EECS C145B / BioE C165: Image Processing and Reconstruction Tomography

Lecture 1

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Topics to be covered

1. What is an image?
2. Digital images
3. Color images
4. Luminance and contrast
5. Examples of image formation and contrast mechanisms
6. What will be covered in this course?
7. Student background and interests questionnaire

What is an image?

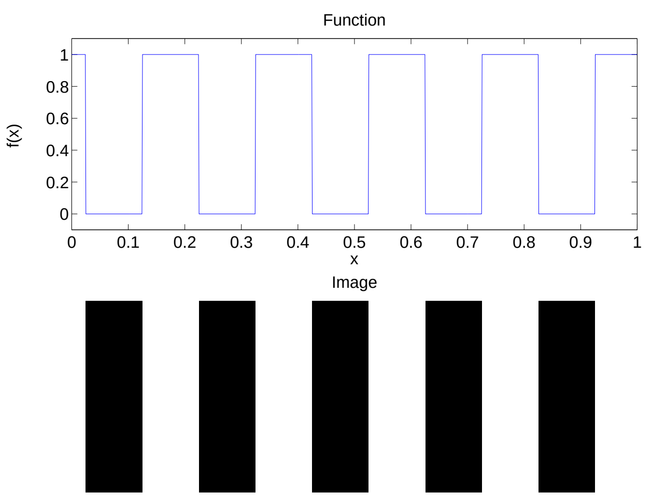


Figure 1: Example of a 1D image

What is an image?

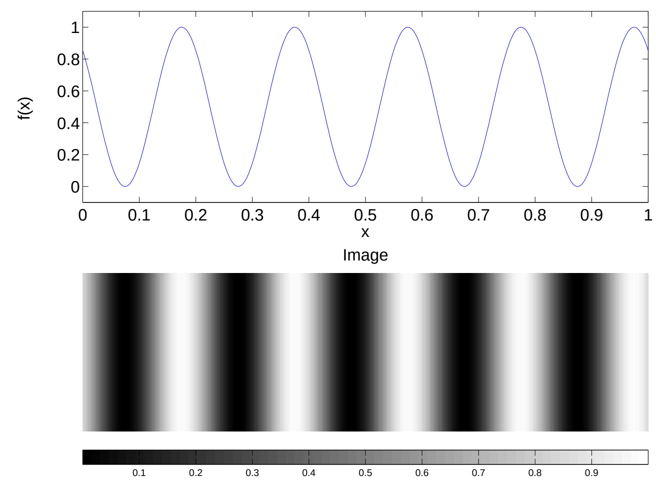


Figure 2: Example of a 1D image

What is an image?

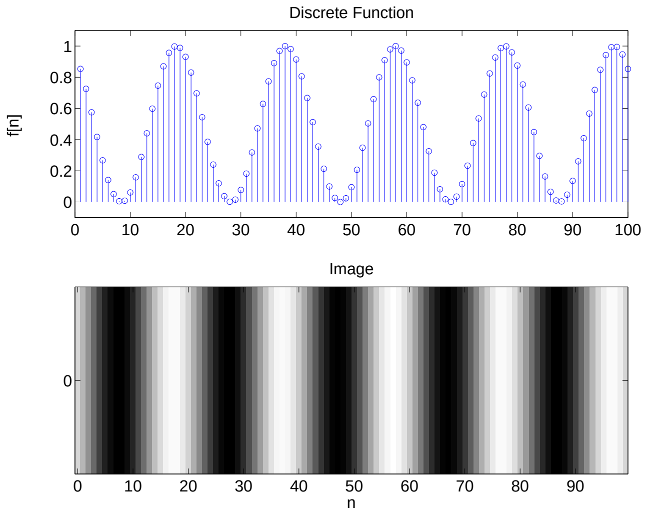


Figure 3: Example of a 1D image of a discrete 1D function

What is an image?

