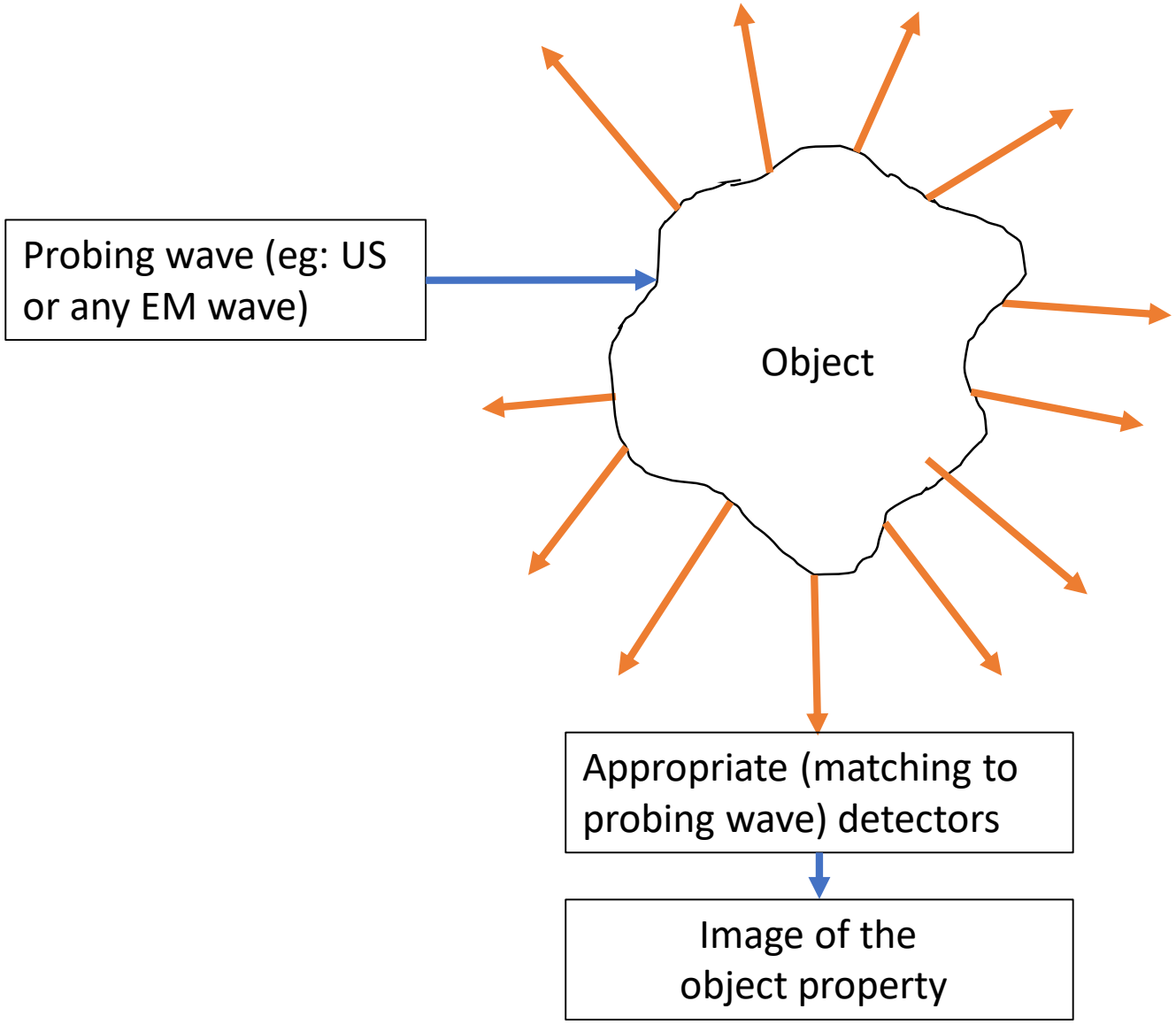
Projection may not be possible in all cases



INVERSE PROBLEM OR IMAGING PROBLEM

Forward and inverse problem



Forward Model/Problem

A physical/mathematical model explaining how probing wave interacts with the object.

Eg: how X-rays interacts with human body (Beer Lamberts Law)

Measurement Model

A physically realizable measurement of the probing wave after interacting with the object.

Inverse Model/Problem

Given the forward model and the measurement model, find the object property.

(eg: the absorption coefficient of the tissue as a 3D map in CT scan.)

