BME I5000: Biomedical Imaging

Lecture 1
Introduction

Lucas C. Parra, parra@ccny.cuny.edu

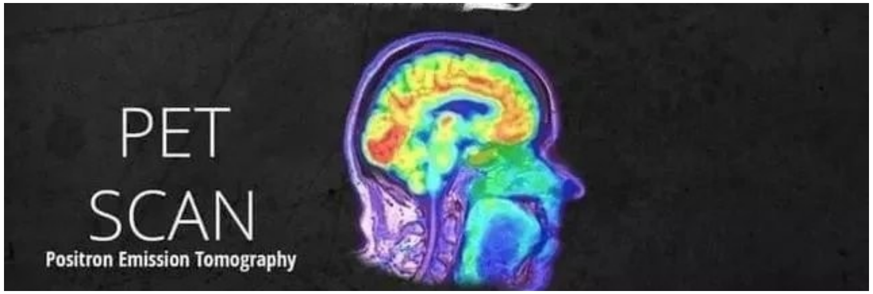
Content

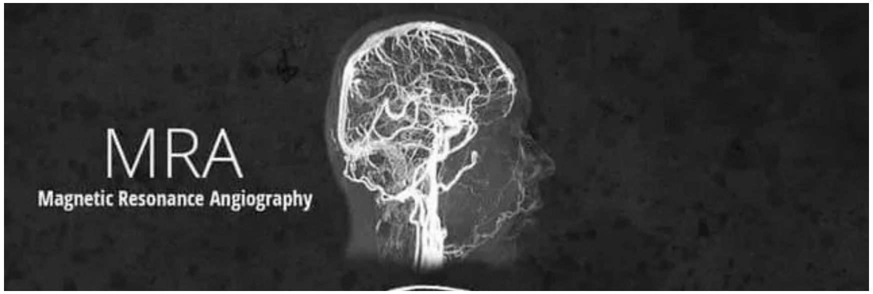
Topics:
Physics of medial imaging modalities (blue)
Digital Image Processing (black)

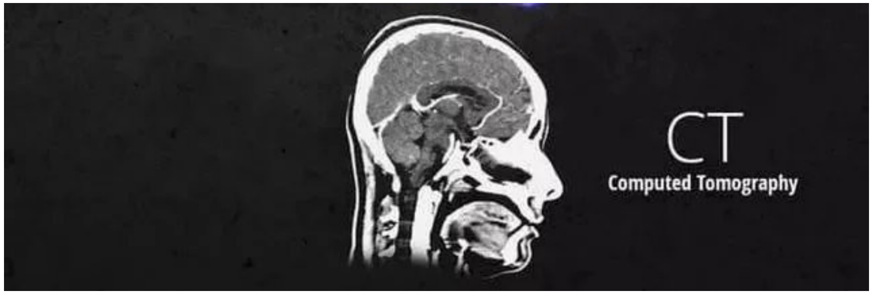
Schedule:
1. Introduction, Spatial Resolution, Intensity Resolution, Noise
2. X-Ray Imaging, Mammography, Angiography, Fluoroscopy
3. Intensity manipulations: Contrast Enhancement, Histogram Equalization
4. Computed Tomography
5. Image Reconstruction, Radon Transform, Filtered Back Projection
6. Positron Emission Tomography
7. Maximum Likelihood Reconstruction
8. Magnetic Resonance Imaging
9. Fourier reconstruction, k-space, frequency and phase encoding
10. Optical imaging, Fluorescence, Microscopy, Confocal Imaging
11. Enhancement: Point Spread Function, Filtering, Sharpening, Wiener filter
12. Segmentation: Thresholding, Matched filter, Morphological operations
13. Pattern Recognition: Feature extraction, PCA, Wavelets
14. Pattern Recognition: Bayesian Inference, Linear classification

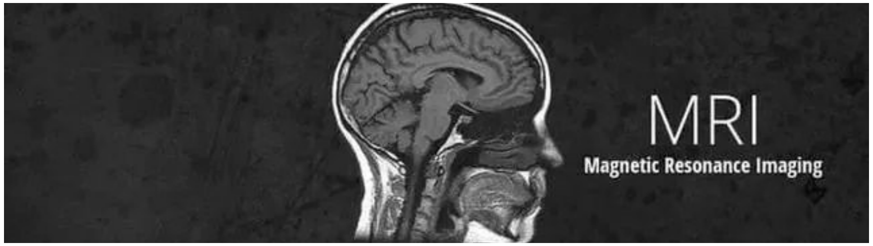
Content


X-RAY


PET
SCAN
Positron Emission Tomography


MRA
Magnetic Resonance Angiography


CT
Computed Tomography


MRI
Magnetic Resonance Imaging

Biomedical Imaging

Prerequisite:
Linear algebra, some programming, complex variables, and maybe probabilities.

Literature

Jerry Prince, Jonathan Links, Medical Imaging (Signals and Systems), Pearson Prentice Hall, 2006
Andrew Webb, Introduction to biomedical Imaging, IEEE Press, 2003
Gonzalez & Woods, Digital Image Processing, Prentice Hall, 2003
Jain, Fundamentals of Digital Image Processing, Prentice Hall, 1988

Grading

30 % final exam, 20% midterm, 50% assignments

- 70% or more = C
- 80% or more = B
- 90% or more = A
- 100% = A+

Assignments:

1. MATLAB or Python programming
   - Turn in next week my email
   - May have pop quizzes to test “undisclosed collaborations”.
2. Proofs and problems
   - Turn in next week
   - Easy, just to exercise the notation

Programing Introduction

For help on MATLAB run

```
>> demo
>> help
```

Useful functions

```
>> lookfor
>> whos
```

Familiarize yourself in particular with the set of functions in the image processing toolbox:

```
>> help images
```

And run the demos of the image processing toolbox.

