UNIVERSITY OF MINNESOTA
Driven to Discover℠

EE 5561: Image Processing and Applications

Introduction

Mehmet Akçakaya

About the Course

- Basic Info [on syllabus]:
  - Instructor: Prof. Mehmet Akçakaya
  - Office: Keller 5-159
  - Contact: akcakaya@umn.edu, 625-1343
  - Office hours: Wednesday11am-12pm or by appointment
  - TA: Merve Gulle, glle0001@umn.edu
  - TA Office Hours: Th 10am-12pm KHKH 2-176 and via Zoom
- Prerequisites: EE 4541, 5581 or instructor consent
- Familiarity with linear algebra and probability is assumed.
- Canvas up and running

About the Course

- Course Description:
  - Multi-dimensional signals & systems, image pre-processing, image enhancement, denoising, segmentation, registration, and computational imaging.
  - 2D image transforms, linear filtering, sparsity and compression, statistical modeling
  - Optimization methods, multiresolution techniques, artificial intelligence concepts, neural networks and their applications in classification and regression tasks in image processing

About the Course

- Topics and Tentative Schedule:
  - Introduction to image processing, 2D Signals & Systems (~2 weeks)
  - Non-statistical methods:
    - Basic image enhancement, image pre-processing and interpolation (~1 weeks)
  - Statistical methods:
    - Linear algebra, random vectors, optimization review (~1 week)
    - Basic image restoration (~1 week)
    - Image compression, sparsity, wavelets, image denoising, deblurring, super-resolution (~1.5 weeks)
    - Image registration (~1 week)
  - Machine learning methods:
    - Machine learning concepts, artificial neural networks, backpropagation, convolutional neural networks, regularization (~2 weeks)
    - AI methods in image classification, segmentation, denoising, super-resolution (~1 week)
    - Generative models, attention, vision transformers (~2 weeks)

About the Course

- Recommended (**not required**) Texts:
  - Gonzalez & Woods, "Digital Image Processing," 4th Edition, Pearson, 2018.
  - S. Theodoridis, "Machine Learning: A Bayesian and Optimization Perspective," 2nd Edition, Academic Press, 2020. (For the last 1/3 of the course)
- Grading:
  - Quizzes: 15%
  - Mini-projects: 30%
  - Homework: 30%
  - Course project: 25%

About the Course

- Quizzes:
  - Released after each lecture
  - Goal: To make sure everyone understands the material on a high-level
  - Cover the lecture materials
  - Can be re-taken twice
  - Should be done independently

About the Course

- Homework:
  - Approximately biweekly
  - Will involve Python (or MATLAB) components as well
  - You may discuss with others, but need to **submit your own work**
  - Grading of each question will be written on the assignment
  - Grade for Homework Component = $\dfrac{\sum_{\text{assignment}} \text{your score for the assignment}}{\sum_{\text{assignment}} \text{total score for the assignment}}$

Mini-Projects

- This is intended for you to understand image processing research
- 2 mini-projects
  - One on image enhancement, one on statistical image processing
  - First one due **Oct. 19**, second one due **Nov. 16**
- Will be performed individually
- Read & understand recent literature
  - One scientific research paper will be assigned for the mini-project (same for everyone)
  - Each student will implement the techniques in Python/MATLAB
  - Each student will submit a written report (~ IEEE conference paper, 4-pages), including introduction, methods, results and discussion
  - Meant to complement lectures, i.e. it will be in addition to what we cover in the class

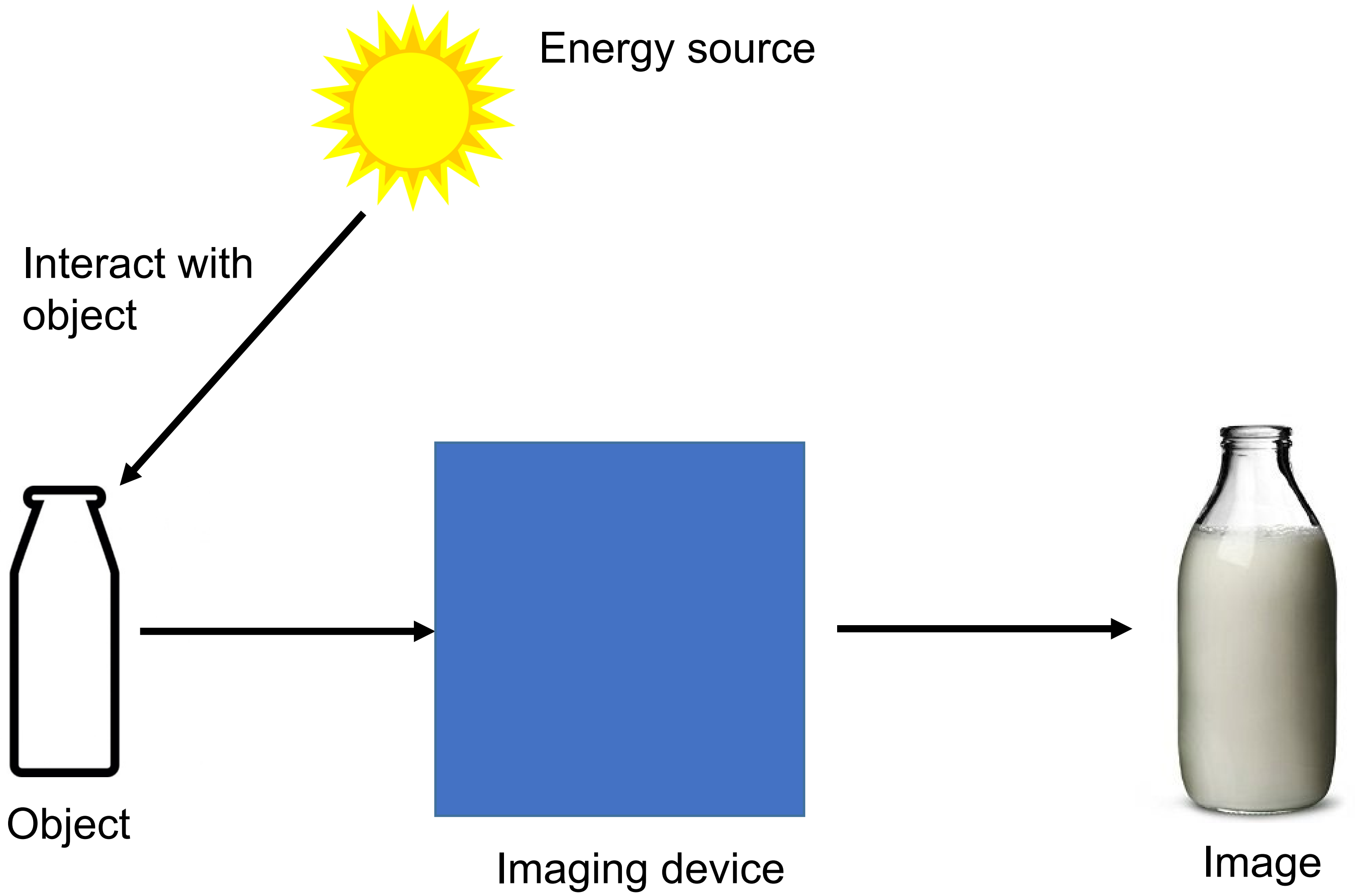
Course Project

- This is intended for you to understand image processing research
- Focus will be on deep learning
  - Will include implementation
- Groups of 2
  - May changed based on class size
- Read & understand recent literature
- I will not give possible papers here
  - You need to do a literature search
  - Propose a project yourself (proposal due: Nov. 20) for approval
  - Can be based on prior published works or original research
- PyTorch/TensorFlow/MATLAB/etc implementation of one or more techniques with numerical or real-life datasets

Course Project

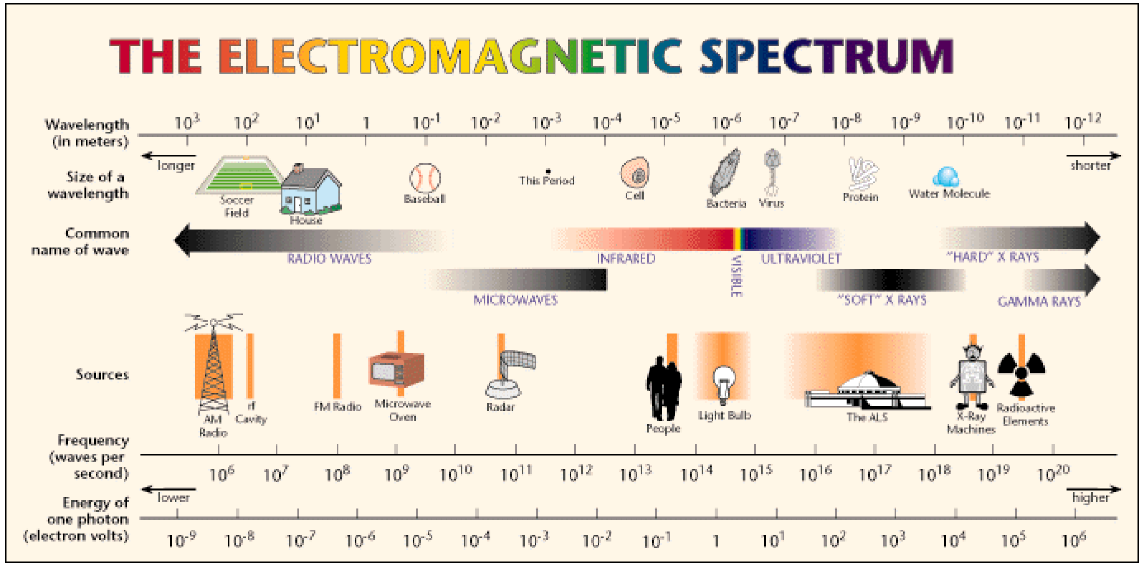
- Written report in IEEE journal format (extended from mini-projects, ~8 pages):
  - Abstract, Introduction, Methods (and Theory), Results, Discussion, Conclusion
  - Discussion must include limitations of the techniques
  - You may provide future research directions that you think would improve these techniques
- Final report (+ source code) due on December 17.
- Implementation of one or more techniques with numerical or real-life datasets

What is an image?