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Relate these concepts to the real life examples.

Identify the forward and inverse problems associated with the following photographs (need not be imaging problems. Some examples are forced ones while others are direct/obvious)

Zagreb, Croatia.

- The movement of the duck leaves behind a wave pattern.
- Is this pattern unique to a duck?
- Given the pattern can you identify the duck?

- Each food is associated with a unique aroma.?
- Can you identify the food from its aroma?

Castelldefels, Barcelona, Spain.

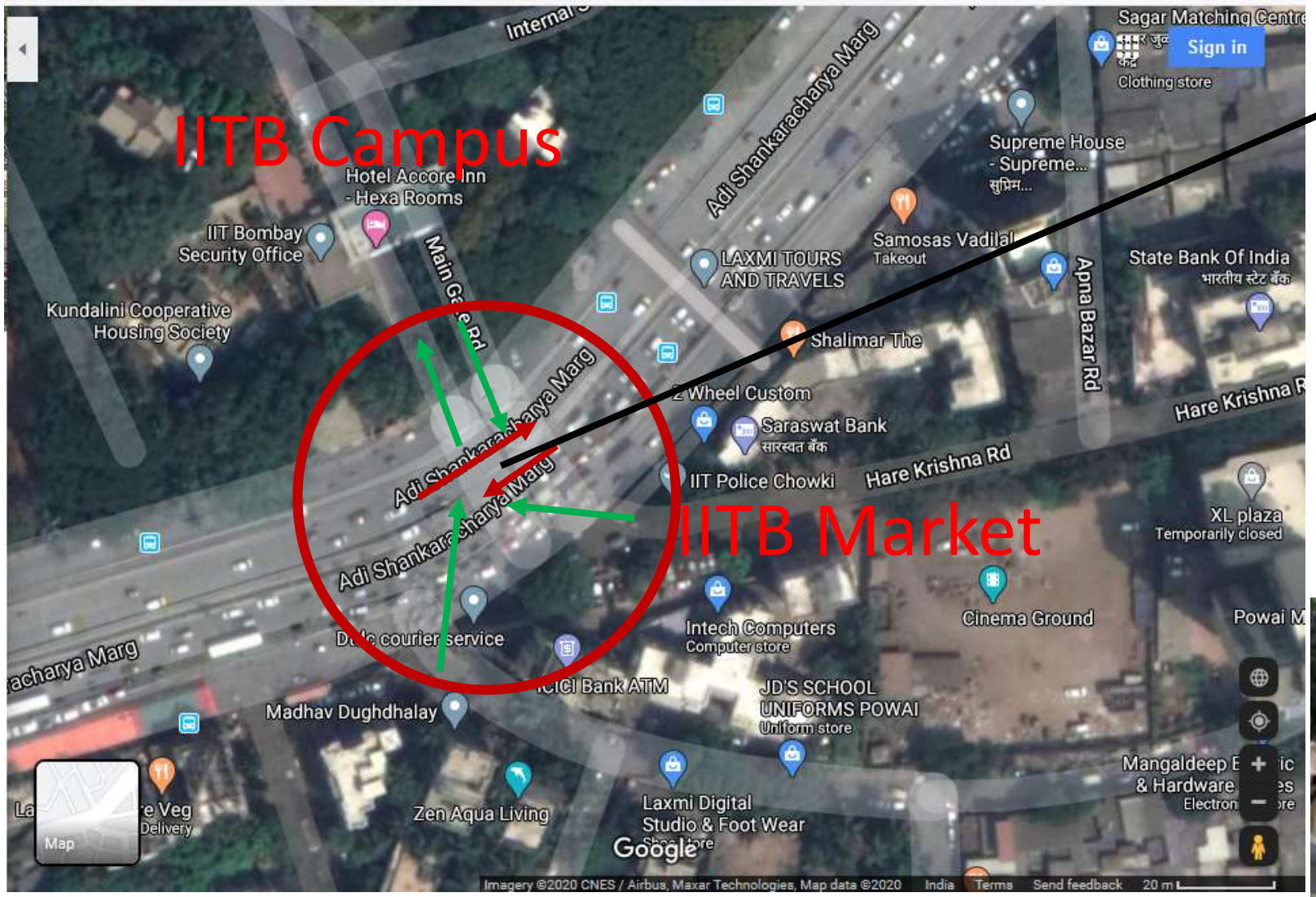
Chandivali, Mumbai.