If you are new to MATLAB, please make substantial time available to run the demo programs which are a very good introduction:

basic matrix operations
matrix manipulations
graphs and matrices
MATLAB language introduction

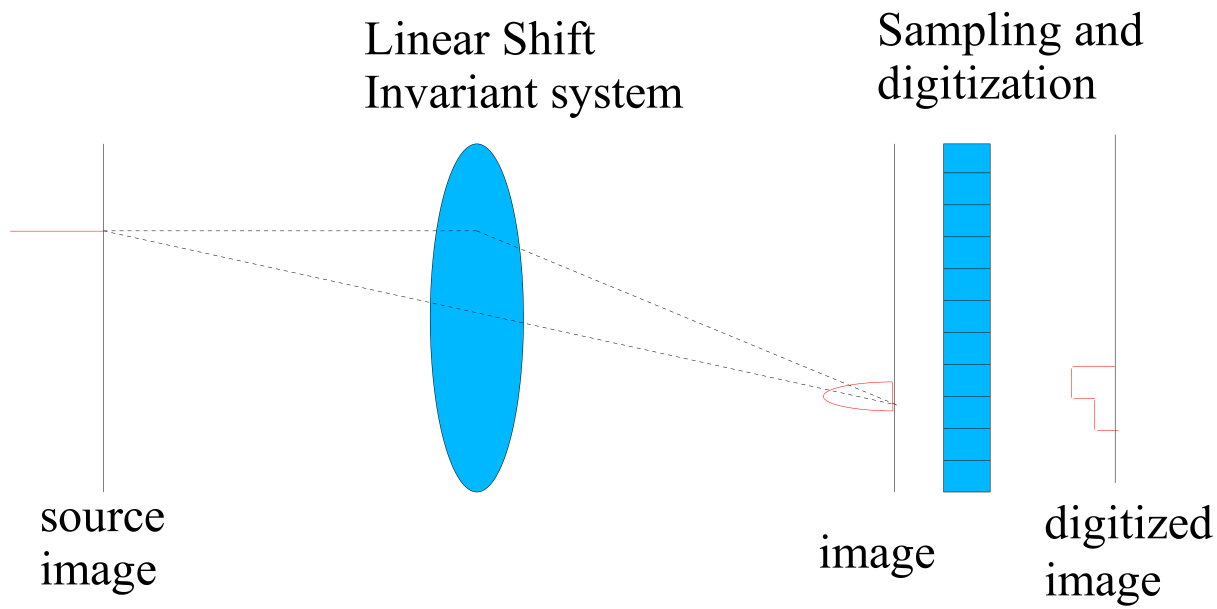
line plotting
2-D plots
axis properties,
desktop environment demos

Programing Assignments

- Will be announced in class and data will be posted on the web.
- Due within a week of assignment. Submit single file called by your name: first_last_#.py or .m , all lower case e.g. john_smith_4.py
- Send homework to bme**i**5000hwork@gmail.com
- Your program loads all data required. Assume data files are in current directory.
- Collaboration is OK. If you do wish to submit the similar work, you MUST name your partner and be prepared to be quizzed after class. **"Similar" submission are easy to spot**, in particular if there are mistakes! Suspected *undisclosed collaborations* will be rejected.
- AI rule: If you used then disclose.
- The criteria for approving should be clear. If not, please ask in class. Do not take chances by assuming that your work is "sort of correct".

Model Imaging System

Model for a simple imaging system ...



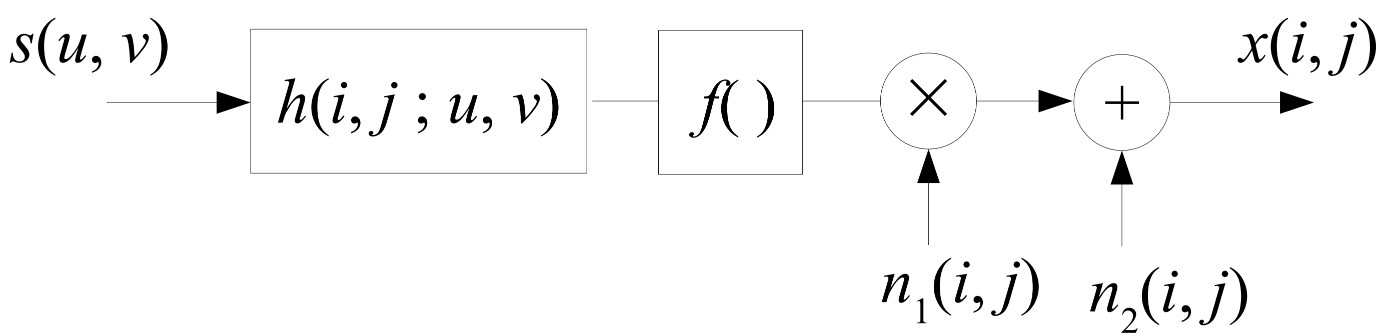
A common simplified mathematical model for an imaging process is that of a linear system with additive noise:

Model Imaging System

The source image *s* passes through a Linear Shift Invariant transformation *h* and sensing generates additive noise *n*.

