THE UNIVERSITY of TEXAS

HEALTH SCIENCE CENTER AT HOUSTON
SCHOOL of HEALTH INFORMATION SCIENCES

Image Basics & Acquisition

For students of HI 5323
“Image Processing”

Willy Wriggers, Ph.D.
School of Health Information Sciences

http://biomachina.org/courses/processing/01.html

Overview

If in doubt look at web site:
http://biomachina.org/courses/processing

Programming assignments

- C++
- Qt
- Unix or Windows

Math background

•Ideally: At least one quantitative discipline (physics, chemistry, mathematics, computer science) with solid background in geometry (ideally vector calculus) .

•Alternative assignments possible in individual cases.

What are Signals?

- Signal: a function carrying information
- Examples:
  - Audio
  - Radio/Television
  - Images

Types of Signals: Dimensions

- Temporal signal: function of time
  - $f(t)$: voice, music, nerve impulses, radar
- Spatial signal: function of two (or three) spatial dimensions
  - $f(x, y)$: images (grayscale, color, multi-spectral)
  - $f(x, y, z)$: medical scans (CT, MRI, PET)
- Spatio-temporal signal: 2/3-D space, 1-D time
  - $f(x, y, t)$: video/movies

Why Signals?

- Communications:
  - Modems/Networks/Wireless
  - Audio
- Images:
  - Restoration/Cleanup
  - Enhancement
  - Storage/Retrieval/Searching
  - Manipulation

Why Digital?

- Perfect storage, transmission, and reproduction
- Easier to manipulate (than analog):
  - Analog signals manipulated by circuits
  - Digital signals manipulated by computer

Why Now?

- Memory is cheap
- Disk storage is plentiful
- Bandwidth increasing

Digital Image Processing

Subclass of signal processing dealing with pictures.

- Signal → Function conveying information.
  - Audio, Radio/Television, etc.
- Image → Signal with (at least) 2 spatial dimensions.
  - A representation, resemblance, likeness, etc.
- Digital → perfect storage, transmission, reproduction
  - General-purpose manipulation.
  - Low cost memory and disk space
  - Bandwidth increasing

Elements of Digital Image Processing

- Computer → To process images
- Input equipment → Image digitizer
- Output equipment→ Image display device

Kinds of Images & Processes

- Nonoptical → generated form other optical images
- Higher dimensional → in three or more dimensions
- Nonstandard sampling→ domain of image is sampled by a scheme
- Nonstandard quantization → quantizing levels are not equally spaced

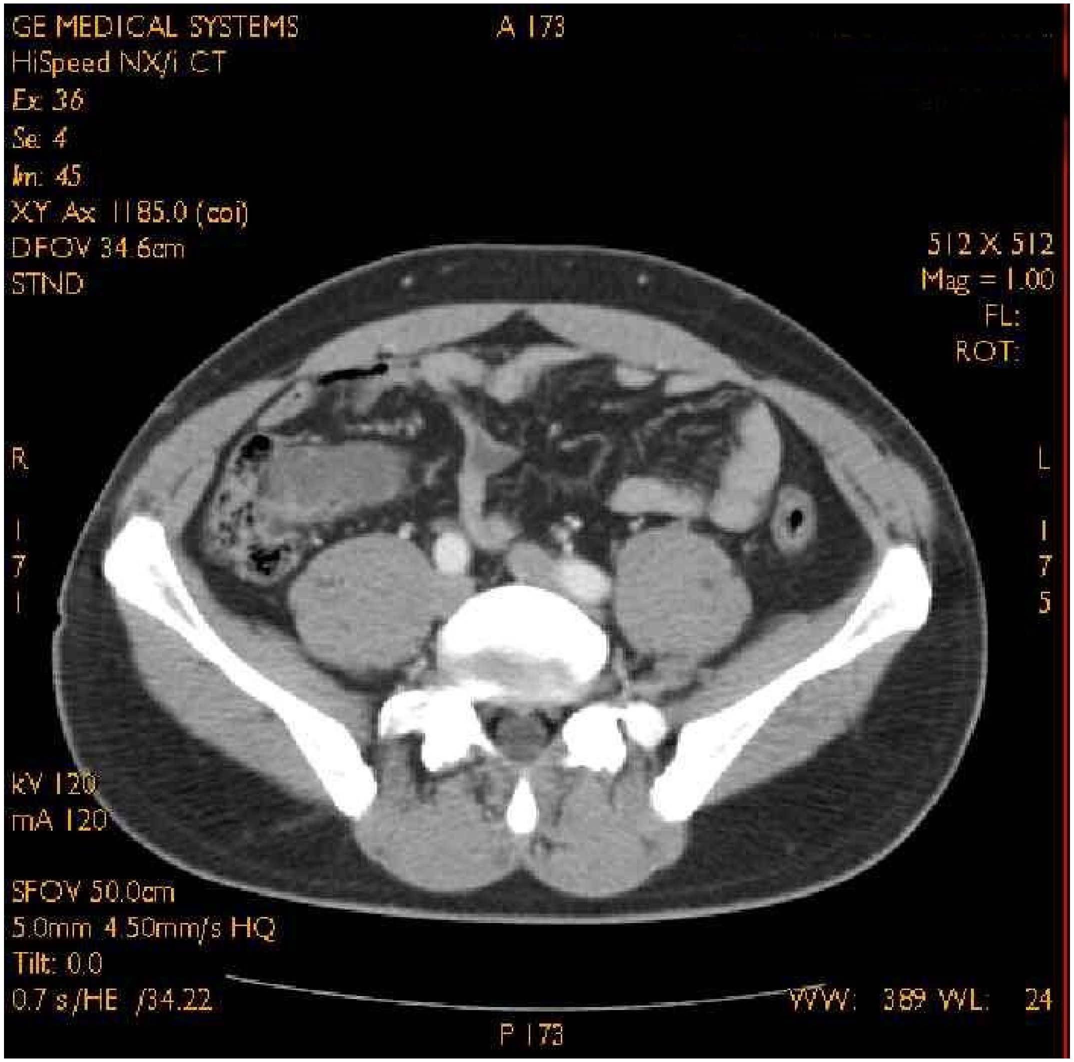
What You Will Learn

- Level (brightness) operations
- Algebraic and logical operations
- Geometric transformations
- Filtering (both spatial and frequency-based)
- Sampling, Restoration, Denoising
- 3D Reconstruction
- Color processing
- Compression
- Pattern Recognition