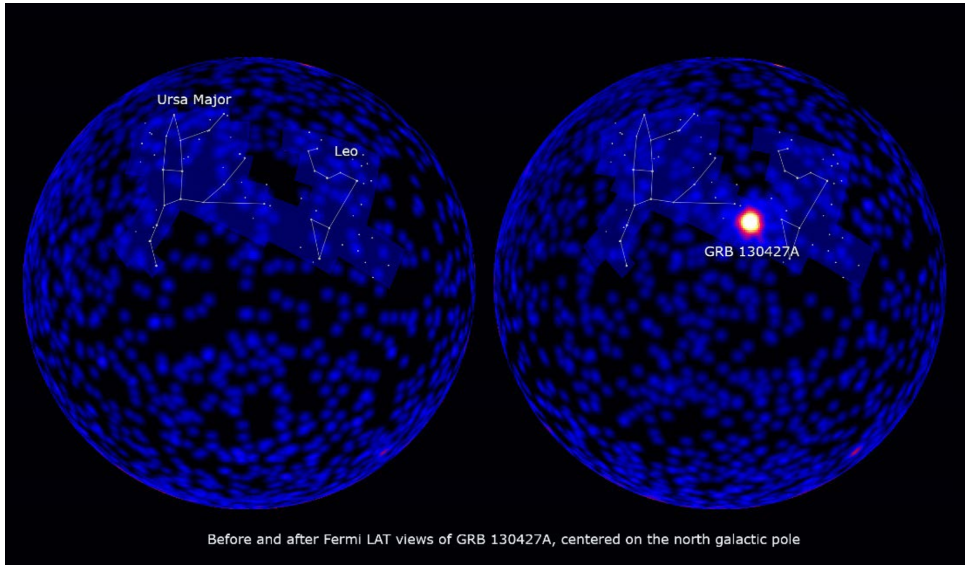
What is an image?

- What can the energy sources be?
- Electromagnetic spectrum
  - Visual band, x-rays, microwaves, radio band



- Sound → geological, medicine

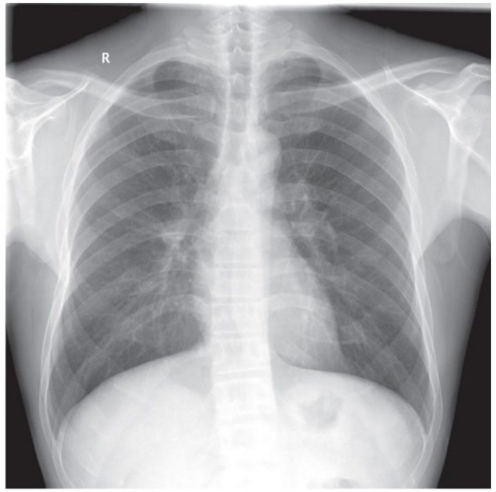
Gamma Rays

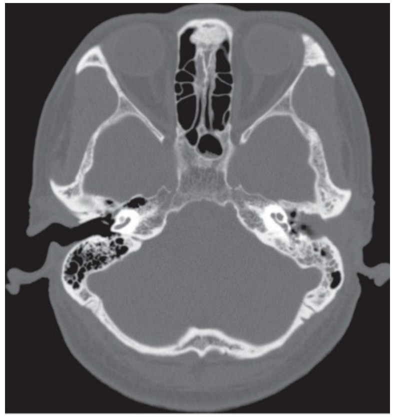


Ref: U Pittsburgh Med Center

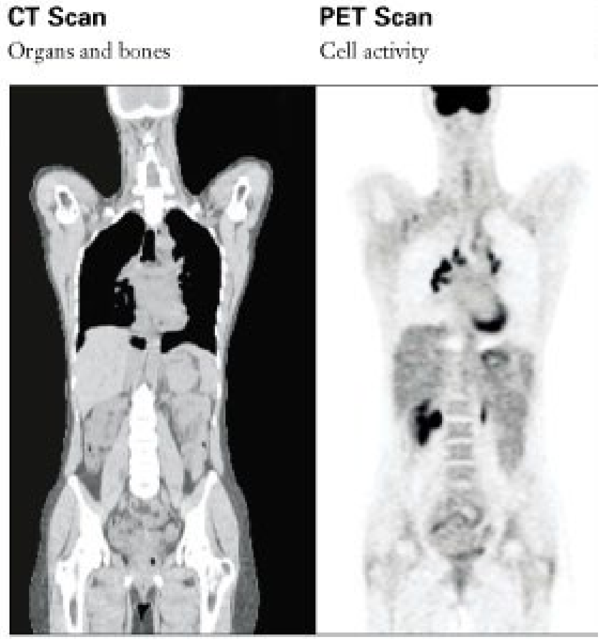
Ref: Wikipedia

X-rays

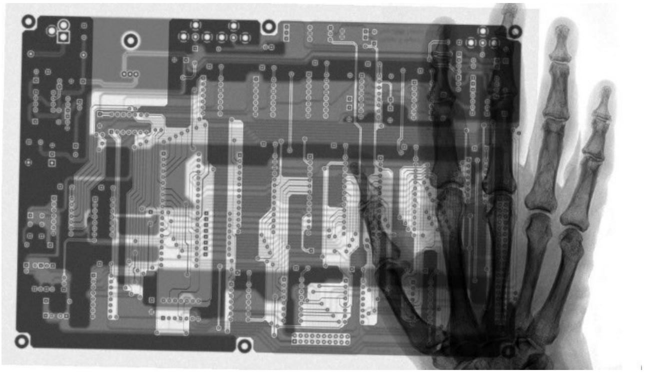




Ref: Prince & Links, Pearson, 2015



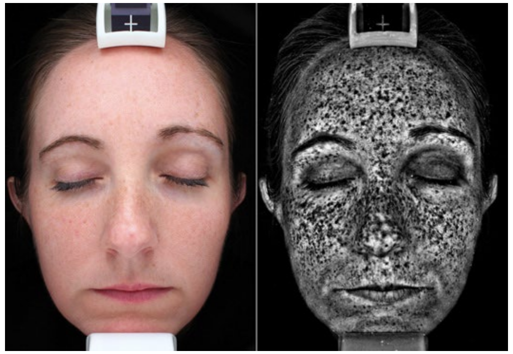
Ref: U Pittsburgh Med Center

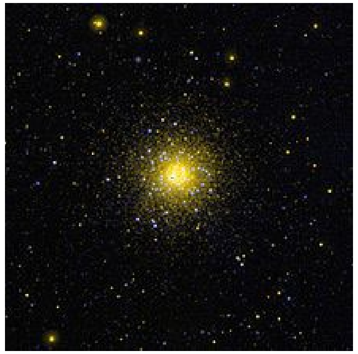


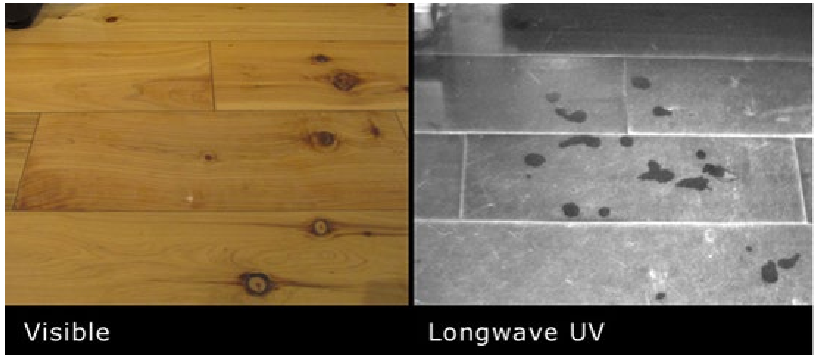
Ref: Wikipedia

Ultraviolet Imaging

- Industry, medicine, anatomy, biology





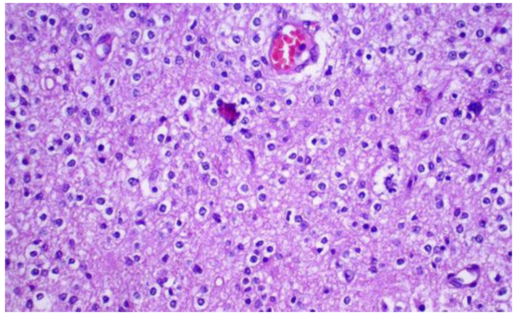


- All of the above: Outside the visible spectrum
- Use special filters/hardware that detects these frequencies
- Process them to get images

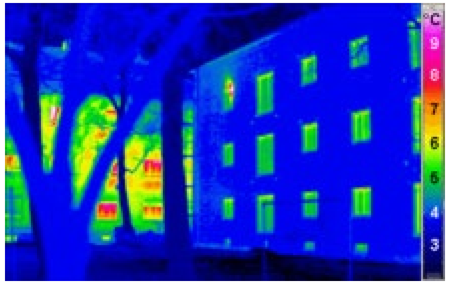
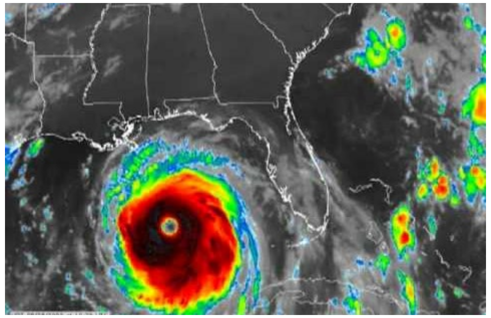
Ref: Wikipedia