- Mumbai roads are infamous for Manholes.
- While we walk in the beautiful Mumbai Monsoon, can you identify the manhole?
  If so, how?

Near AIIMS, Rishikesh.

ECHOLOCATION:

- Bats use sound to navigate.
- Sound waves are emitted which on reflection from the object is picked up the ear and processed in the brain to find location, size and shape of the object.
- Is this an inverse problem?



IITB main gate

- **From IITB main campus, we can cross the road to the market through the junction as circled. The green arrows shows the vehicle movement during the "walk" sign.**
- **We take measurements of vehicle movements from all sides and decide to cross, change directions, stop etc.**
- **The problem is even tougher during night when the signal is off so that vehicles with red arrows also moves without stops.**

This simplifies the problem (have to worry about law offenders)

- Driving in a rainy or misty day/night in heavy traffic. How many inverse problems we instantly solve in the brain? If the location is familiar then it simplifies the problem (apriori information).

- Note that the usual traffic rules and driving rules acts as the forward model along with the local habits (it is very common in Mumbai to overtake from left by two wheelers), local terrain etc.

Mumbai Taxis , Autos and the Monsoon.

Monsoon in IITB campus

Learning process in children

- They observe and make forward models.
- Eg: One of the developmental milestones from 12-18 months is to find hidden objects. Is this can be categorized as some sort of inverse problem?

Powai Fine Arts, Nahar, Chandivali, Mumbai

- There are musicians who compose film music based on ragas. Can you identify the raga by hearing the film song?
- Can you catch the copy cats?

Eg:T._Sreenidhi
https://wikivisually.com/wiki/T._Sreenidhi

Can One Hear the Shape of a Drum?
Mark Kac

Can One Hear the Shape of a Drum?Author(s): Mark Kac Reviewed work(s):Source: The American Mathematical Monthly, Vol. 73, No. 4, Part 2: Papers in Analysis (Apr.,1966), pp. 1-23

La Merce festival, Barcelona, Spain

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Helsinki, Finland.

- How many images are formed by a pair of mirrors?
- Count the image and find the number of mirrors used, relative orientation etc?

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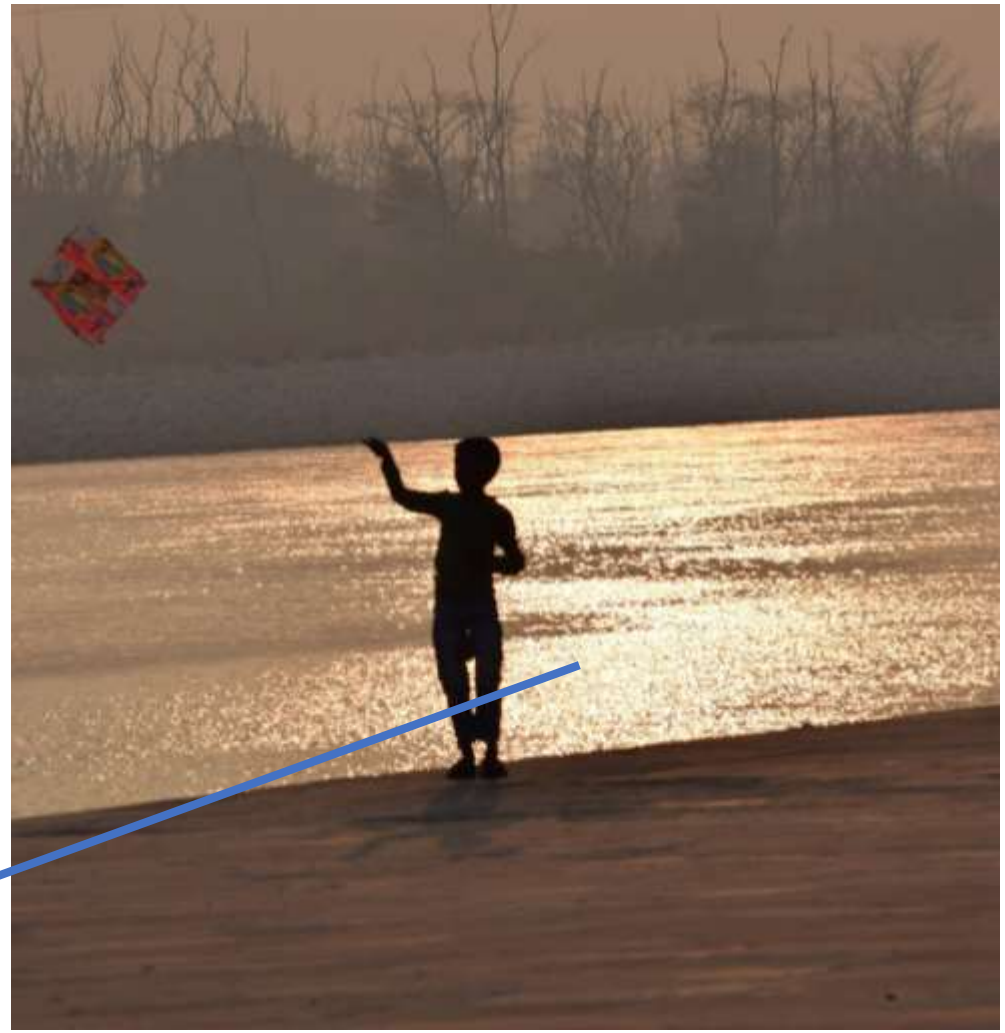
Deblurring