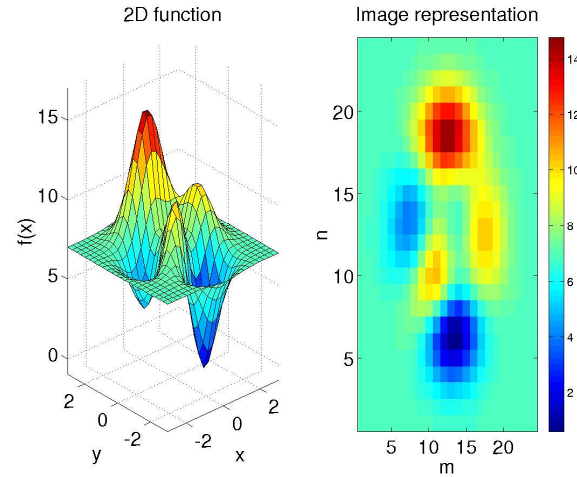


Figure 4: Example of a 2D image

What is an image?

- An image is a representation of a function. The intensity at a point in the image represents the value of the function at that point.
- A digital image is comprised of discrete picture elements or pixels. The intensity of a pixel represents the value of some function over a certain region of space. Pixels are most commonly rectangles. In 3D, images are composed of voxels, or "volume elements". These are usually rectangular prisms.

2D digital image ≡ 2D map of function sample values

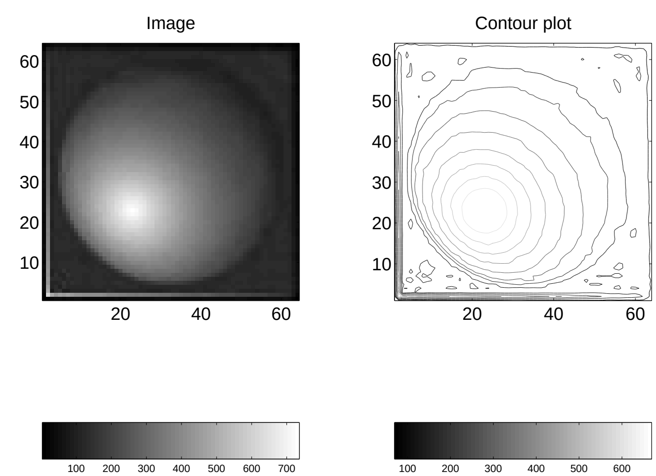
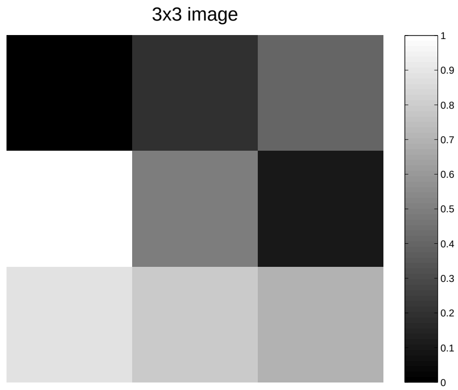


Figure 5: A 2D image is a representation of a 2D function. In this example, intensity (luminance) is directly proportional to amplitude.

Digital images

3×3 matrix

$$\begin{bmatrix} 0 & 0.2 & 0.4 \\ 1 & 0.5 & 0.1 \\ 0.9 & 0.8 & 0.7 \end{bmatrix}$$



Digital images are conveniently represented using arrays of numbers. In 2D, a monochromatic digital image can be defined by a matrix of intensity (luminance) values.

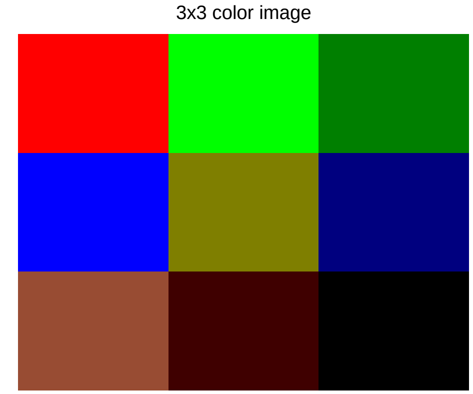
Digital color images

3×3 matrices

$$R = \begin{bmatrix} 1.00 & 0.00 & 0.00 \\ 0.00 & 0.50 & 0.00 \\ 0.60 & 0.25 & 0.00 \end{bmatrix}$$

$$G = \begin{bmatrix} 0.00 & 1.00 & 0.50 \\ 0.00 & 0.50 & 0.00 \\ 0.30 & 0.00 & 0.00 \end{bmatrix}$$