Visible and Infrared

- Visible: Most familiar

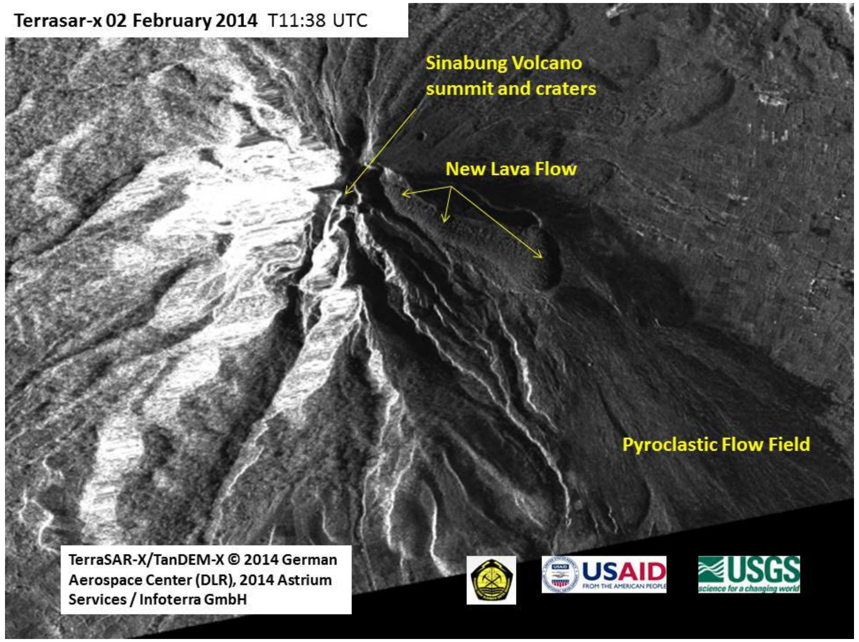
- Infrared: Most familiar application is thermograms

Ref: Wikipedia

Microwave Band Imaging

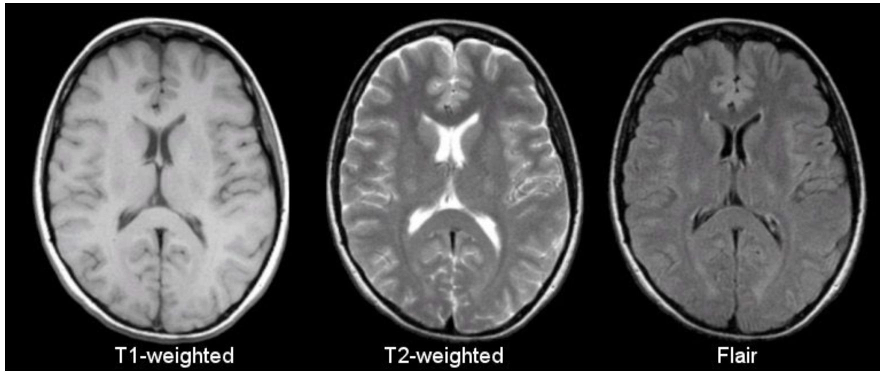
- Radar

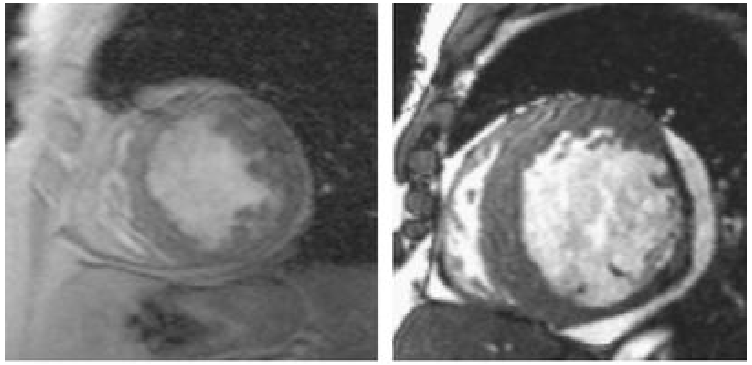


Ref: USGS

Radio Band Imaging

- MRI

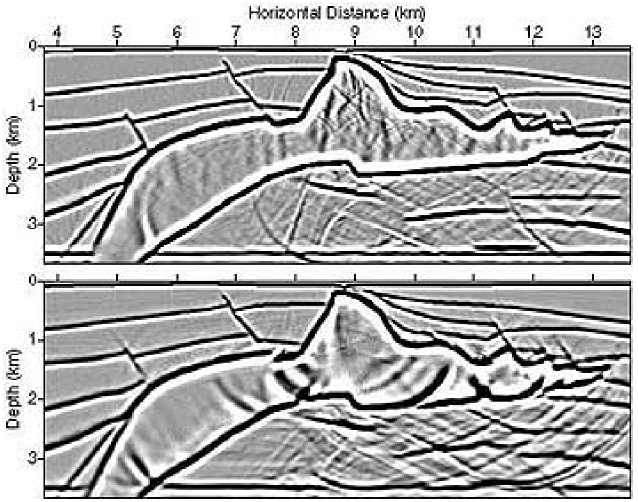




Ref: Case Western; Prince & Links

Acoustic Imaging

- Does not use light! Uses sound
- It has its own spectra
- Ultrasound > MHz, geological ~ 100’s Hz

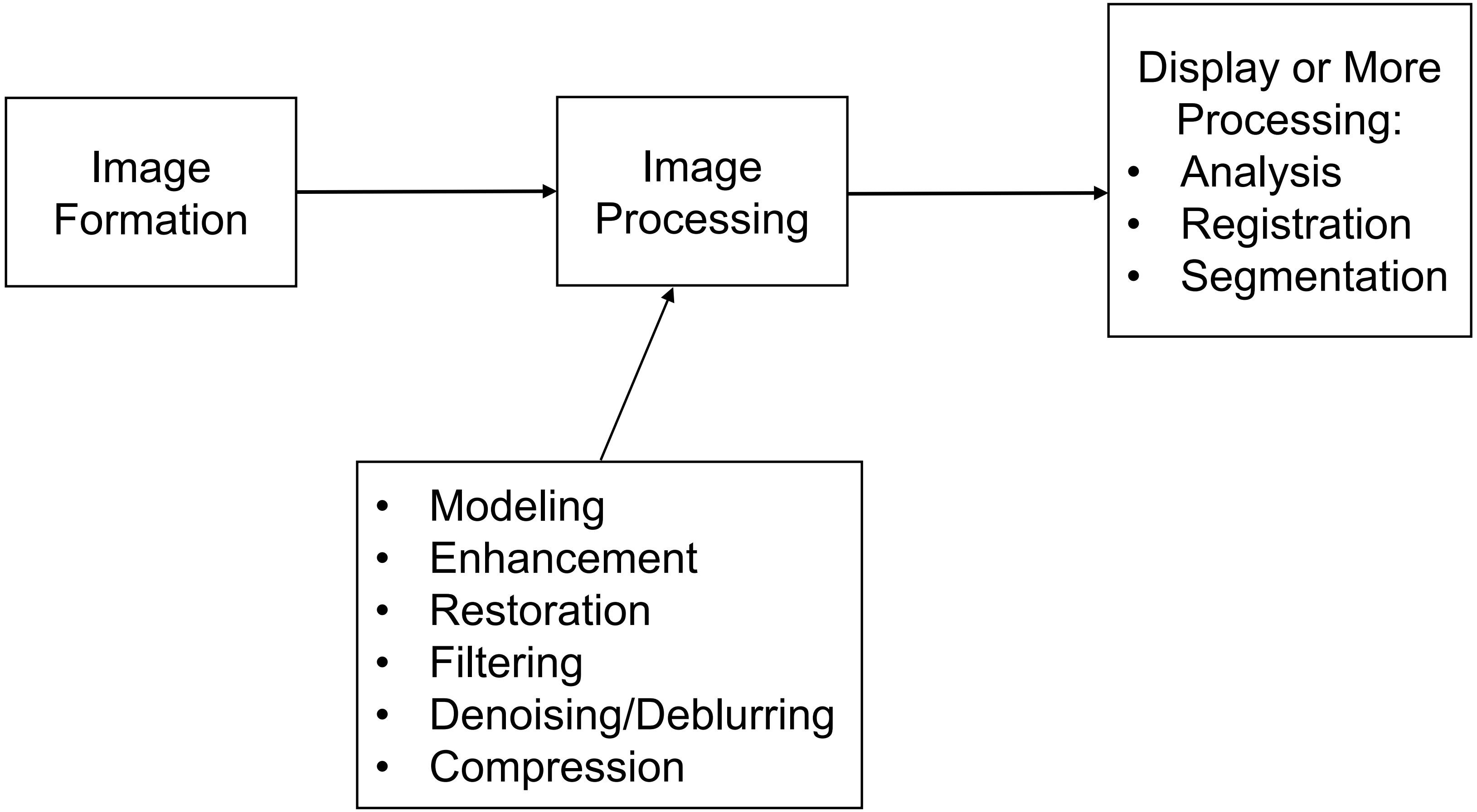


Ref: Prince & Links, Pearson, 2015

Ref: Los Alamos NL

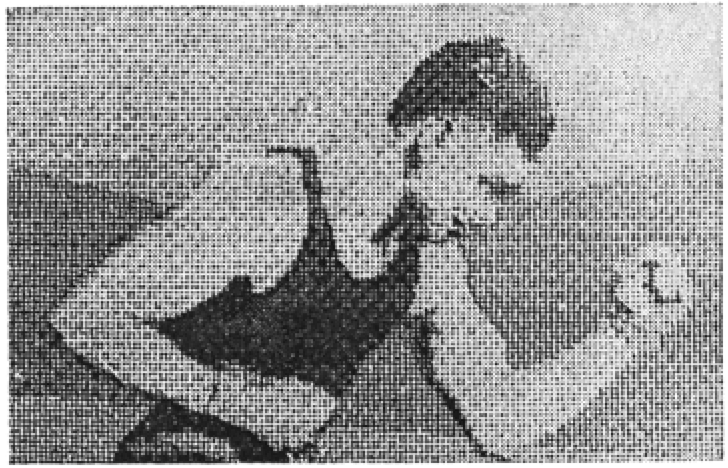
What is Image Processing?