Vashi Bridge, Navi Mumbai

- Bridge is distorted by the moving rain drops in the window glass of a moving train.
- Can you find the velocity of the train or the velocity of the rain drops?



River Ganga, Haridwar

- It is very common to see the light reflected from the water body to fade while wind blows.
- Can you find the wind velocity from the blurred image?

https://commons.wikimedia.org/wiki/File:OxyWatch_C20_Pulse_Oximeter.png

Pulse oximeter

- Near Infrared light can penetrate human body and can carry information about absorption coefficient of tissue.
- This can then be “inverted” to find the tissue oxygen saturation.

My own report: lost one teeth which served 38 years

- X ray imaging: 2d projection of dental cavity.
- Here it is just the projection measurement on film: Intra Oral Periapical radiograph.
- The inverse problem associated is carried out by the dentist by looking at the measurement.
- CBCT (cone beam computed tomography) of teeth gives a 3D image.

Airports/sensitive buildings

- Non destructive testing (NDT)
  Eg: baggage check using X-rays.
- Full body scanner for travellers in airports.

https://commons.wikimedia.org/wiki/File:Check_in_area_and_Baggage_screening_at_Jodhpur_Airport.jpg

Near infrared spectroscopy of painting

Mona Lisa, Louvre Museum, Paris.

- The final art of any artist involve a lot of corrections.
- The corrections are made one above the other thus having different layers.
- The outer layer is the finished work.
- Is it possible to reconstruct each layer so that we can get an idea of how a beautiful work evolve in the mind of an artist.

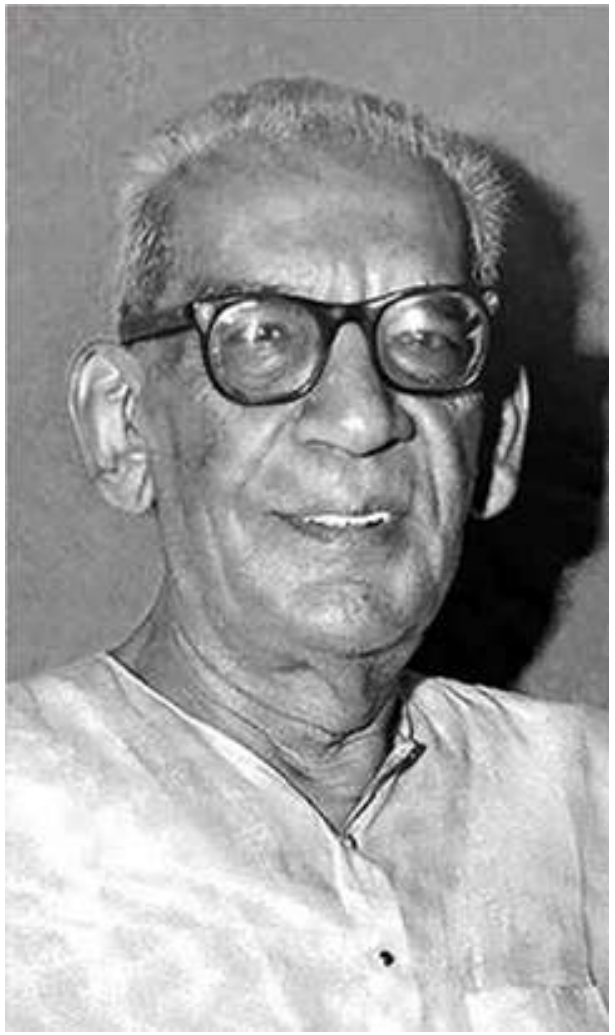
Forensics or crime scene reconstruction, archaeology

Arthur Conan Doyle: creator of Sherlock Holmes and Dr. Watson.