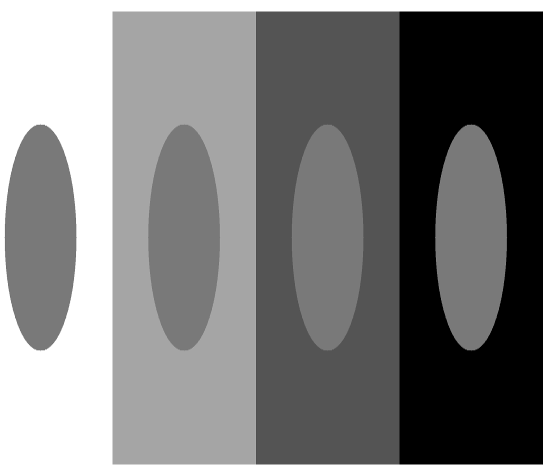
$$B = \begin{bmatrix} 0.00 & 0.00 & 0.00 \\ 1.00 & 0.00 & 0.50 \\ 0.20 & 0.00 & 0.00 \end{bmatrix}$$



In 2D, a color digital image can be defined by 3 matrices. Many different representations exist. RGB is the most popular. Each matrix gives the luminance for one of the color components.

The importance of contrast

Simultaneous contrast: Which elliptical patch has the highest luminance?



Simultaneous contrast: Luminance profile

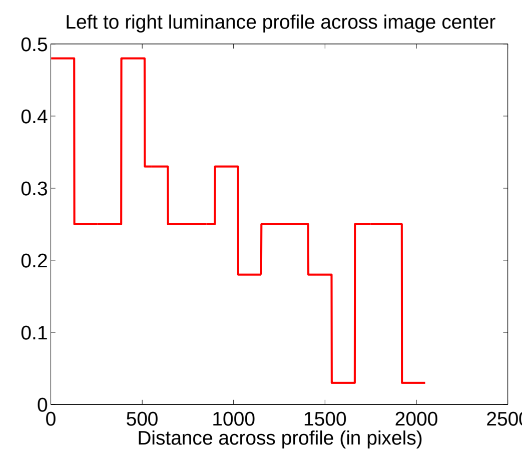


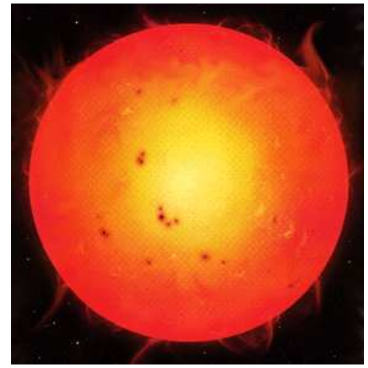
Figure 6: All the ellipses have the same luminance. The human eye cannot quantify absolute luminance. Relative luminance or **contrast** is more important.

Methods for creating and manipulating contrast

- Images allow us to observe scenes and processes using our eyes.
- Our eyes and brain measure contrast, not luminance.
- To perform imaging we need:
  1. a contrast mechanism
  2. instrumentation and procedures to obtain and capture contrast
  3. methods to enhance the contrast of certain image features
  4. methods of restoring contaminated and blurred images with poor contrast

Image formation example I: Photography

Sources of illumination:



Sun photo courtesy NASA. Flash photo courtesy Nikon, Inc

Image formation example I: Photography

Scene:

Image formation example I: Photography

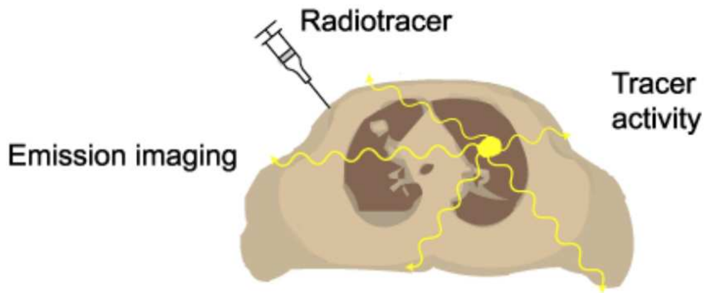
Imaging instrumentation:

Image of scene is focussed onto film by lens.
Contrast is based on the **differential absorbtion and reflection of light** of the illuminated surfaces.