- 2D signal processing methods on images



Origins

- 1921: Photographic reproduction made from tapes perforated at the telegraph receiving terminal
  - Bartlane cable picture transmission system
  - i.e. First digital images (5 grayscale levels)
  - Between London & NYC
  - 15 grayscale levels by 1929



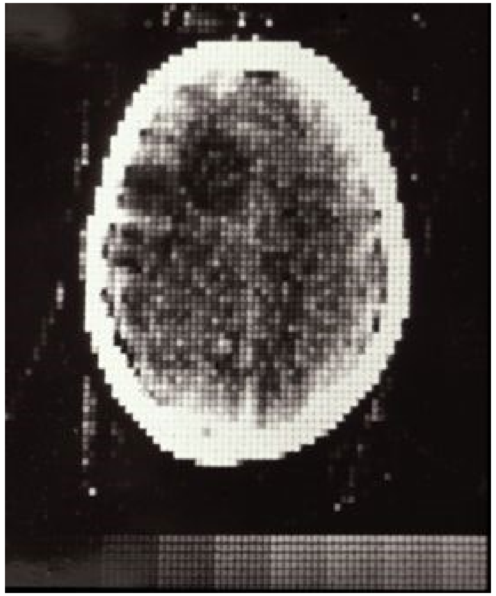
Origins

- Astronomy and Medicine came along in 1960s
- Computer techniques devised to improve images from a space probe @ JPL in Pasadena (1964)

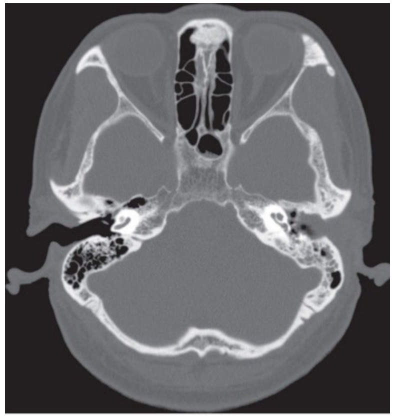
First picture of moon taken from a U.S. spacecraft, Ranger 7

Origins

- Astronomy and Medicine came along in 1960s
- CT imaging in medicine (1971)



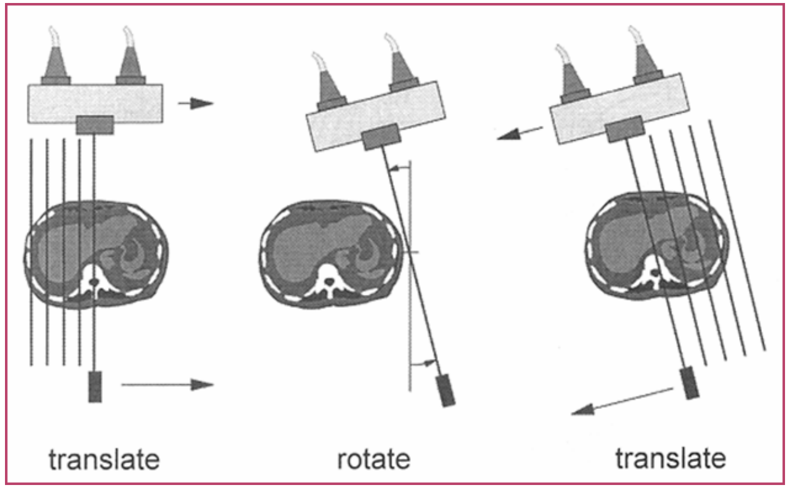
First CT image (Sir Godfrey N. Hounsfield)



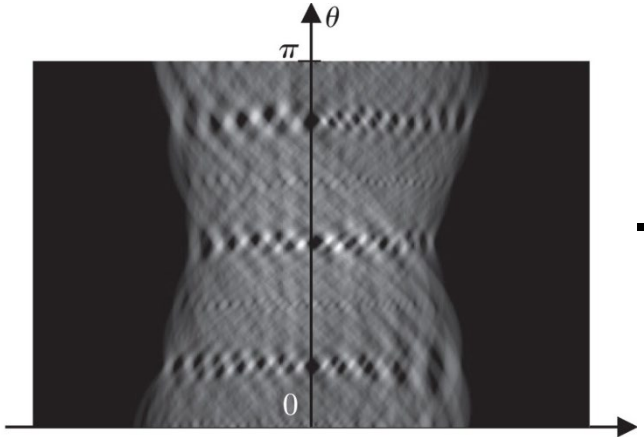
- Nobel Prize in 1979!

Origins

- Astronomy and Medicine came along in 1960s
- CT took projections across a slice



- Raw data is called a sinogram



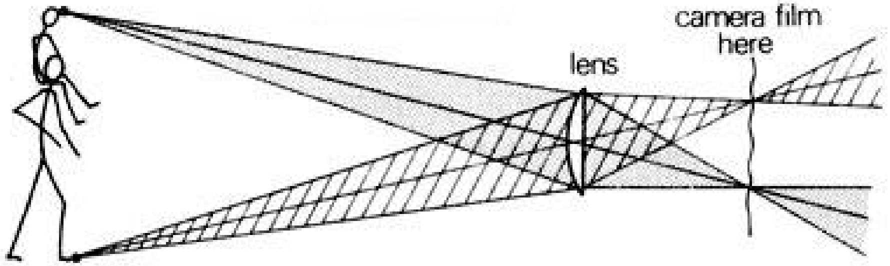
Applications of Image Procssing

- Medicine (radiology, microscopy)
- Defense (radar, satellites)
- Entertainment industry
- Robotics / machine vision
- Compression
- Industry, manufacturing (inspection)

- We will focus on the fundamental methods, more than the applications

Image Formation

- Camera idea



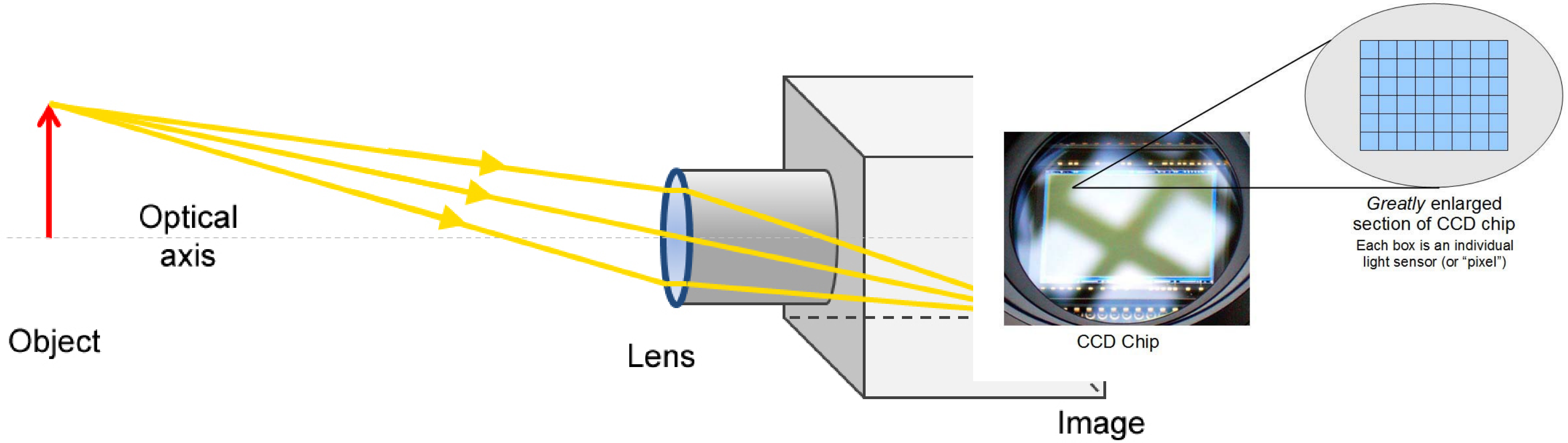
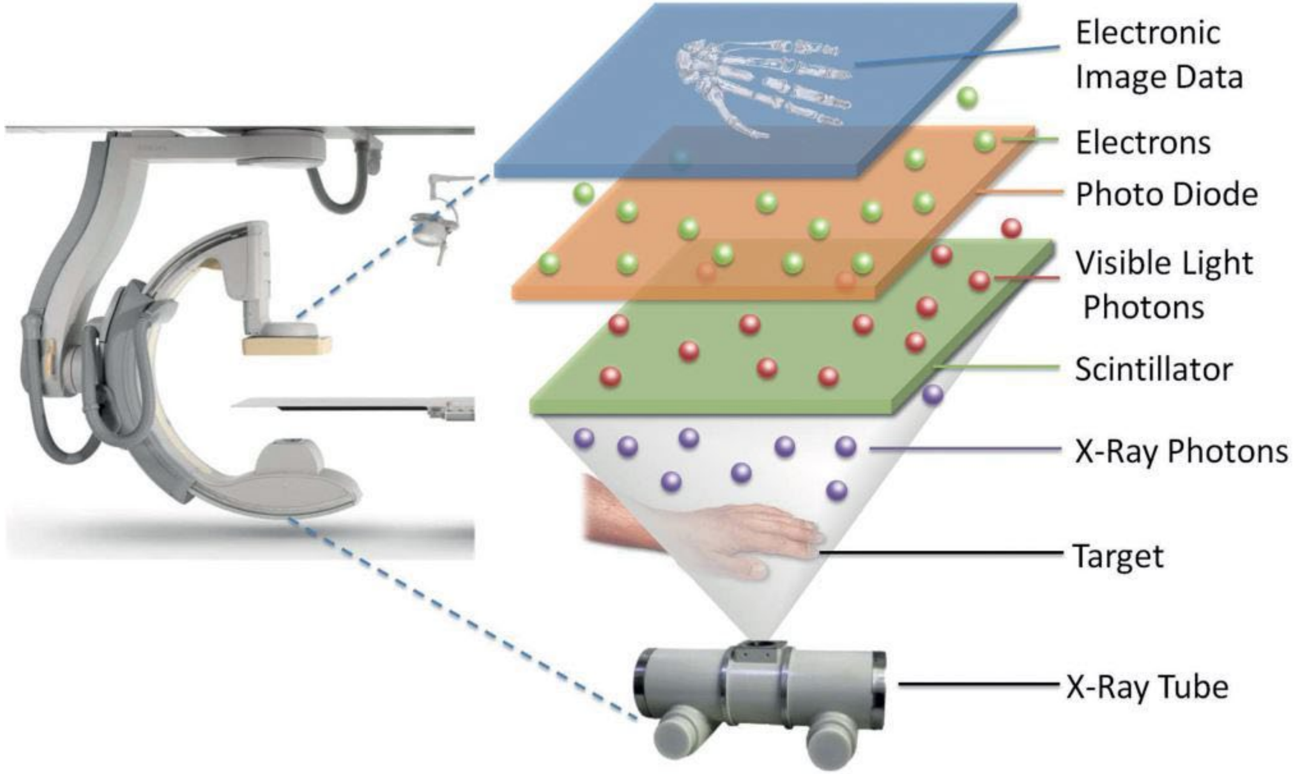