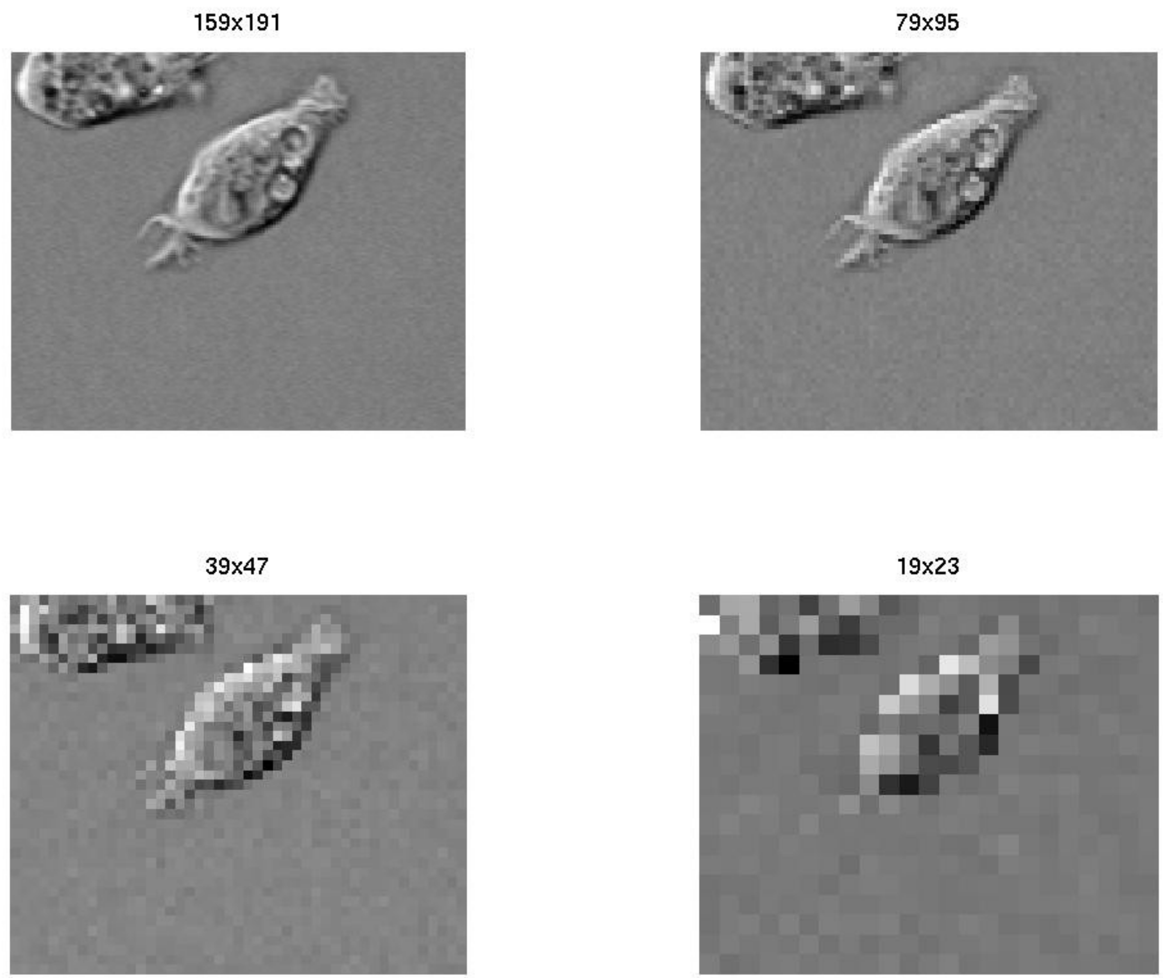
$$x(i,j) = \int\int du\,dv\,h(i-u,j-v)\,s(u,v) + n(i,j)$$

A more realistic model includes spatial dependence of *h*, non-linearity *f*(), as well as multiplicative noise:



Spatial Resolution

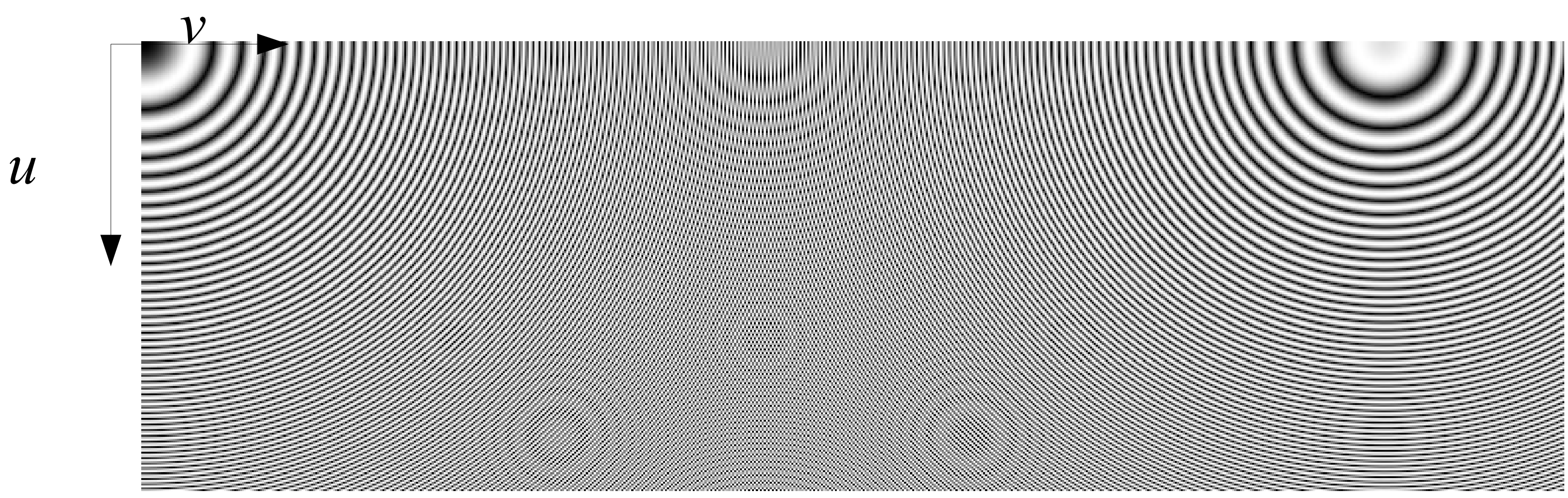
Required to see sufficient detail … Resolution given as number of pixels per length, or, size of a pixel.



Spatial Resolution

Another problem with sampling is that it may cause aliasing.

Example: $s(u,v) = |\sin(u^2 + v^2)|$. 240x720 pixels and amplitude scaled to [0 255] and discretized.

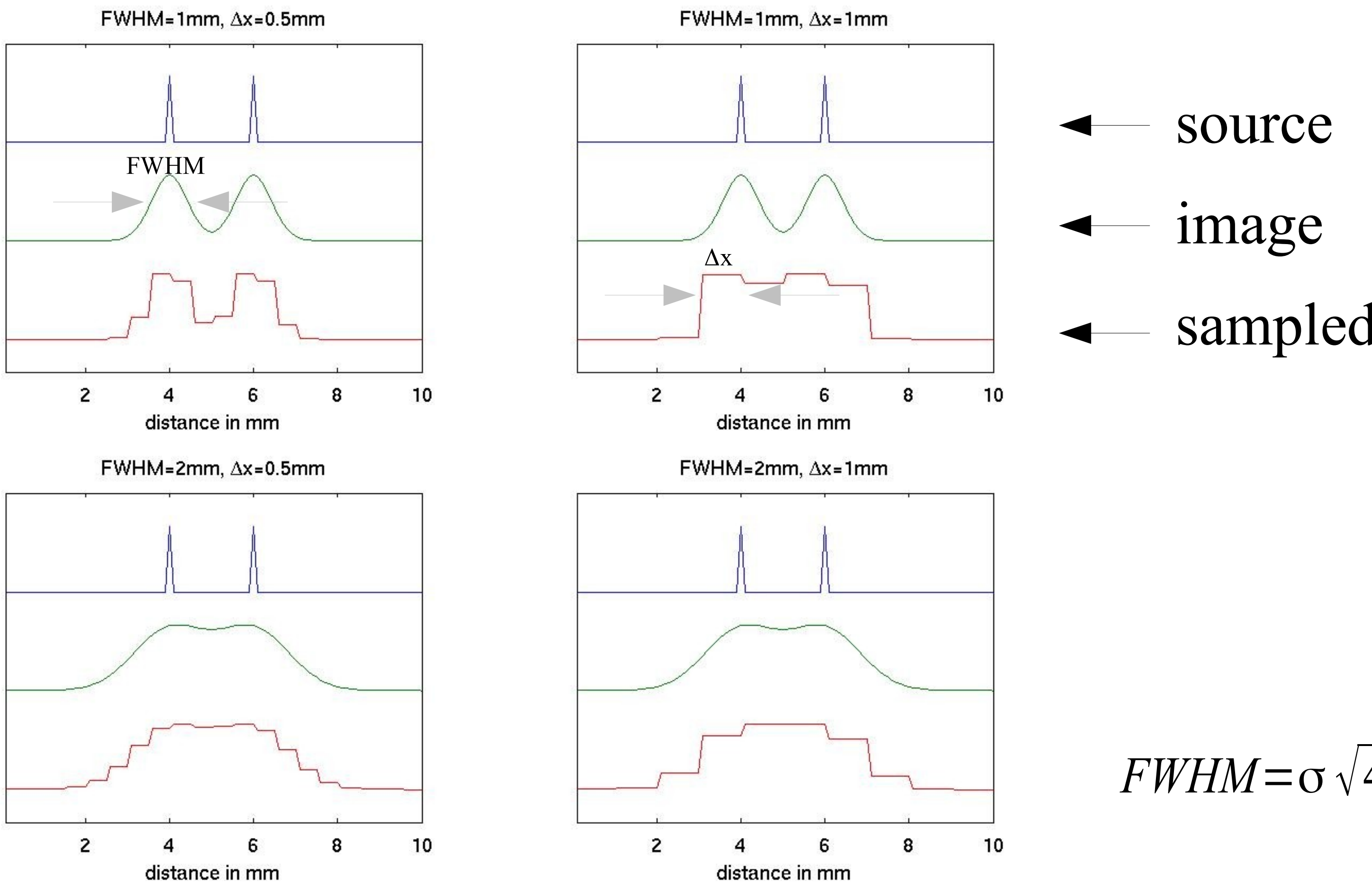


Sampling creates artifacts in the *space domain*.