Camera photo courtesy Nikon, Inc. Film photo courtesy Eastman Kodak Co., Inc

Image formation example II: Nuclear emission imaging

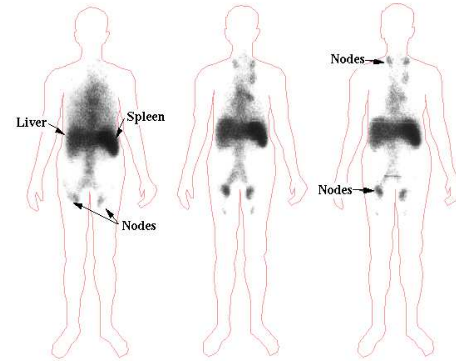
Illumination:



Injected radiotracer emits gamma photons. These photons can be detected as after they emerge from the body. Using tomographic reconstruction, the distribution of radiotracer in the body can be mapped. Contrast is based on radiotracer concentration differences.

Image formation example II: Nuclear emission imaging

Contrast mechanism example: Hodgkin's Disease



Injected radiolabeled lymphocytes concentrate in cancerous lymph nodes as well as the liver and spleen. Lymphocyte radioactivity is shown 2, 18 and 36 hours after injection. Contrast is based on the number of lymphocytes per unit volume. Thakur et al., Thomas Jefferson University and LBNL

Image formation example III: Nuclear emission imaging: Gene expression

"Scene":

The scene is the tracer distribution (related to presence of an enzyme coded for by DNA) inside a mouse.

Image formation example III: Nuclear emission imaging: Gene expression

Instrumentation:

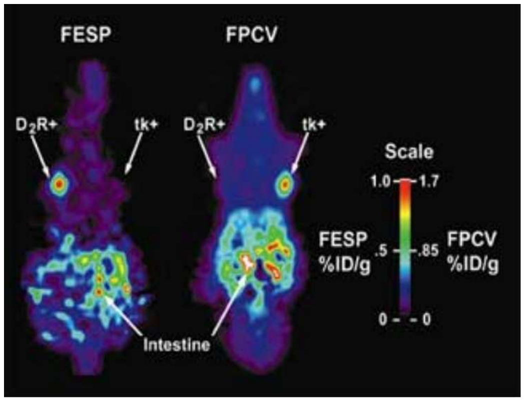
SPECT/PET scanner counts the number of gamma photons and estimates their direction of travel.

This information is used to reconstruct a tomographic image.

Photo courtesy Concorde Microsystems, Inc.

Image formation example III: Nuclear emission imaging: Gene expression

Image:



Activity concentrates in tumors that express certain genes. Here, gene expression provides the contrast. Gambhir et al. (UCLA)

Course Outline

Part I: Basic image processing

1. Introduction to digital images
2. Review of convolution, sampling and the 1D Fourier transform (FT)
3. 2D convolution
4. Expression of convolution as a matrix operation
5. The discrete Fourier transform
6. The FT of images
7. Filtering images in the space and frequency domains
8. Signal and image processing using Matlab
9. Image enhancement
10. The image histogram

Example 2D DFT

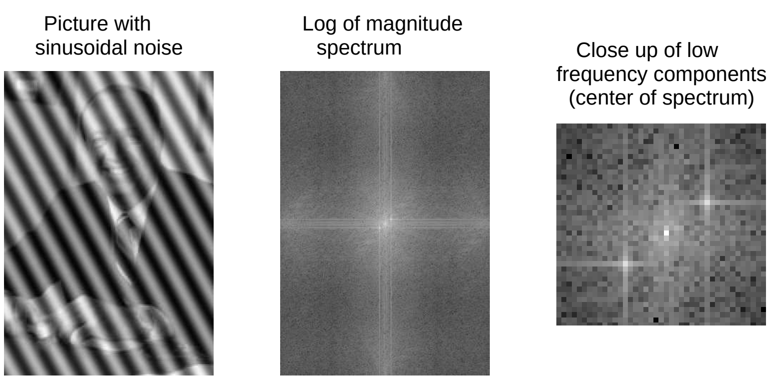


Figure 7: Raised sinusoidal noise (sinusoid plus positive offset) appears disctinctly as three bright points in the spectrum of the image.