Image Formation

- X-ray detection



Ref: tue.nl

Image Processing

- 2D signal processing methods on images
- How do we represent images as signals?

$$f : \mathbb{R}^2 \to \mathbb{R}$$

- Image is a function
- More likely, the image will have finite support

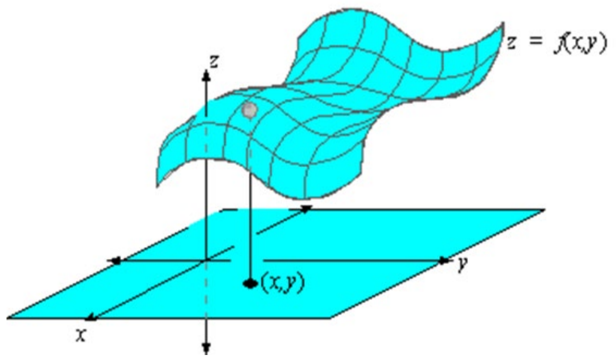
$$f : [a, b] \times [c, d] \to \mathbb{R}$$

- A color image will be (more on this later)

$$f(x, y) = \begin{bmatrix} r(x, y) \\ g(x, y) \\ b(x, y) \end{bmatrix}$$

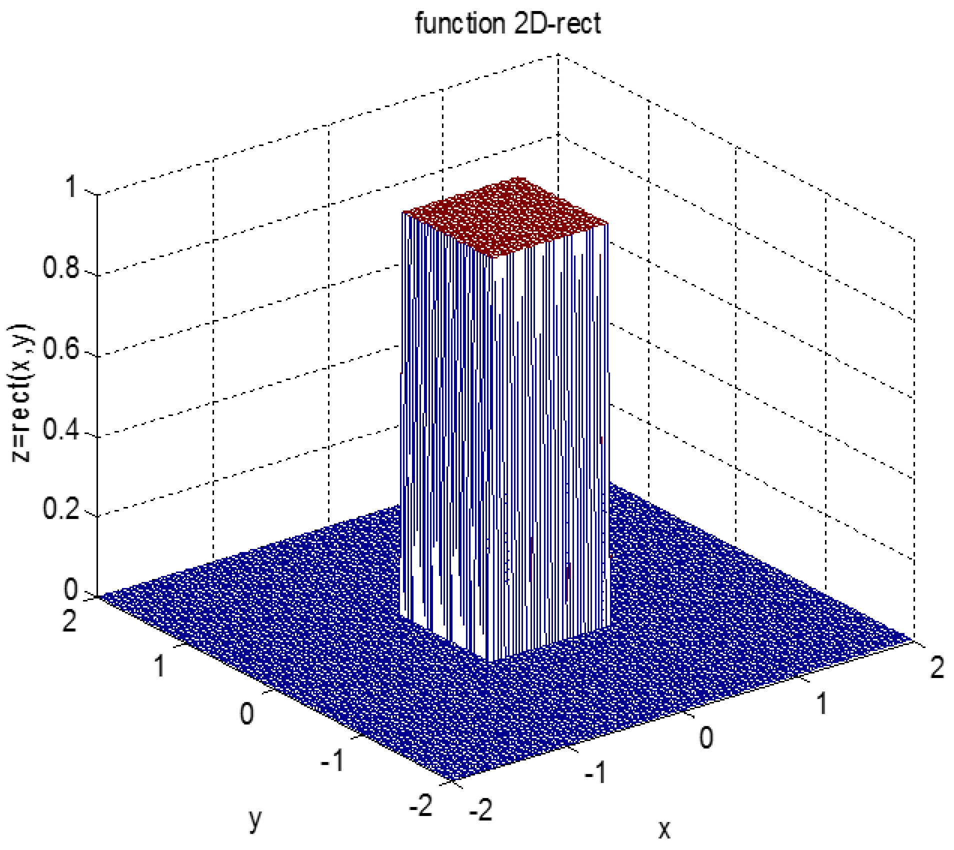
Image Processing

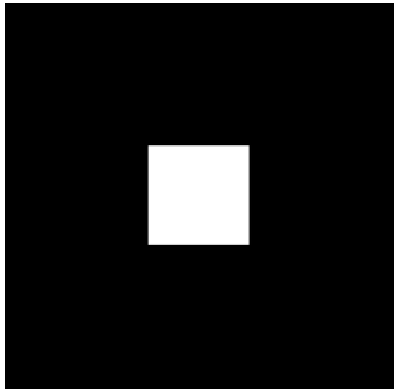
- How to view them?
- $z = f(x, y)$ is a surface → This is similar to what you saw in calculus



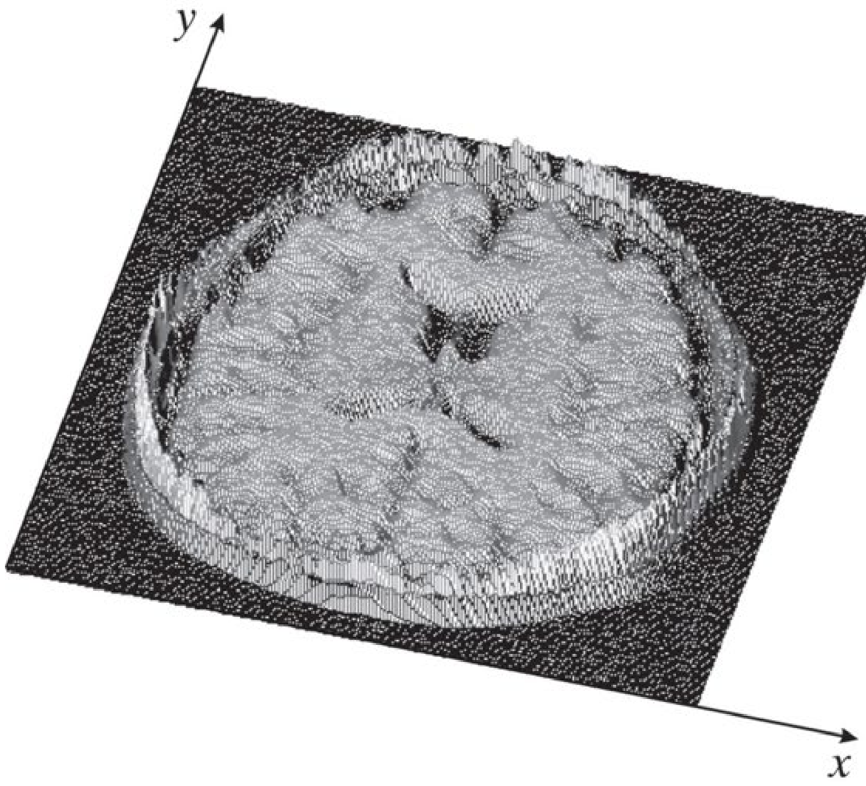
- Or signal can be displayed by assigning an intensity or brightness proportional to its value at (x, y) → how we mostly view images