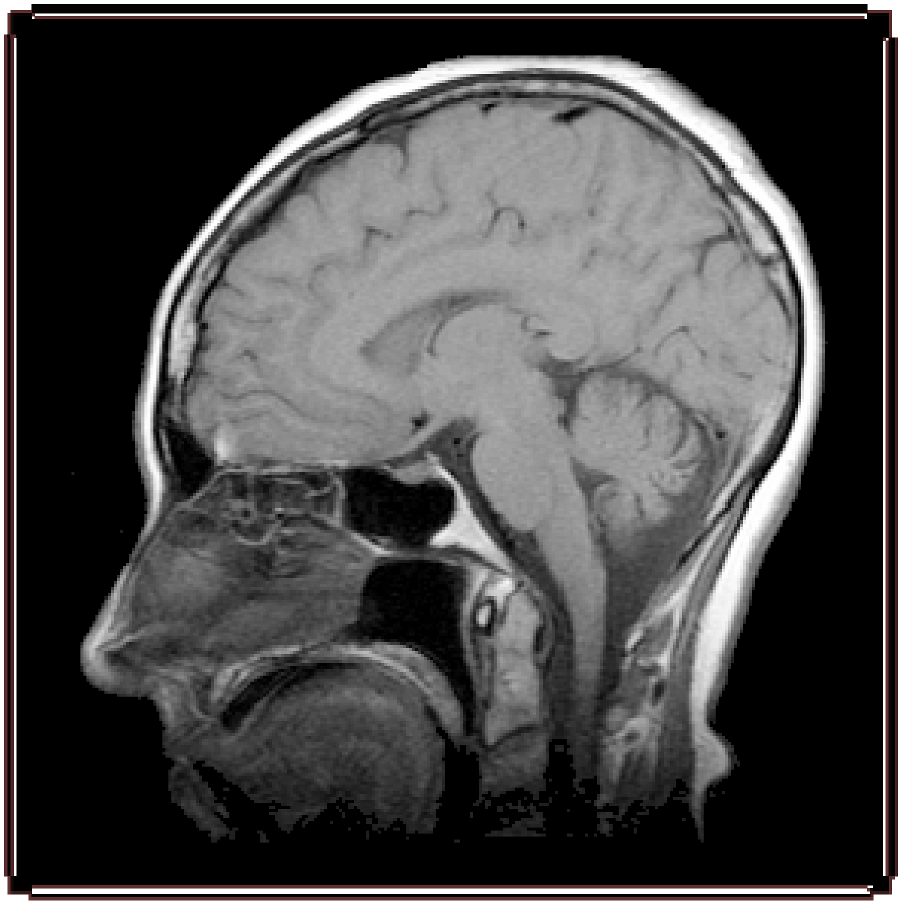
Applications

- Multimedia (just look at the web)
- Image Editing and Manipulation (Photoshop)
- Medical Imaging (CT, MRI, EM)
- Compression (PNG, JPEG)
- Document Processing (OCR)
- Image Libraries (restoration/cleanup, storage, retrieval)
- Many More