Spatial Resolution

Resolution is limited by *LSI* and *sampling* and quantified by:

- Minimal distance of two points that can be resolved – measured as “full width half max” FWHM.
- Area covered by one pixel – measured as Δx

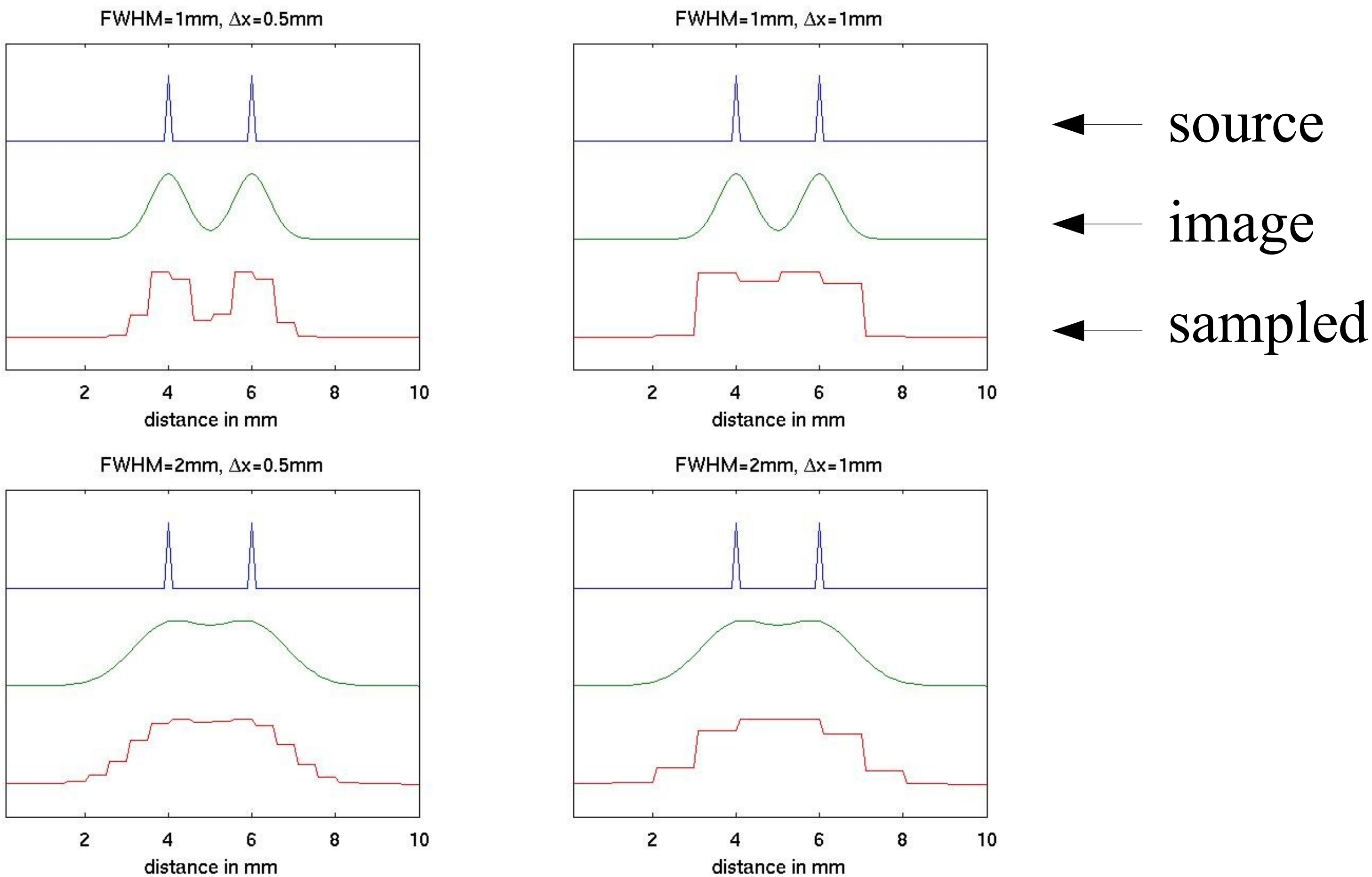


$$FWHM = \sigma \sqrt{4 \ln 4}$$

Spatial Resolution

Note (due to sampling theorem):

- Sampling resolution should be 2 times the imaging resolution.
- Imaging resolution should be 2 times highest frequency of interest.