Images as Functions

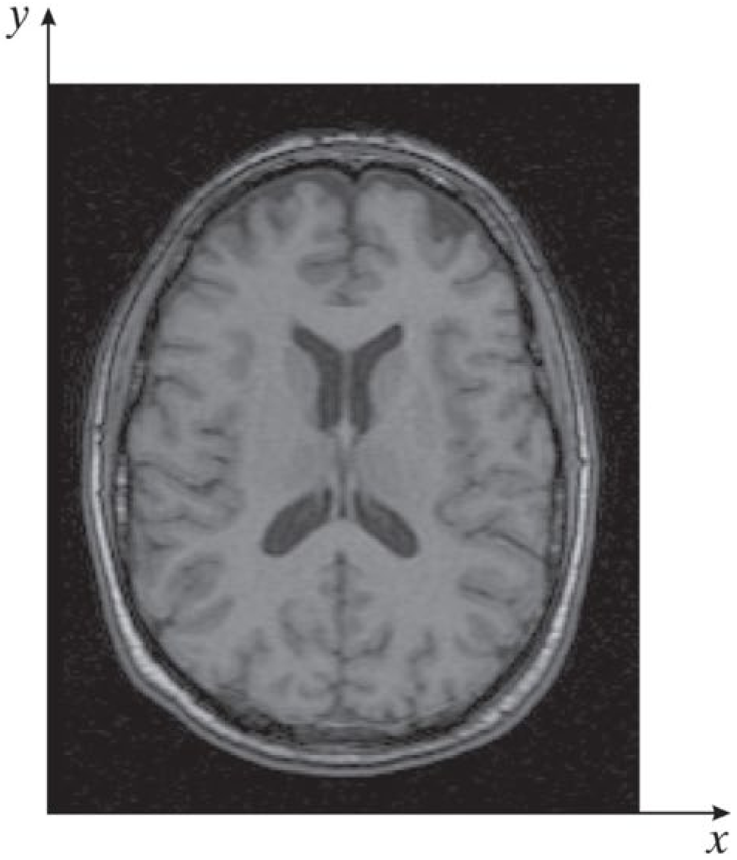




Images as Functions



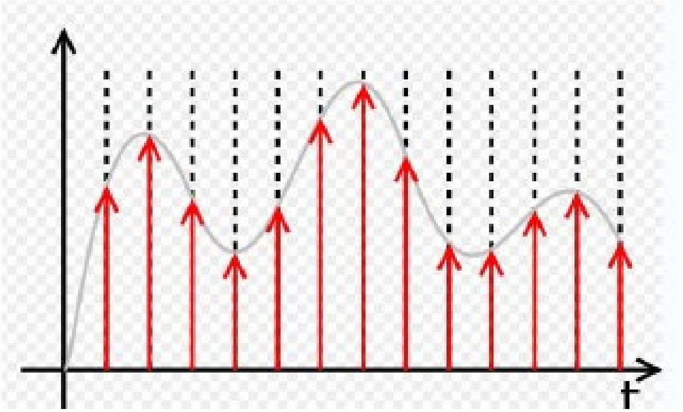
(a)



(b)

Image Representation

- Images are usually digital
  - Discrete: Sampled on the 2D space (usually on a rectangular grid)
  - Quantized to integer values with some precision (not always)



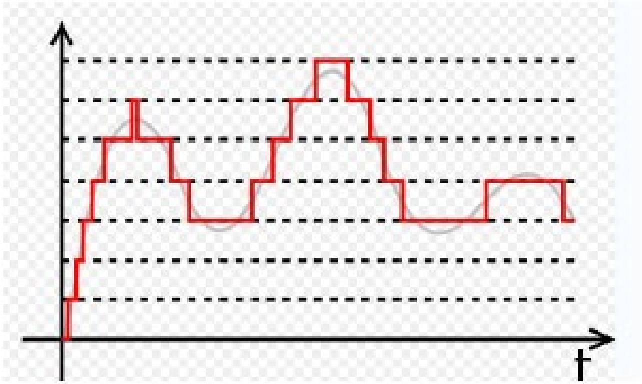


Image Representation

- Images are usually digital
  - Discrete: Sampled on the 2D space (usually on a rectangular grid)
  - Quantized to integer values with some precision (not always)
- Image can now be represented as a matrix of integers

pixel

j

i

62	79	23	119	$\boxed{120}$	05	4	0
10	10	9	62	12	78	34	0
10	58	197	46	46	0	0	48
176	135	5	188	191	68	0	49
2	1	1	29	26	37	0	77
0	89	144	147	187	102	62	208
255	252	0	166	123	62	0	31
166	63	127	17	1	0	99	30

Image Transforms

- Basic: Resolution, scale

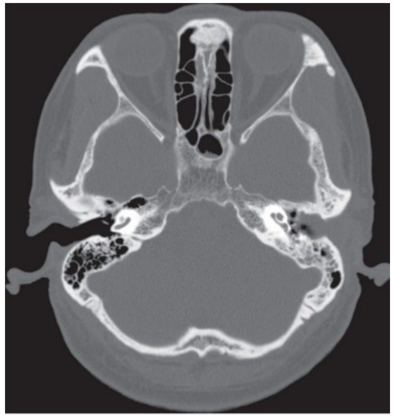


Image Enhancement

- Accentuate certain features for subsequent analysis/display
  - Contrast stretching
  - Sharpening
  - Noise reduction

- How?
  - e.g. Filtering, Fourier space

Image Enhancement

- Accentuate certain features for subsequent analysis/display
  - Contrast stretching