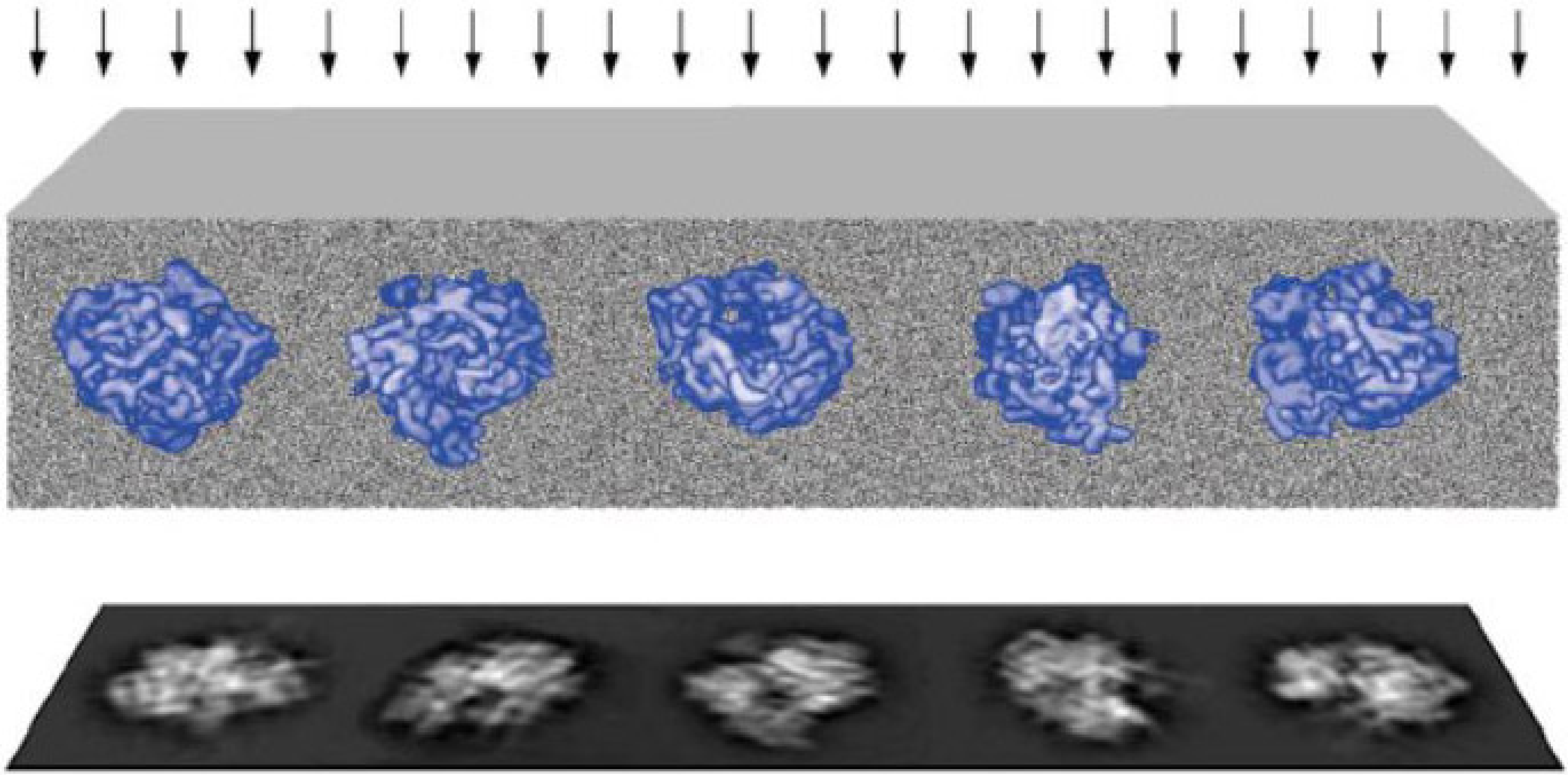
CT


GE MEDICAL SYSTEMS
HiSpeed NX/i CT
Ex: 36
Se: 4
Im: 45
XY Ax: 1185.0 (coi)
DFOV 34.6cm
STND
A 173
512 X 512
Mag = 1.00
FL:
ROT:
R
171
L
175
kV 120
mA 120
SFOV 50.0cm
5.0mm 4.50mm/s HQ
Tilt: 0.0
0.7 s/HE /34.22
WW: 389 WL: 24
P 173

MRI



EM / Single Particle Imaging



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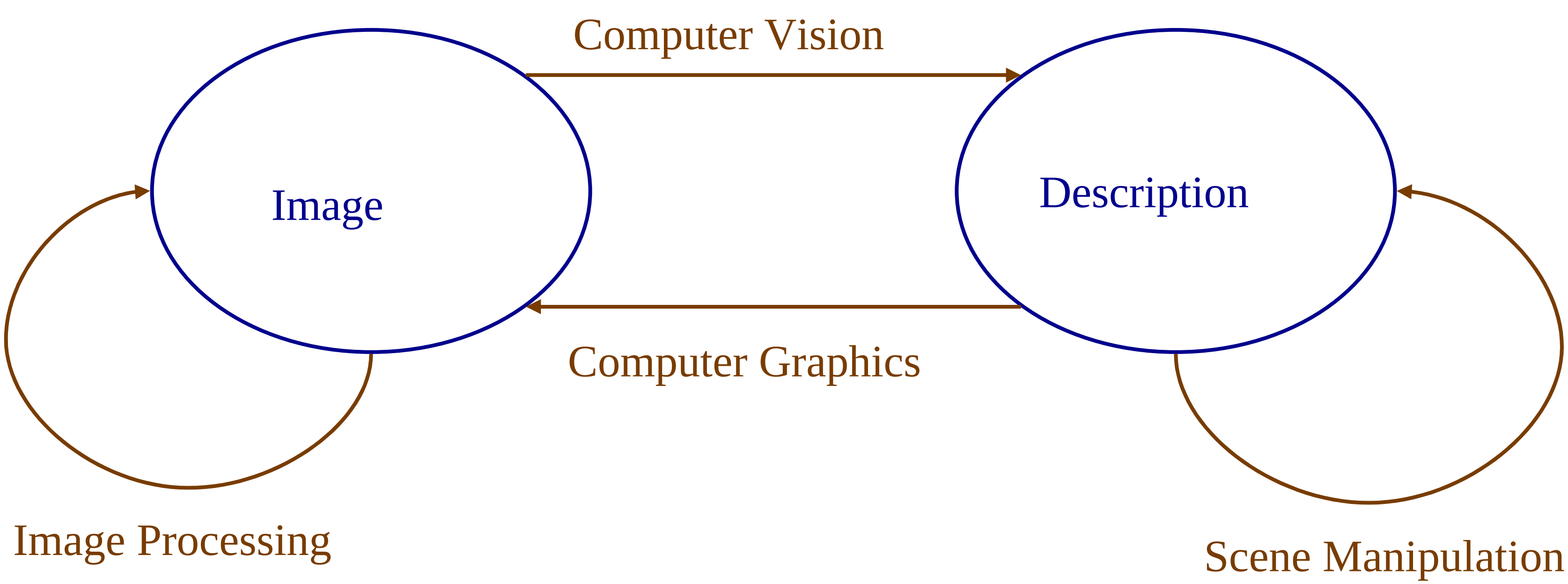
Relation to Other Fields