Intensity Resolution

2 gray levels

4 gray levels

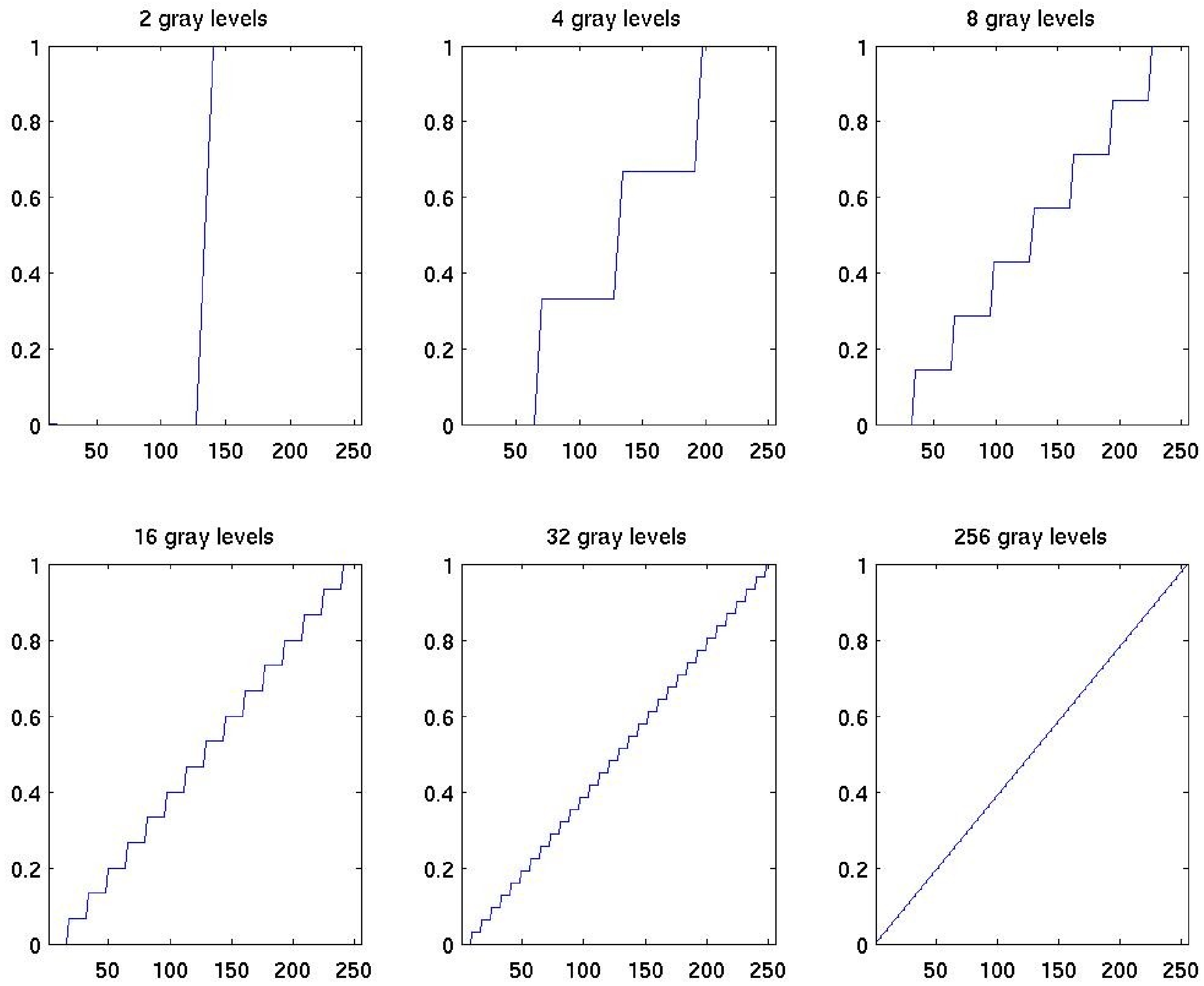
8 gray levels

16 gray levels

32 gray levels

256 gray levels

Intensity Resolution

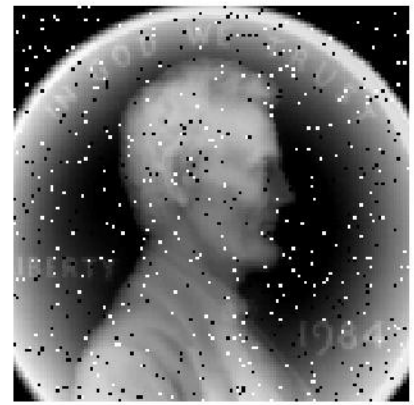


Noise

There are a number of possible noise sources and we will discuss in the different applications. Three important noise models are

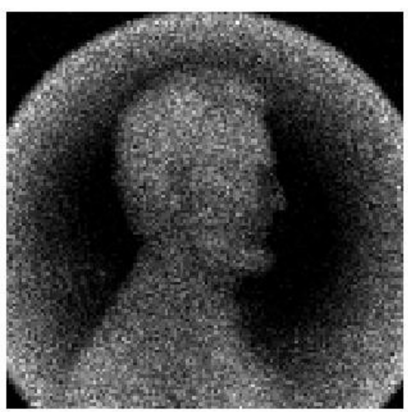
no noise

Salt & Pepper noise (12 dB)

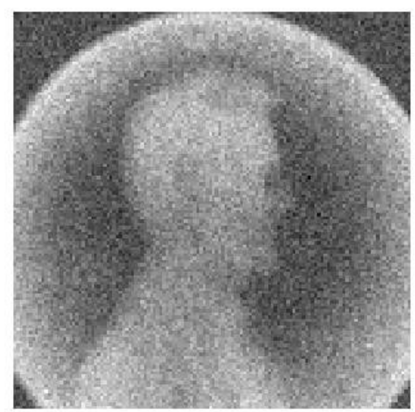


Impulse Noise: Outliers due to faulty electronics.