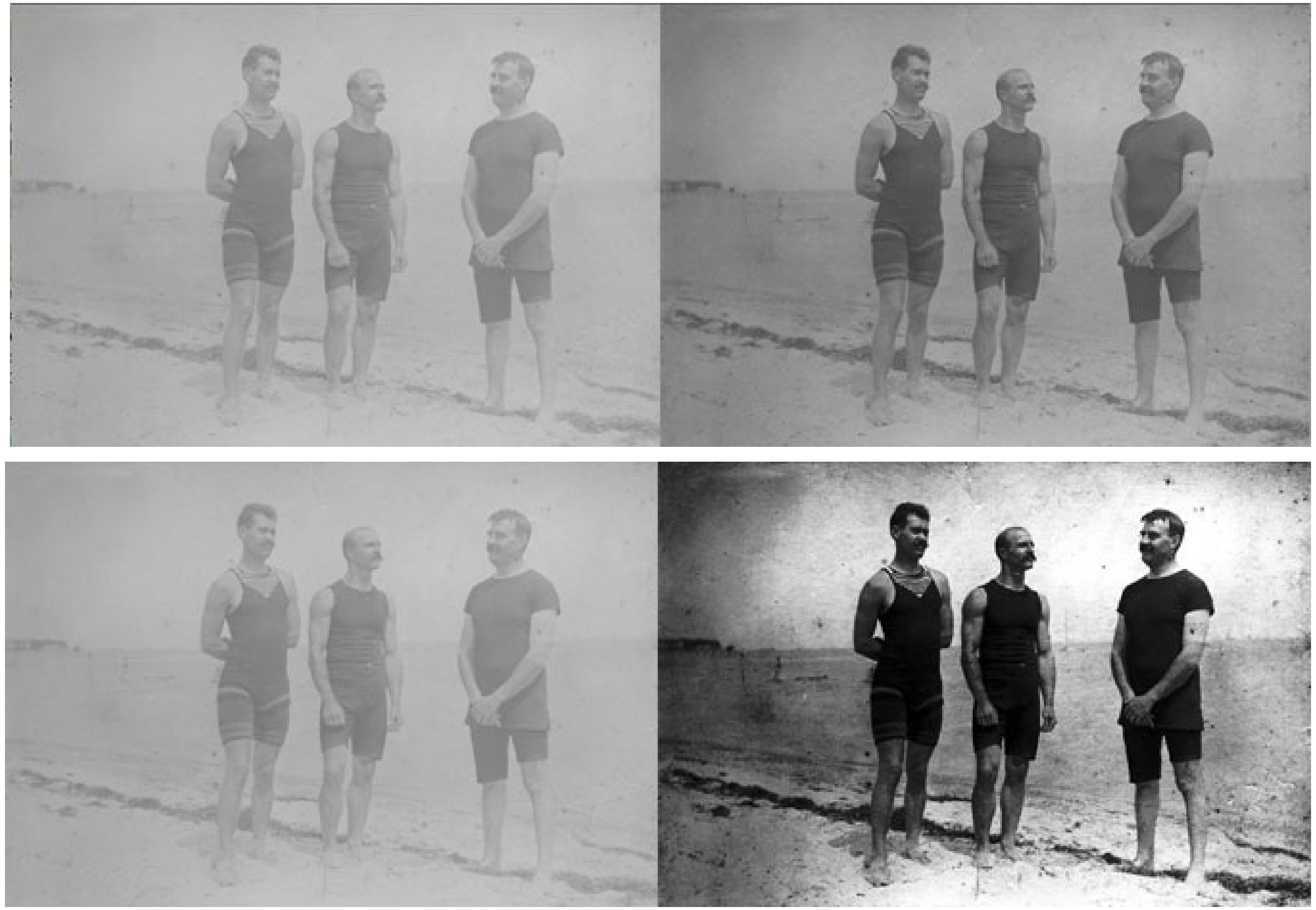


Image Enhancement

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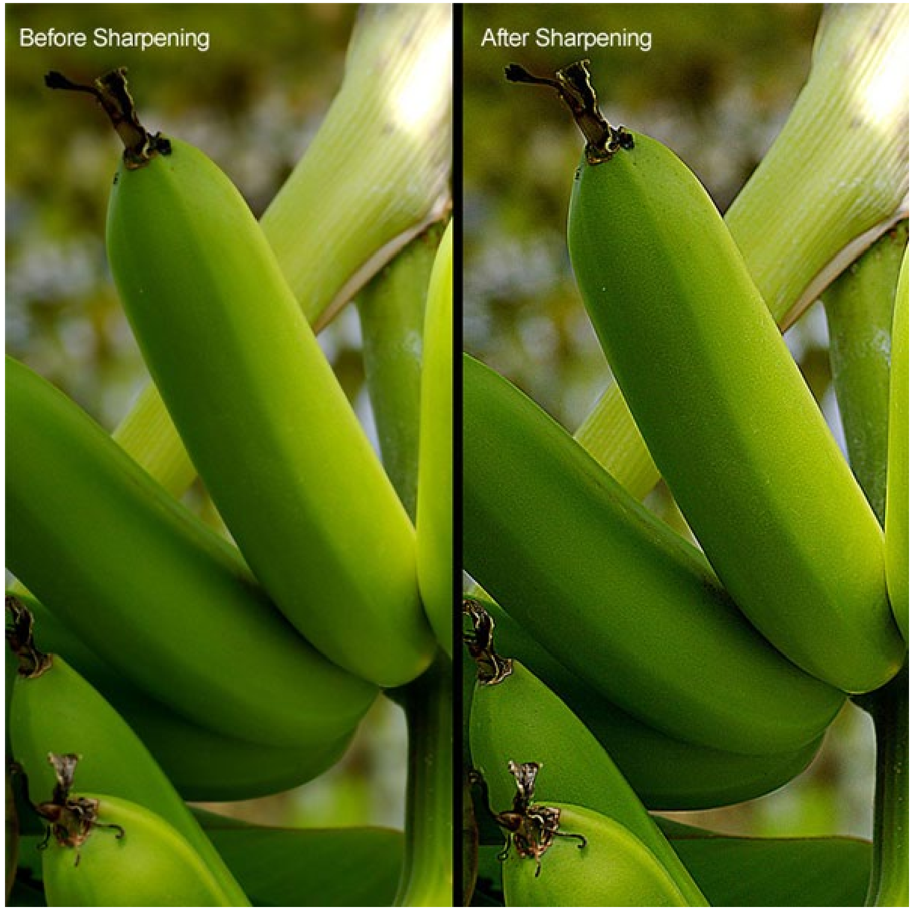


Image Restoration/Filtering

- e.g. Remove image blurring
- Some prior knowledge about the degradation
- Objective goal (not just “fixing” to make it look better) → try to get the true underlying image
  - Invert known degradation operation

Original

Known Blur

Restored

Image Compression

- Efficiently store and transmit images
- Redundancies exist in images
- Information theory concepts
- Transformation to “sparsify” data

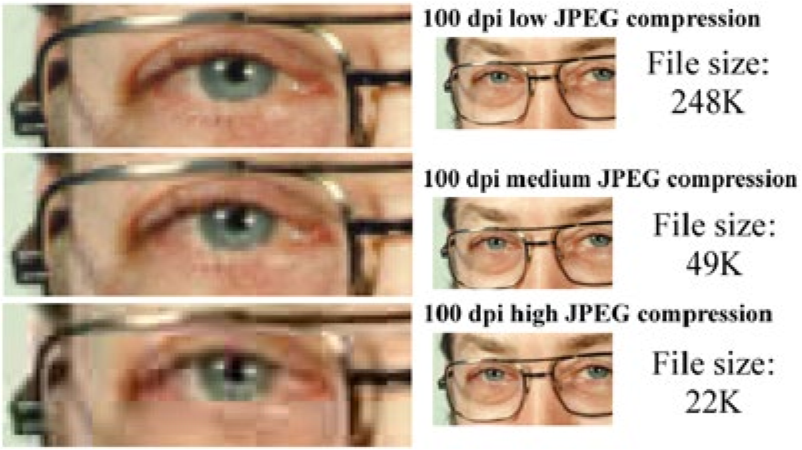
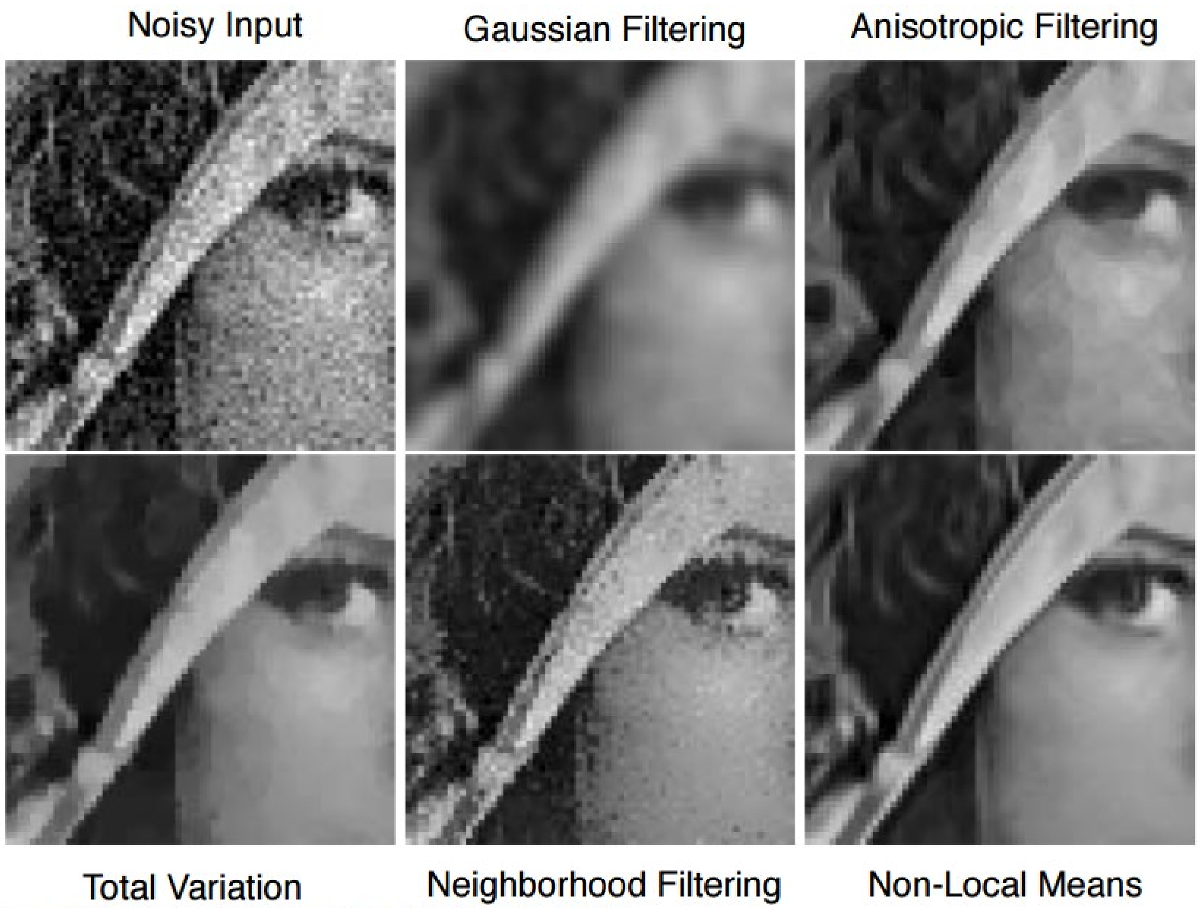


Image Restoration/Filtering

- Knowing these image redundancies will also help improve our image restoration techniques → non-linear methods



Paper/Source: Buades, Coll, Morel. "A non-local algorithm for image denoising" CVPR 2005.

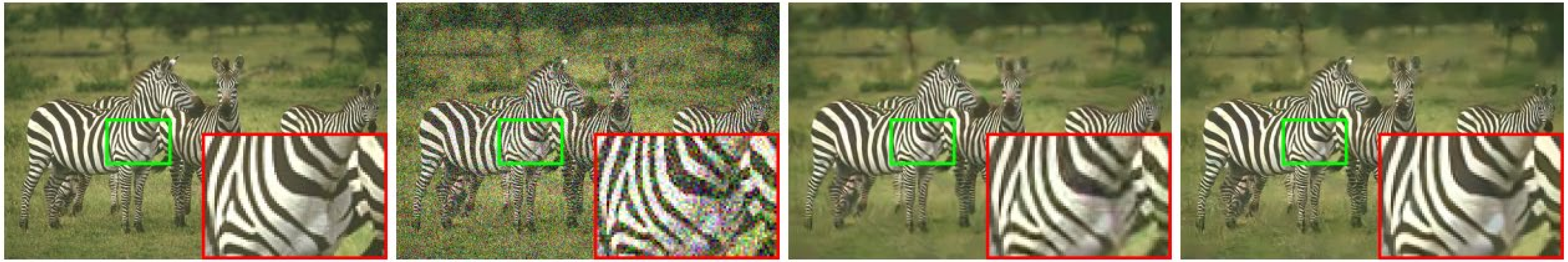
Image Restoration/Filtering

- Once modeling comes in, we can do cool things
  - Inpainting

  - Or you “hire” people to do that pixel-by-pixel

Image Denoising

- Reduce noise in images
- Simplest: Linear filtering
- For a long time: Nonlinear methods using statistical models
- Now: Deep learning for state-of-the-art