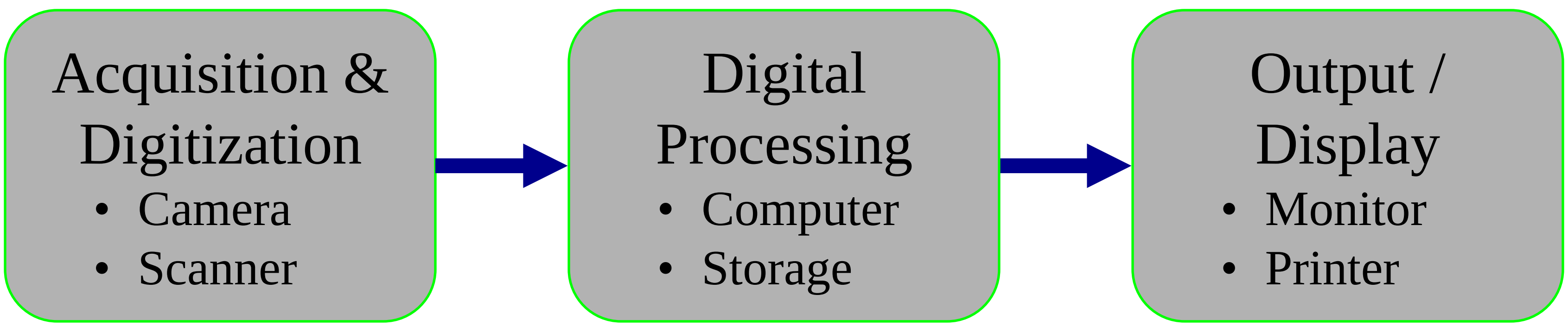
- Image Processing: Transform an image into another representation (image), often as a step to achieving some goal

- Computer Vision: Create a description of the imaged scene

- Computer Graphics: Create an image of the described scene



Imaging System



Any Questions?

Signals and Functions

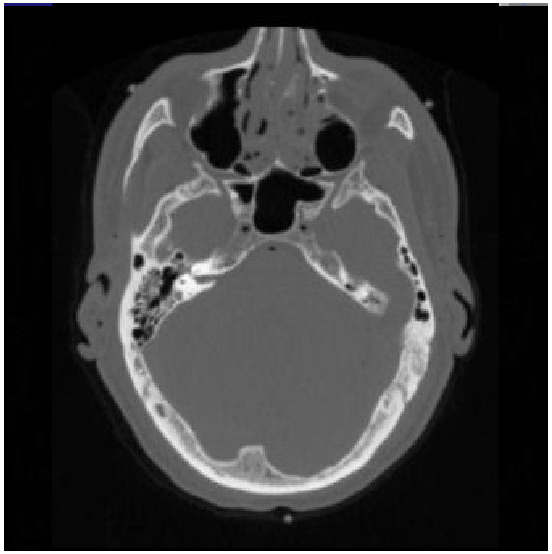
- Signal: a function carrying information
- Functions have domains and ranges:

$$f(\Theta) = v$$

Domain:	Range:
(t)	sound (air pressure)
(x,y)	graylevel (light intensity)
(x,y,t)	color (RGB, HSL)
(x,y,z)	LANDSAT (7 bands)
(x,y,z,t)	

What do the Range Values Mean?

- May be visible light:
  - Intensity (gray-level)
  - Color (RGB)
- May be quantities we can ***not*** sense:
  - Radio waves (e.g., doppler radar)
  - Range images
  - Ultrasound
  - Magnetic resonance
  - X-rays (e.g., CT)



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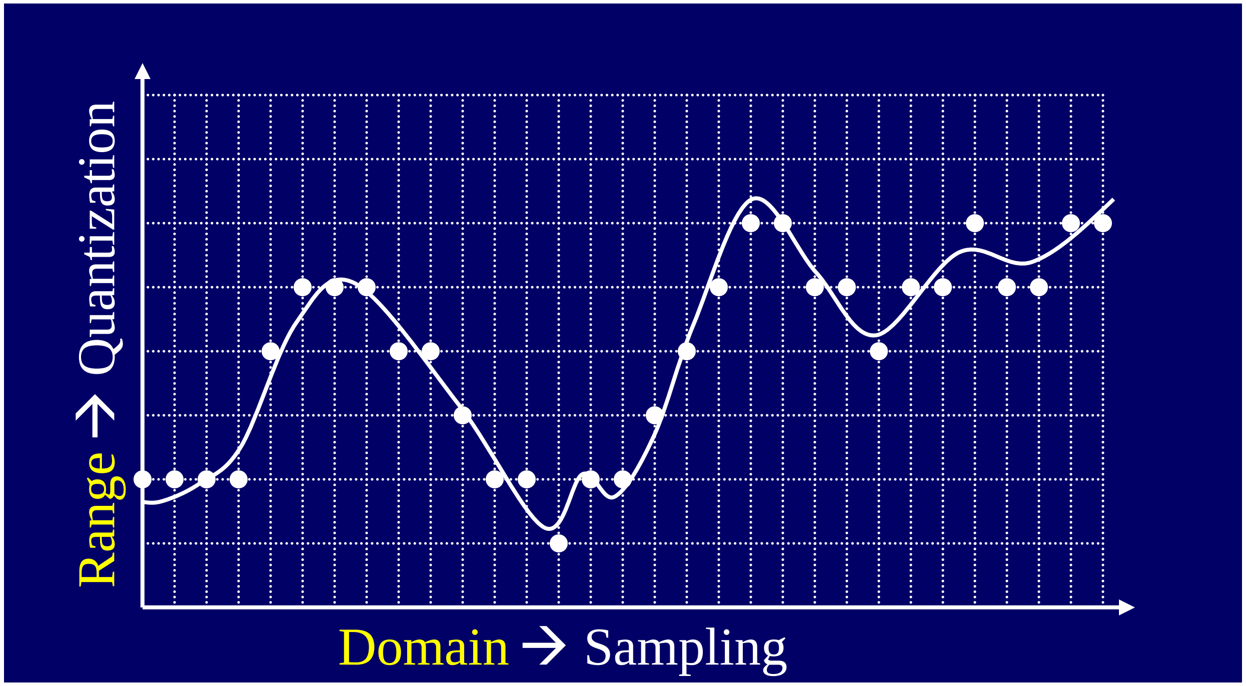
Domains & Ranges

- Analog: continuous domain and range
- Digital: discrete domain and range
- Converting from continuous to discrete:
  - Domains: selection of discrete points is called ***sampling***
  - Ranges: selection of discrete values is called ***quantization***



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Sampling or Quantization?