Sharadindu Bandyopadhyay: Creator of Byomkesh Bakshi.

Experience + intelligent observation = forward model

Catacombs of Paris



https://en.wikipedia.org/wiki/Category:Arthur_Conan_Doyle#/media/File:Conan_doyle.jpg

https://en.wikipedia.org/wiki/Sharadindu_Bandyopadhyay#/media/File:SharadinduBandyopadhyayPic.jpg

Police Dogs

Rishikesh.

- Train them: forward model is created in brain.
- In crime scene: measurement is taken.
- An inverse problem is attempted in its brain to get the criminal .

Kitchen

Gas levels of cylinders, Food quality testing: vegetables and fruits, milk etc…

Alcohol detection

http://chdtransport.gov.in/Webpages/DrunkenDriving.html

- Transdermal alcohol concentration
- Breath analyzer: Henrys Law.

Politics: Opinion Polls

Critical states in Political Trends. How much reliable is a poll on Twitter? A study by means of the Potts Model https://arxiv.org/abs/1901.10984

https://eci.gov.in/about/about-eci/the-functions-electoral-system-of-india-r2/

Sudoku

	1	2		3	4	5	6	7
	3	4	5		6	1	8	2
		1		5	8	2		6
		8	6					1
	2				7		5	
		3	7		5		2	8
	8			6		7		
2		7		8	3	6	1	5

https://commons.wikimedia.org/wiki/File:Minimal_9x9_Sudoku_with_40_givens.svg

Generating Sudoku Puzzles as an Inverse Problem https://sites.math.washington.edu/~morrow/mcm/team2306.pdf.

Each row , column and 3x3 sub matrices should be filled with 1 to 9 without repetition starting from a partially filled matrix.

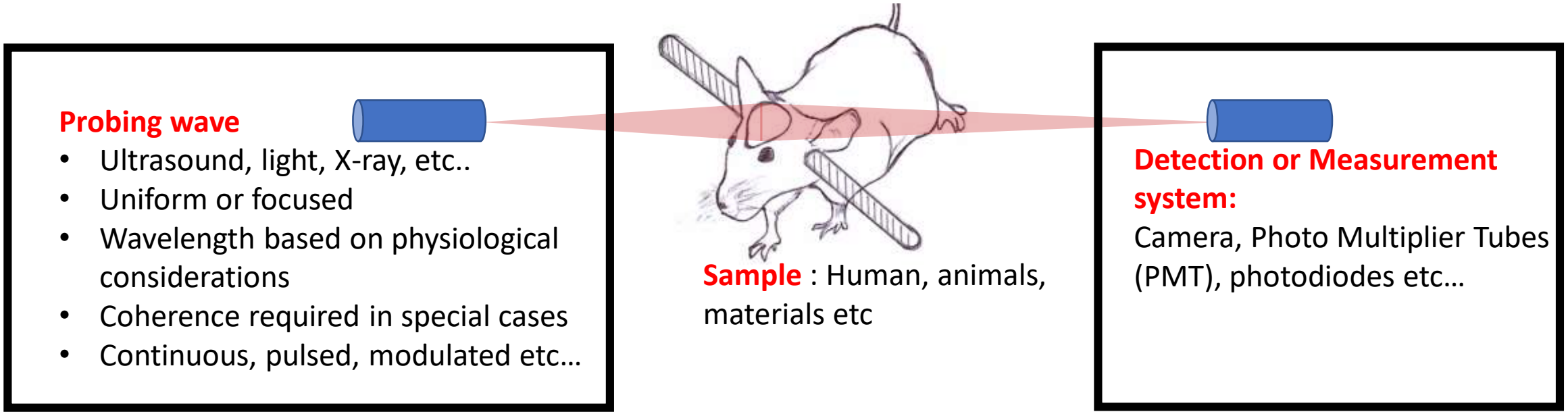
Cards and chess

Gymkhana, Indian Institute of Science

Indian Card Game 28 or 56: guessing the cards in opponents hands

Search “Inverse Chess”