Poisson noise (12 dB)



Gaussian noise (12 dB)



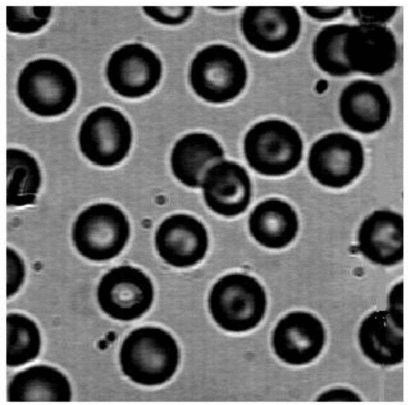
Poisson Noise: Due to limited photon counts.

Gaussian Noise: Often due to electronic or thermal fluctuations.

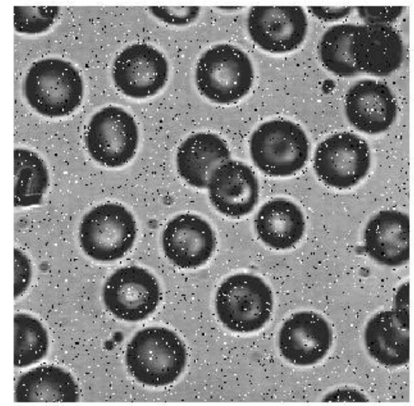
Noise

There are a number of possible noise sources and we will discuss in the different applications. Three important noise models are

no noise



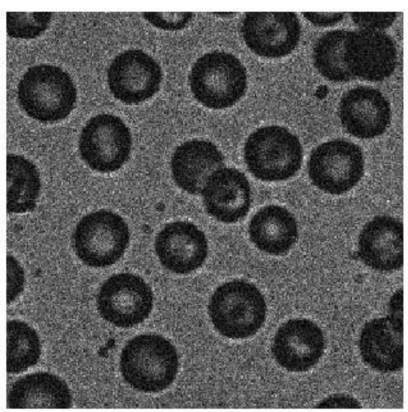
Salt & Pepper noise (14 dB)



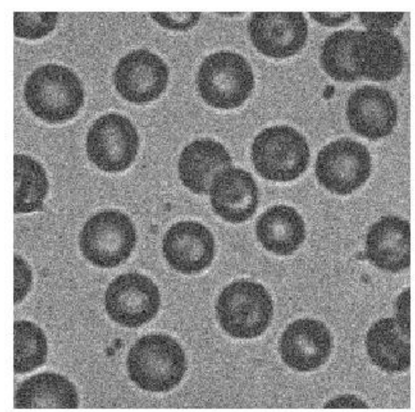
Impulse Noise:
Outliers due to faulty electronics.

Poisson Noise:
Due to limited photon counts.

Poisson noise (12 dB)



Gaussian noise (13 dB)



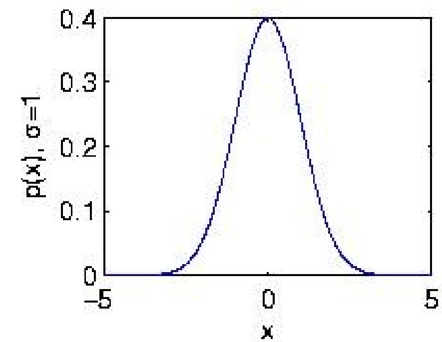
Gaussian Noise:
Often due to electronic or thermal fluctuations.

Noise

Noise models are defined by their probability distribution (discrete) of probability density function (continuous)

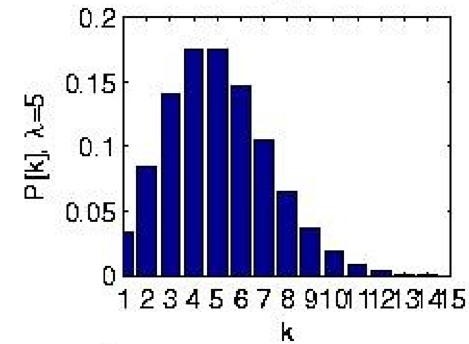
Gaussian Noise:
Continuous valued, magnitude given by standard deviation σ

$$p(x) = \frac{e^{-\frac{x^2}{2\sigma^2}}}{\sigma\sqrt{2\pi}}$$



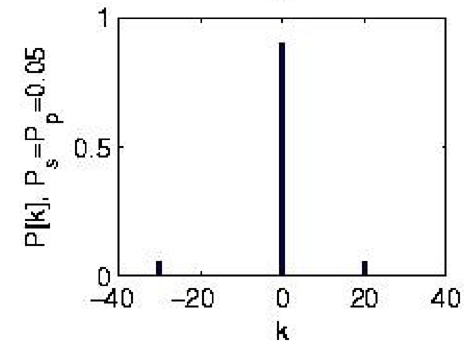
Poisson Noise:
Discrete valued.
Magnitude given my the mean λ

$$P[k] = \frac{\lambda^k e^{-\lambda}}{k!}$$



Impulse noise:
Discrete valued.
Magnitude given by likelihoods P_s and P_p

$$P[k] = \begin{cases} 1 - P_s - P_p, & k = 0 \\ P_s, & k = k_s \\ P_p, & k = k_p \\ 0, & else \end{cases}$$