- Dots per inch
- Black and white images
- Frames per second
- 44.1 KHz audio
- 16-bit audio
- 24-bit color

Sampling vs. Quantization

- Sampling described using terms such as:
  - Rate
  - Frequency
  - Spacing
  - Density
- Quantization is referred to as:
  - # of discrete values
  - # of bits per sample/pixel

Resolution

- Ability to discern detail – both domain & range.
- *Not* simply the number of samples/pixels.
- Determined by the averaging or spreading of information when sampled or reconstructed.

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Acquisition Devices

- Aperture – “size” of sampling area.
- Scanning – ordered sampling of signal/image.
- Sensor – measures quantity of sample.
- Quantizer – converts continuous to discrete.
- Output storage medium – saves quantized samples.

Compare: pinhole w/film & CCD cameras

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Apertures

- Point measurements are impossible
- Have to make measurements using a (weighted) average over some aperture:
  - Time window
  - Spatial area
  - Etc.
- Size determines resolution:
  - Smaller → better resolution
  - Larger → worse resolution

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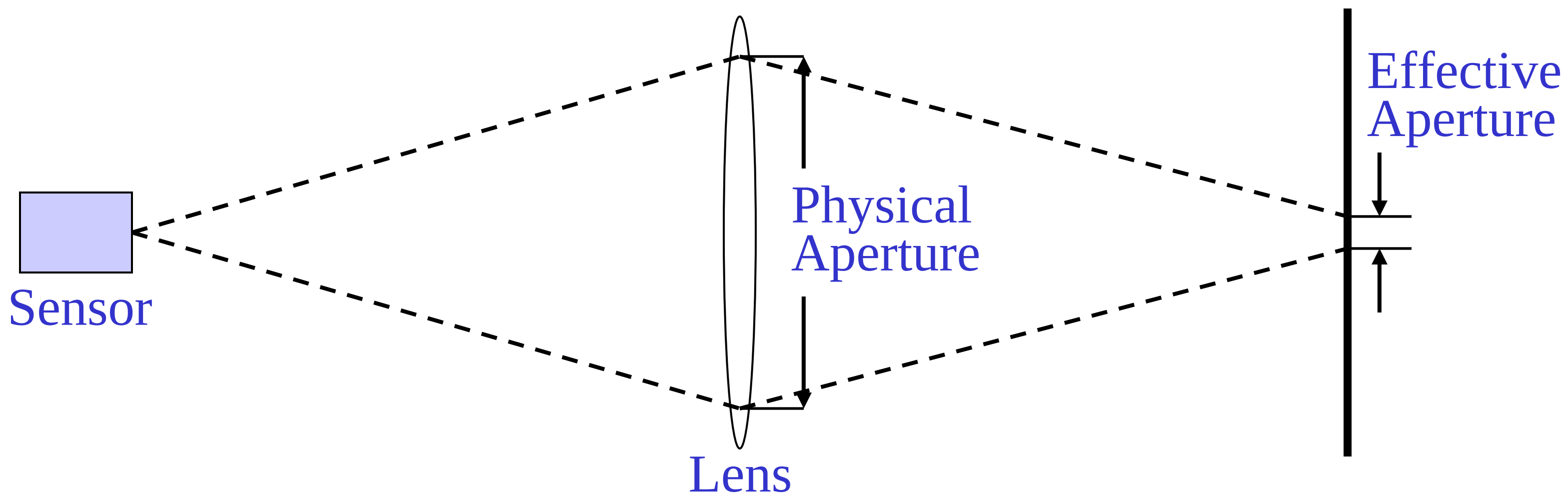
Apertures

- Lenses allow physically larger aperture with effectively smaller one



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Sensor

- Converts physical property (e.g., light/photons) to chemical and/or electrical response.

- Examples:
  - Film: silver halide crystals
  - Eyes: photoreceptors (rods, cones)
  - Digital camera: charge-coupled device (CCD)

Capture Images

- Focus the optics correctly to capture images
  - Camera for macroscopic scenes: distance measure technology:

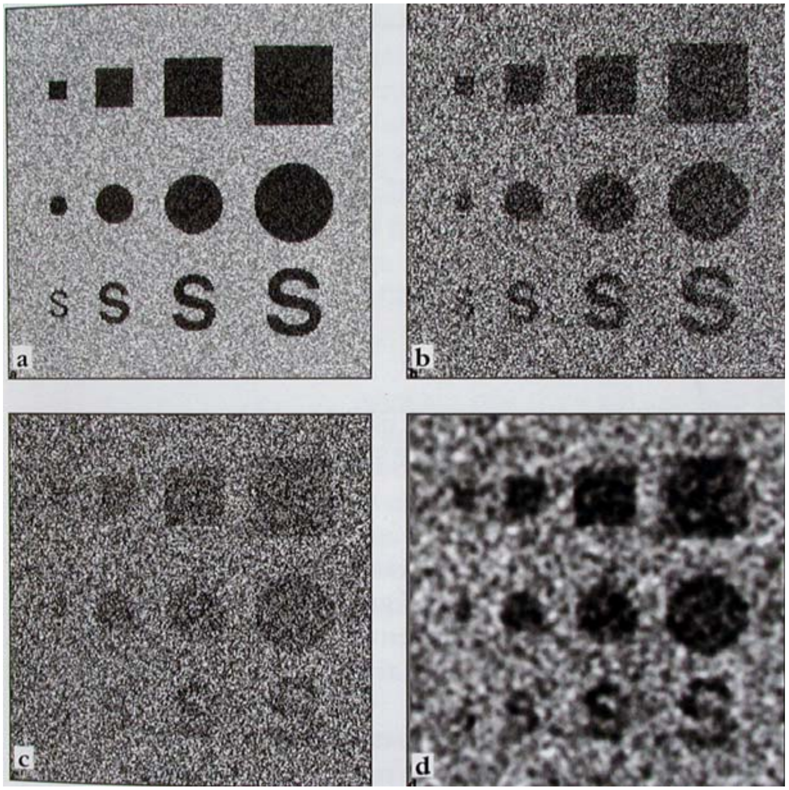
    High frequency sound, infrared light