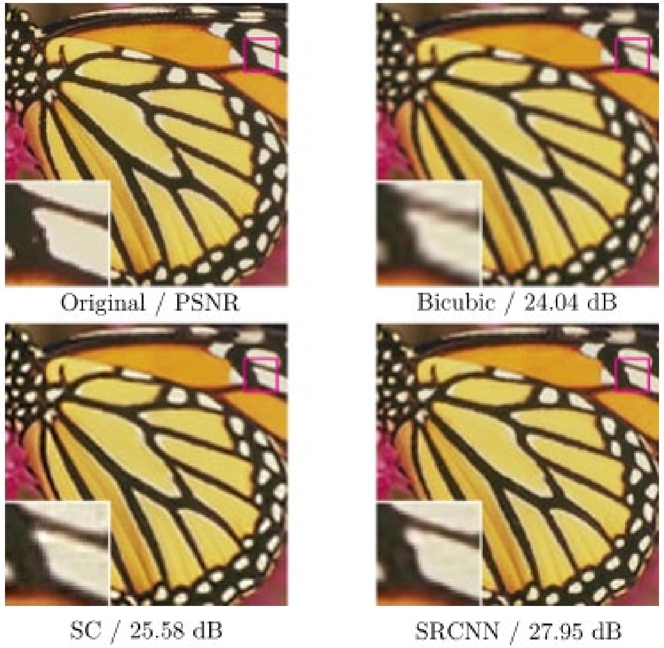


(a) Ground-truth (b) Noisy / 15.07dB (c) CBM3D / 26.97dB (d) CDnCNN-B / 27.87dB

https://arxiv.org/pdf/1608.03981.pdf

ImageSuper-Resolution

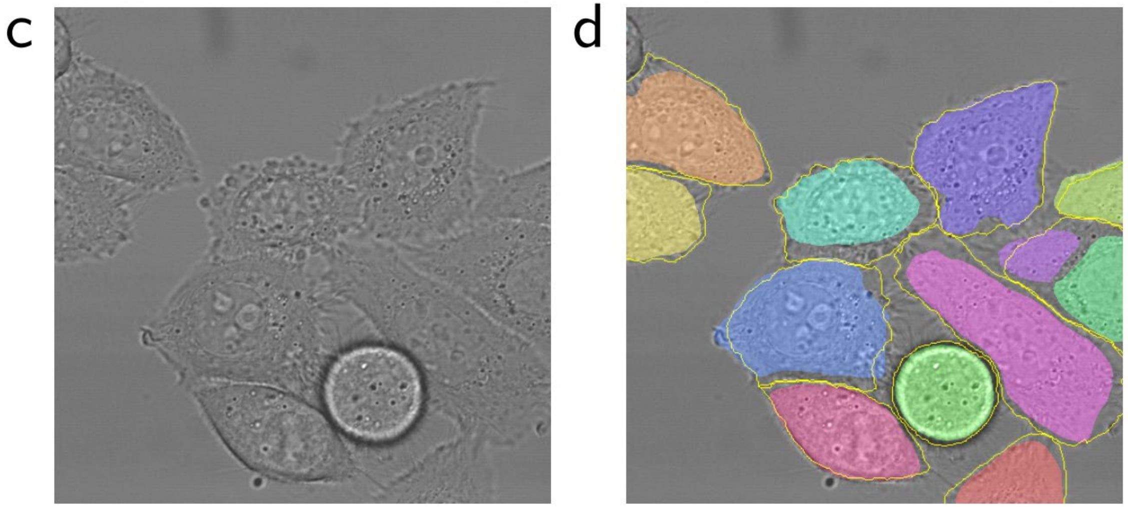
- Improve resolution of images
- Simplest: Linear interpolation
- For a long time: Using statistical methods
- Now: Also deep learning for state-of-the-art



https://arxiv.org/pdf/1501.00092.pdf

Image Segmentation

- Partition an image into multiple segments/labels/“super-pixels”
- Typically used to locate objects or boundaries
- Prime application for machine learning



e.g. in medical applications
https://arxiv.org/pdf/1505.04597.pdf

Image Segmentation

- Partition an image into multiple segments/labels/“super-pixels”
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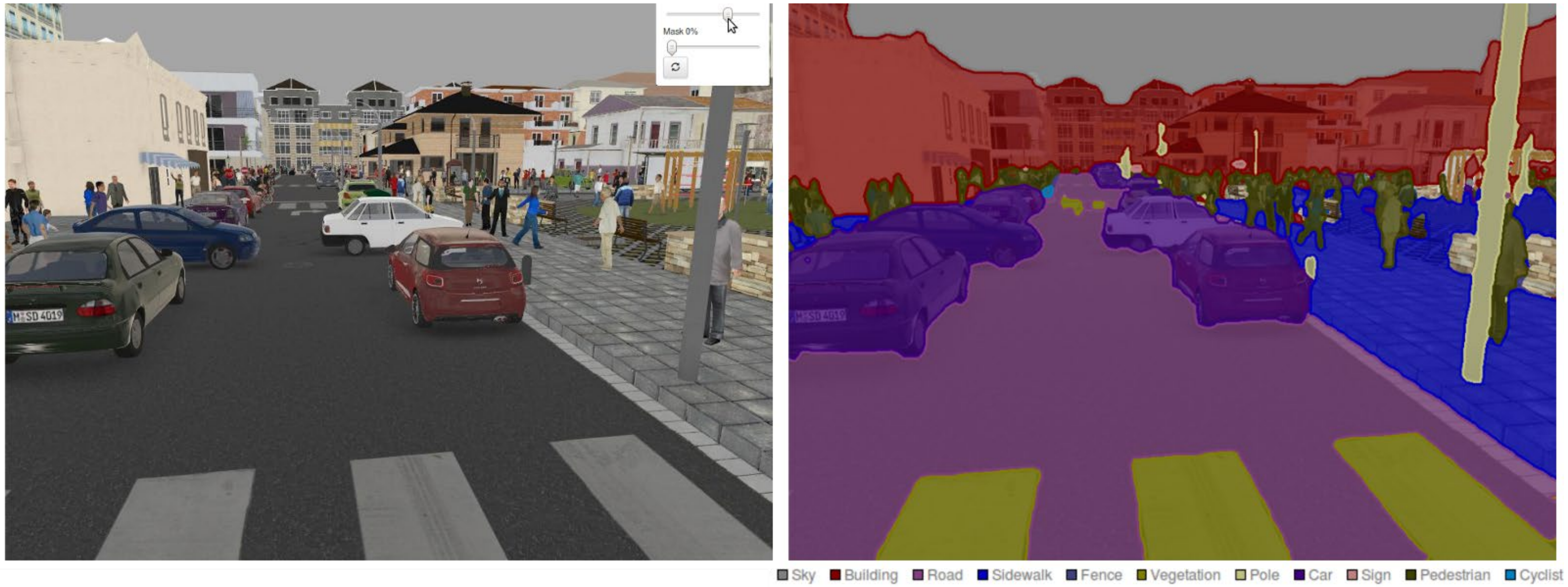
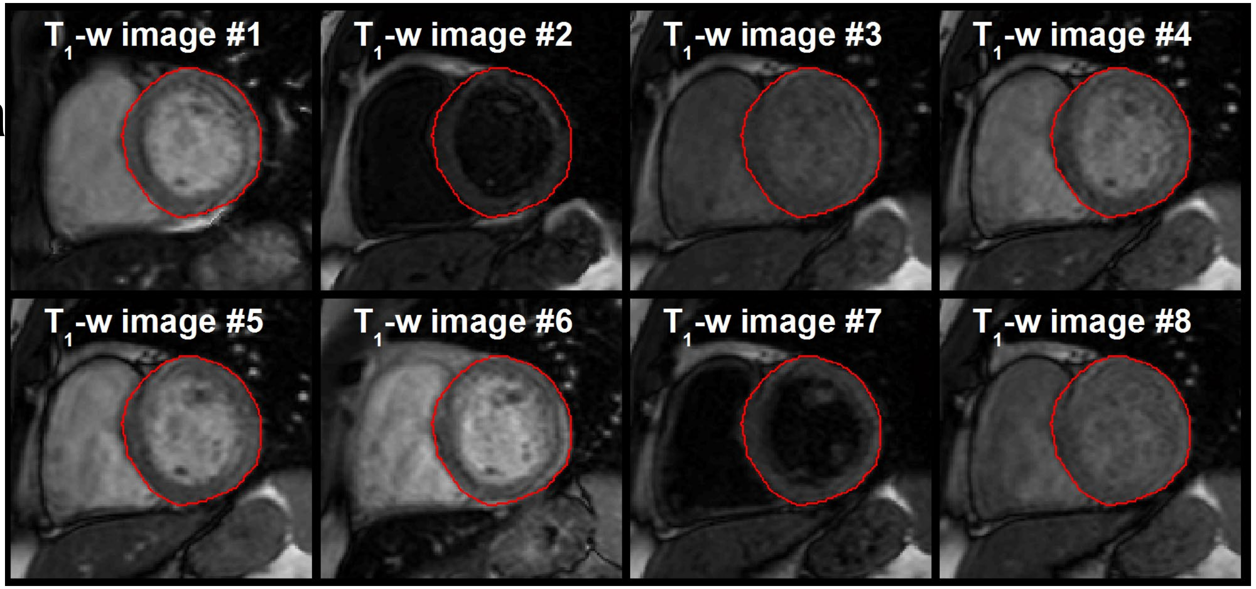


e.g. in semantic segmentation (~segmentation + classification)
https://arxiv.org/pdf/1703.06870.pdf

Image Registration

- Find the spatial transform that maps points in one image to points in a second image
- Why?
  - Motion between objects
  - Multi-view or multi-contrast datasets (very common in medical imaging)
- Both classical a



Next Class

- Start with 2D Signals & Systems
- Your undergraduate Signals & Systems in 2D
- Note:
  - I will move quickly through this material
  - Need more time for the later “cooler” topics
  - If you are a non-EE major, this may seem a bit daunting
  - Let me or Merve know if you have issues following
  - Concepts like Fourier transforms and convolutions will be important throughout the term