Course Outline

Part II: Inverse problems in imaging

1. Inverting non-square matrices (singular value decomposition)
2. Image restoration
3. Reconstructing images from projection measurements
4. The Radon transform and its inversion
5. Practical reconstruction algorithms

Image restoration example: Correcting the Hubble space telescope

Photos courtesy of the Space Telescope Science Institute

Course Outline

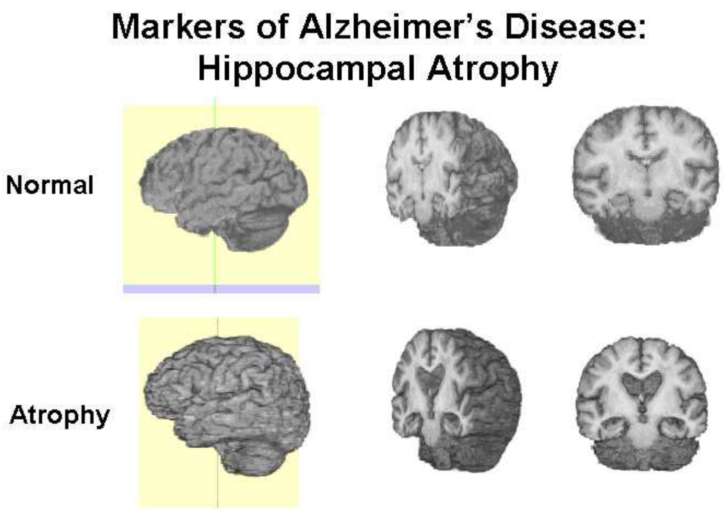
Part III: Tomographic imaging modalities

Physics, contrast mechanisms, instrumentation and applications:

1. Transmission computed tomography (x-ray CT)
2. Emission computed tomography (SPECT and PET)
3. Magnetic resonance imaging (MRI)
4. Ultrasound imaging

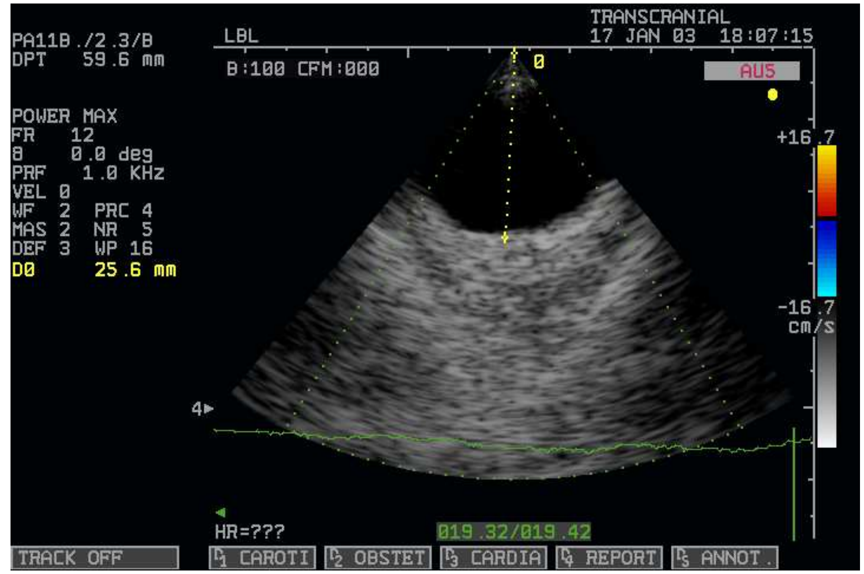
Combined transmission/emission imaging system