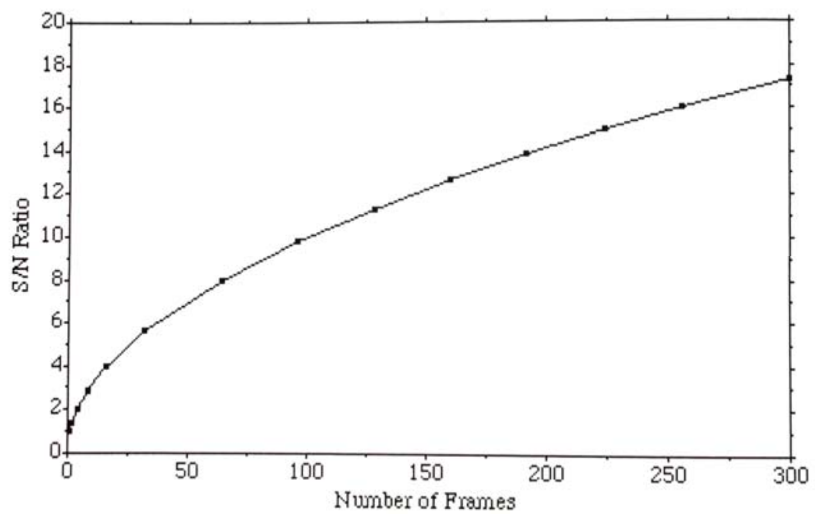
  - Camera for microscopy application
- Detect the quality of image sharpness
  - Hardware
  - Software

Noise

- Unavoidable/undesirable fluctuation from "correct" value:
  - The nemesis of signal and image processing
- Usually random: modeled as a statistical distribution
  - Mean (μ) at the "correct" value.
  - Measured sample varies from μ according to distribution (σ).
- Signal-to-Noise Ratio (SNR) = μ/σ:
  - Measures how "noise free" the acquired signal is.

Signal to Noise Ratio





A) Signal to noise ratio 1:1
B) Signal to noise ratio 1:3
C) Signal to noise ratio 1:7
D) Image c after spatial smoothing

Signal-to-noise ratio of averaged image improves as the square root of the number of frames summed

Sources of Noise

- Quantum: discrete nature of light (photons)
  - Poisson distributed: $\sigma = \sqrt{\mu}$
  - SNR increases with more light:
    - Turn up light source
    - Larger aperture
    - Collect longer
- “Background” (Thermal) : a.k.a. “Dark” current
  - Thermal electrons indistinguishable from photoelectrons.
  - Builds up over time.
  - Decreases with:
    - Cooler environment
    - Shorter collection time

Sources of Noise (cont.)

- Sensor In homogeneity: every sensor is unique
  - Dark current levels vary from element to element.
  - Long exposures produce fixed patterns:
    - Can be subtracted out.
- Circuitry: (prior to converting to digital)
  - Electromagnetic interference from other circuits.
  - Shifting charge from well to well (CCD):
    - Some photoelectrons lost: (charge-transfer efficiency < 1)
  - "Dead" pixels.

Noise vs. Resolution

- Smaller Aperture:
  - Higher resolution
  - Less area → fewer photons → more noise
- Larger Aperture:
  - Lower resolution
  - More area → more photons → less noise
- Lens
  - Larger physical (photon collection) area.
  - Smaller effective (resolution) aperture.

Noise vs. Resolution

- Example 1: Camera settings
  - F-stop: aperture
  - Shutter speed: collection time
- Example 2: Film crystals
  - Larger : lower resolution but faster (short exposure)
  - Smaller: higher resolution but slower (long exposure)

High Resolution Imaging

- High numbers array sensors
- Great display depth
- High number of gray levels

Tradeoff

- Cooling the camera to reduce electronic
- Slower image acquisition and digitization

Ideal Sensor Response

- Multiplying input by a constant value multiplies the output by the same constant:

$$f(a\boldsymbol{x}) = a\, f(\boldsymbol{x})$$

- Adding two inputs causes corresponding outputs to add:

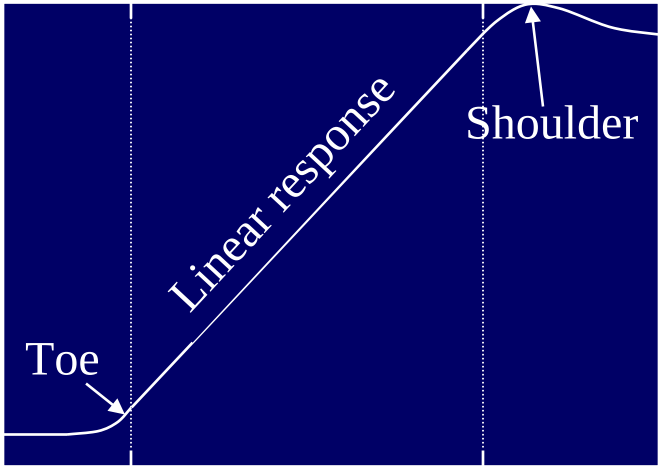
$$f(\boldsymbol{x} + \boldsymbol{y}) = f(\boldsymbol{x}) + f(\boldsymbol{y})$$

- Linearity:

$$f(a\boldsymbol{x} + b\boldsymbol{y}) = a\, f(\boldsymbol{x}) + b\, f(\boldsymbol{y})$$

Typical Sensor Response

- Every sensor has an effective dynamic range.
- Most “approximately linear” devices are linear over some range:
  - Low (< toe): flat (nonzero) response
  - Middle: linear response (effective dynamic range)
  - High (> shoulder): saturation and blooming
- Example: H & D curve for film.