Imaging system



- How do we select the sources and the detectors?
- What energy..X ray, US, light etc…
- What wavelength? How much intensity?
- White light? LED's? lasers?- If so, CW or pulsed? Focussed or uniform illumination??
- Detectors: should match the source: sensitivity (Quantum efficiency), area detector etc..
- Sample: invitro, invivo?? Size? Which probe to use? Info like the physiological window etc..
- Imaging: spectroscopy (no spatial but an average information) or tomography? Forward models?? Inversion models: computational costs (real time ???) Speed etc…

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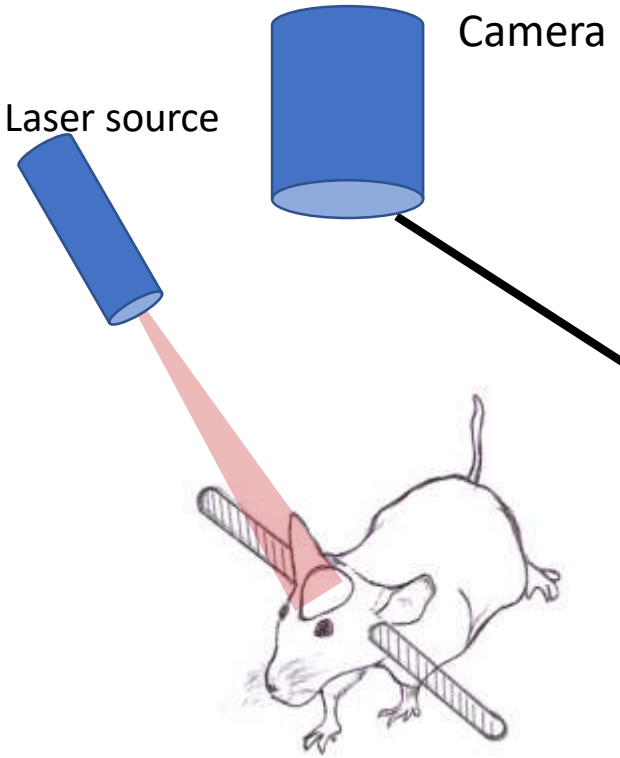
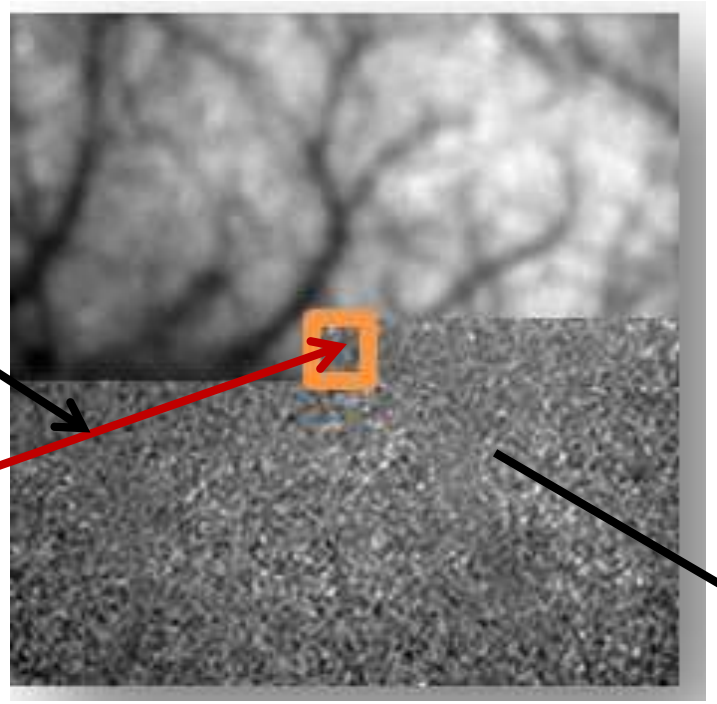
An example of imaging





Intensity speckles

This is what you get from camera..! So called images..

Speckle contrast, $\kappa(r,T) = \frac{\sigma}{<I>}$

σ = standard deviation of intensity

$< I >$ = mean of intensity

Image processing? Yes, but how do we arrive at quantity speckle contrast??? How do we relate it to say blood flow???Physics????

D. Briers et. al., J. Biomed. Opt. 18, 066018 (2013).
A. K. Dunn, Ann. Biomed. Engg. 40, 367–377 (2012).
R. Bandyopadhyay et al, Rev. sci. instrum. 76, 2005