Example MRI images

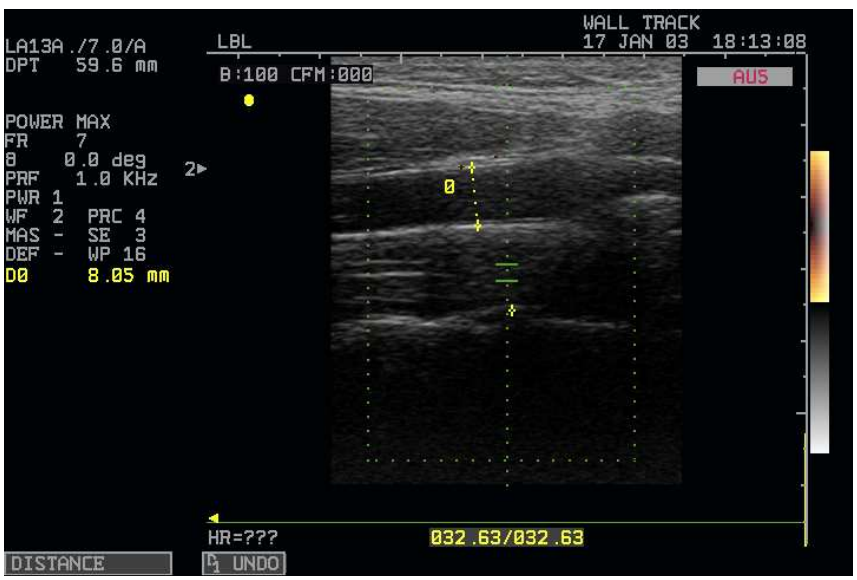


Ultrasound imaging system

Ultrasound of eyeball



Ultrasound of carotid artery

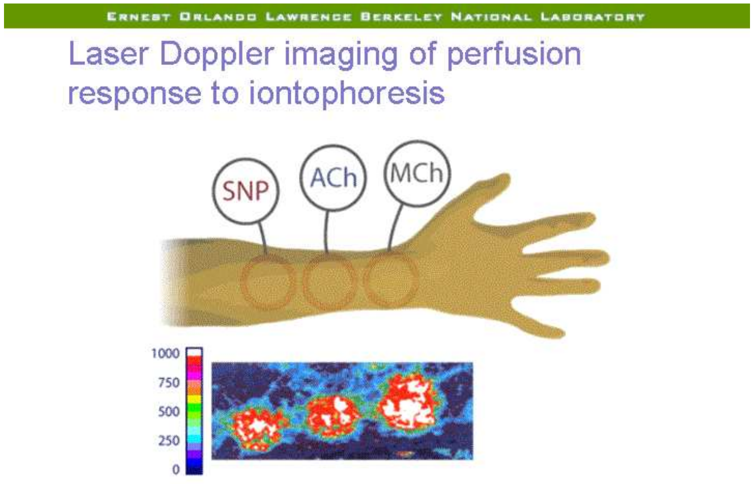


Course Outline

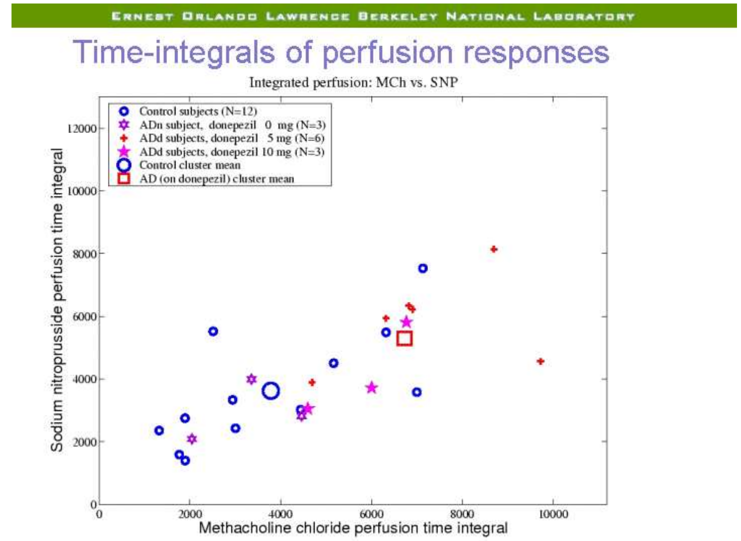
Part IV: Interpreting images

1. Fitting models to image sequences
2. Making decisions from images: Is a feature there or not?
3. Imaging study design
4. Image segmentation and classification

Study example: Imaging skin vascular response in Alzheimer's disease



Processed study data



Study conclusions based on statistical image analysis

ERNEST ORLANDO LAWRENCE BERKELEY NATIONAL LABORATORY

Results

Agent	Action	AD vs Control
Methacholine	Muscarinic endothelium dependent vasodilator (EDV)	AD increased 78% $p < 0.003$
Acetylcholine	Cholinergic EDV	AD increased 68% $p < 0.03$
Sodium nitroprusside	NO donor to smooth muscle	AD increased 46% $p < 0.05$

Suggested reading

Gonzalez & Woods: Skim Chapters 1 & 2