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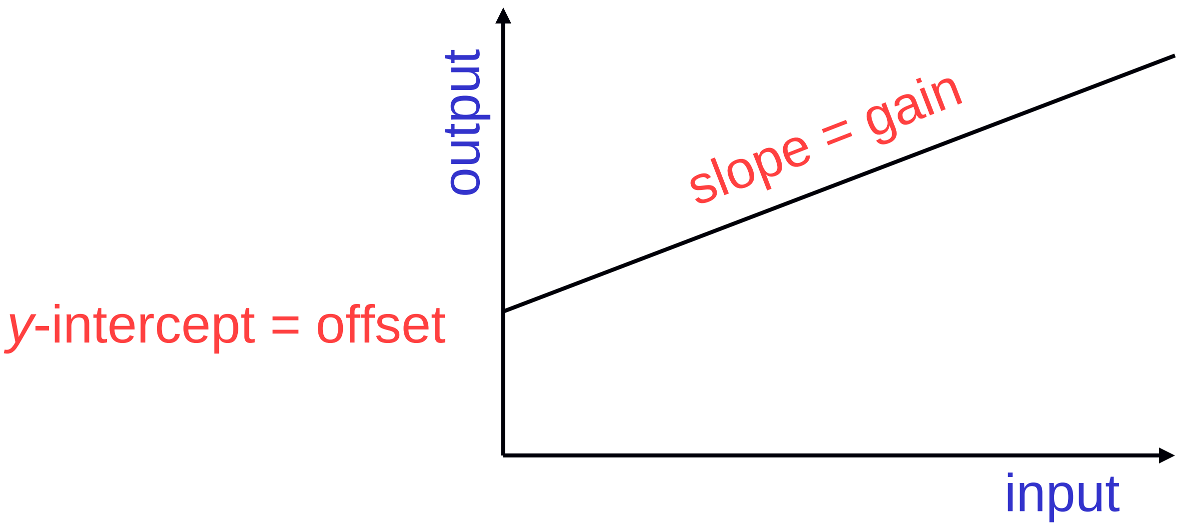
Gain and Offset

Gain = proportionality of output to input.

Offset (Bias) = constant addition to output.



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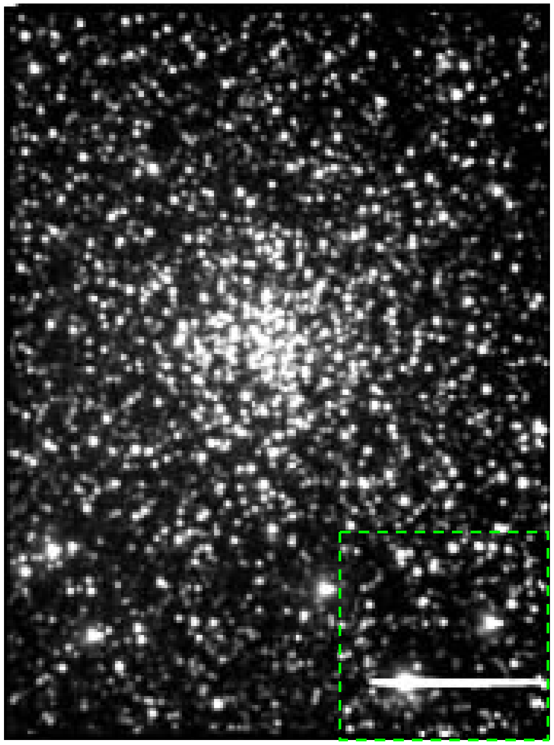
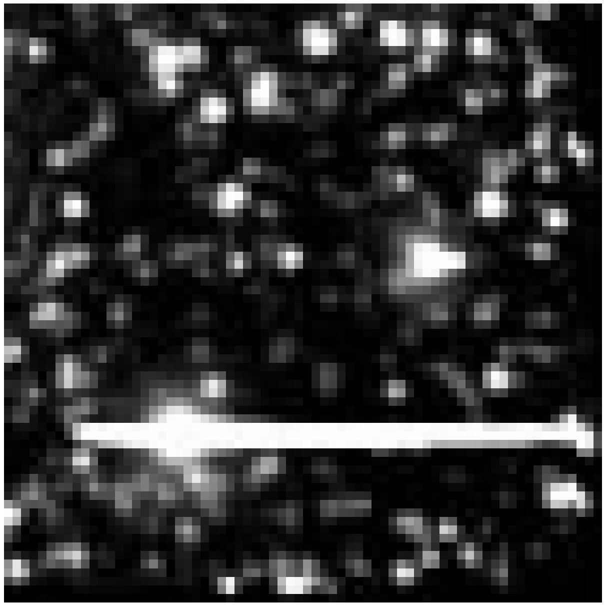
Other Sensor Problems

- Blooming: Photoelectrons "overflow" from one sensor well to neighboring (electrically connected) wells.





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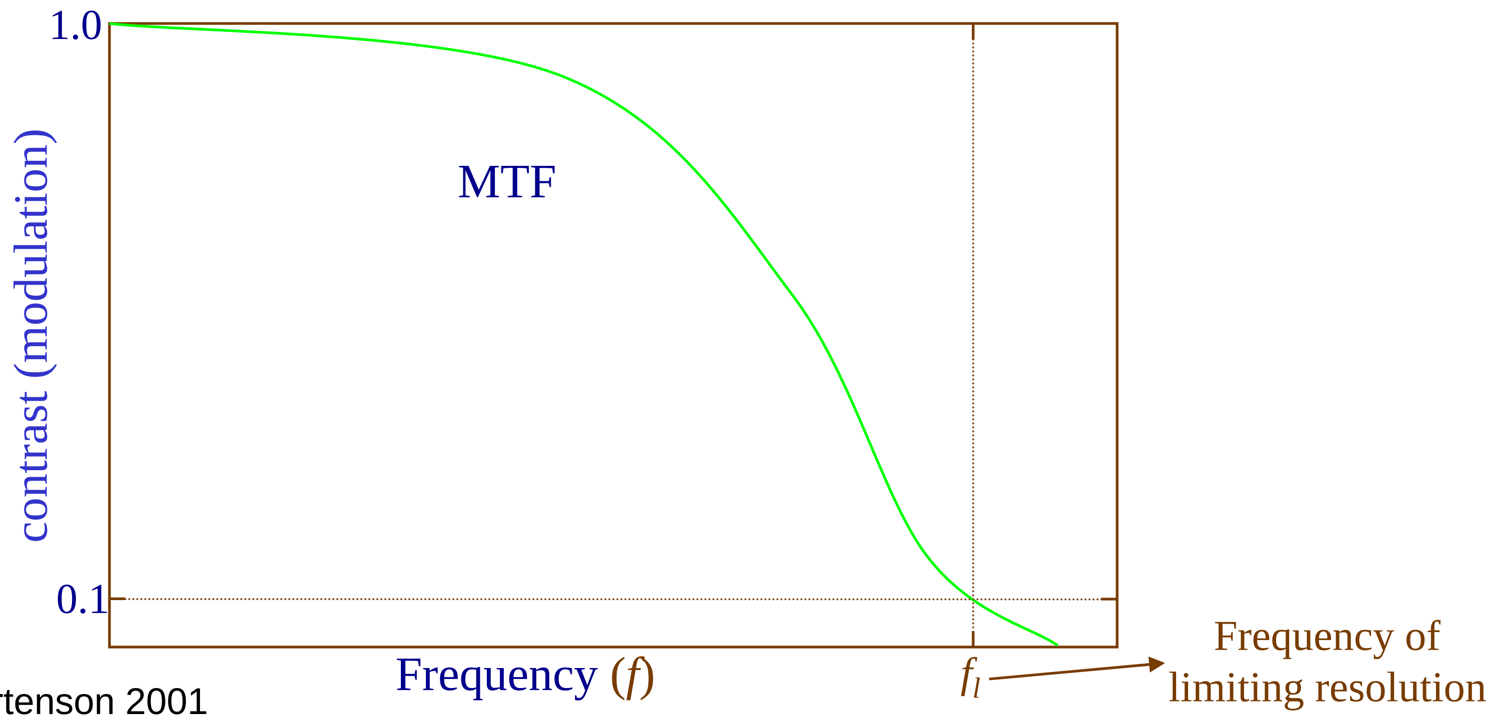
Modulation Transfer Function

- A way of measuring resolution:
  - Instead of line-pairs, uses sine waves
- Measure the contrast of the response as a function of frequency:



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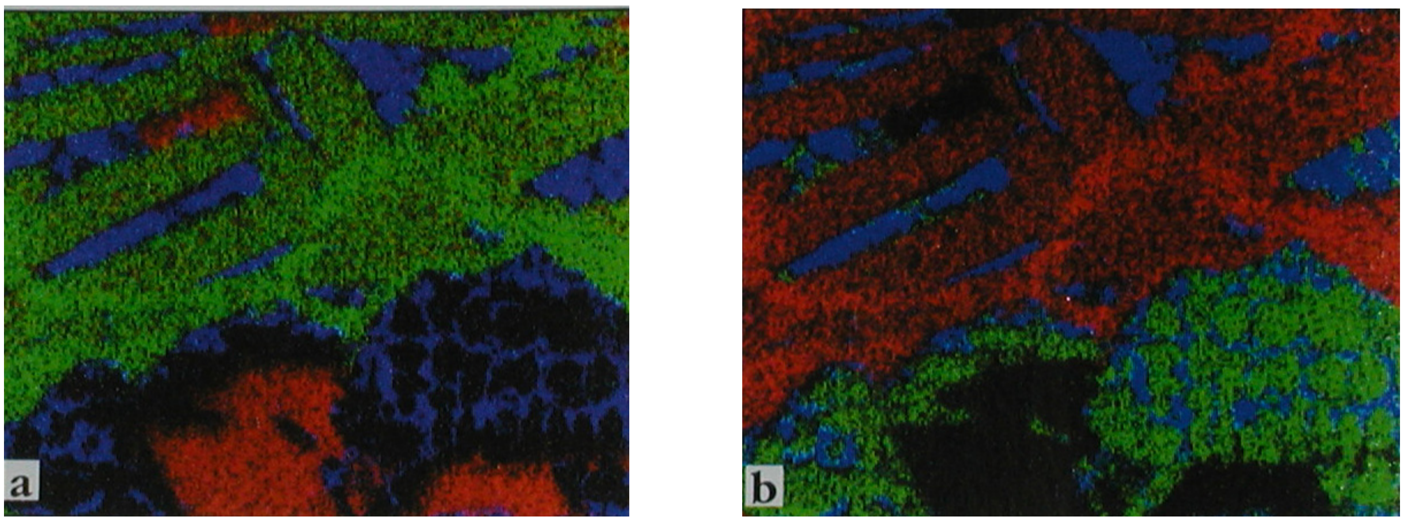
Color Imaging

- RGB et al.
- e.g. pseudo-color display



Color composites made from SEM electron and X-ray images

Color Space

Conversion from RGB to YIQ/YUV (no information loss)

Y = 0.299R + 0.587G + 0.114B	R = 1.000Y + 0.956I + 0.621Q
I = 0.596R – 0.274G - 0.322B	G = 1.000Y – 0.272I – 0.647Q
Q = 0.211R – 0.523G + 0.312B	B = 1.000Y – 1.106I + 1.703Q

Interconversion of RGB and YIQ color scales

Resources and Further Reading

Textbooks:

Kenneth R. Castleman, Digital Image Processing, Chapter 1, 2

John C. Russ, The Image Processing Handbook, Chapter 1

Reading Assignment

Textbooks:
Kenneth R. Castleman, Digital Image Processing, Chapter 3, 4, 5
John C. Russ, The Image Processing Handbook, Chapter 3, 4

Figure and Text Credits

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http://web.engr.oregonstate.edu/~enm/cs519