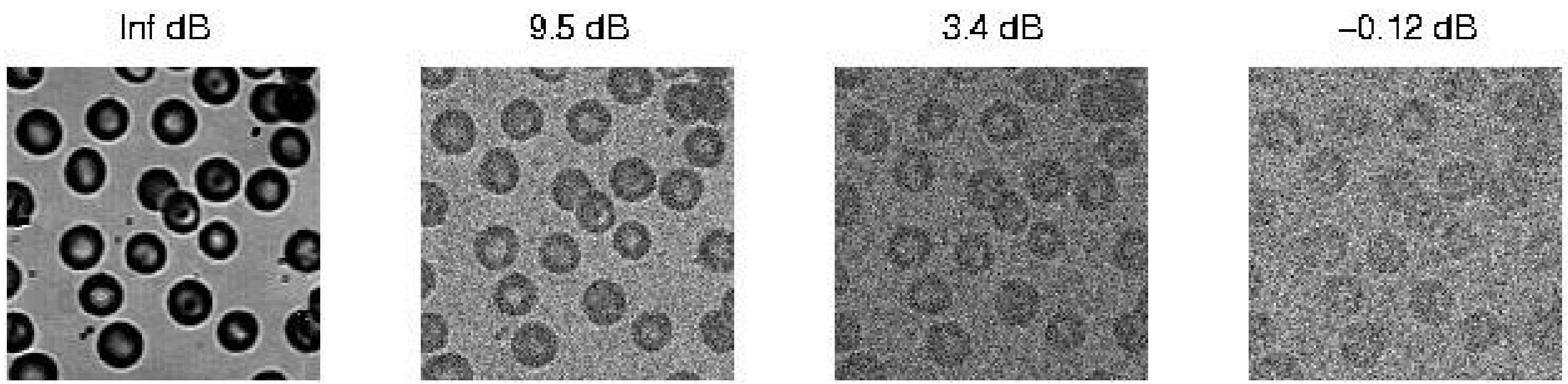


Noise

Empirically noise is quantified with the ***Signal-To-Noise Ratio*** (SNR). It quantifies the ratio of signal power to noise power and is specified in decibel (dB):

$$x(i,j) = s(i,j) + n(i,j)$$

$$SNR = 10\log_{10}\left(\frac{\sum_{ij}|s(i,j)|^2}{\sum_{ij}|n(i,j)|^2}\right)$$



Assignment

Assignment 1:

Generate three figures from slides 10, 14, and 19. Deliver executable code and not the figures. Data files are in the MATLAB directory under:

```
toolbox/images/imdemos/cell.tif
toolbox/images/imdemos/blood1.tif
toolbox/matlab/demo/penny.mat
```

Or better yet, use your own images.

useful functions:

```
load, imread, double, subplot, imshow, imagesc, interp1,
colormap, title, axis off, axis equal, num2str
```

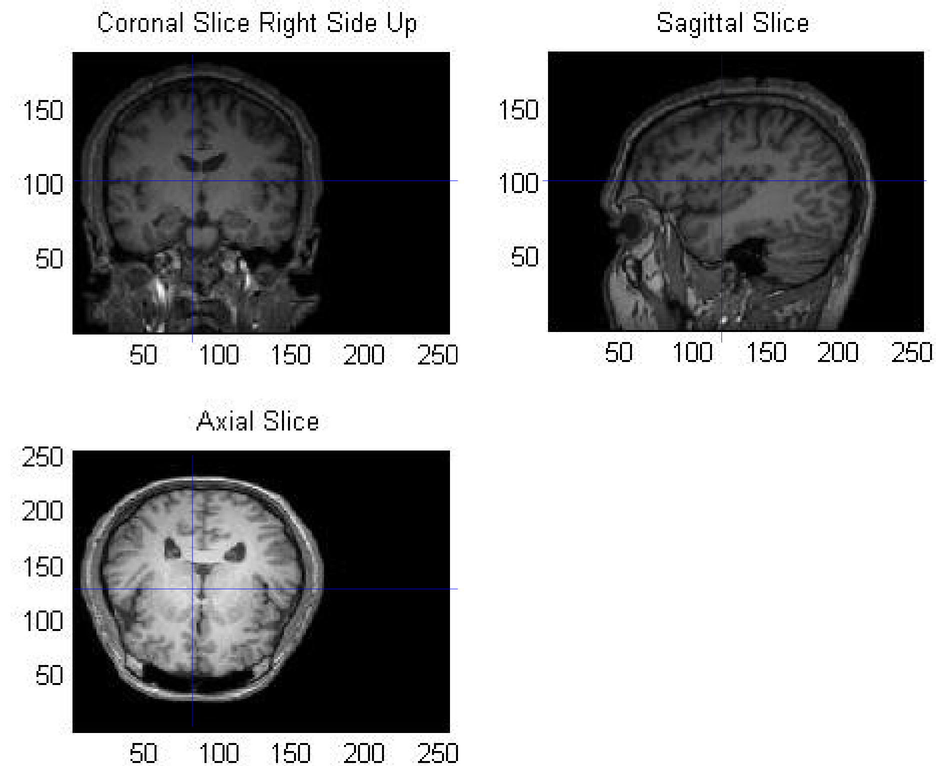
You may also use Python to do this assignment using the numpy and matplotlib libraries. Here is a tutorial on basic image loading and display:

https://matplotlib.org/stable/tutorials/introductory/images.html

Assignment

Assignment 1B: 3D interface

1. Load MRI of the brain and display coronal, sagittal and axial views cutting through a specific (x,y,z) position in the volume. Indicate the slice with a cross through each slice. Use sub-figures in a 4x4 arrangement as shown here.
2. Implement a simple loop that allows the user to pick a new set of slices by clicking on one of the three slices. Determine from the click position and the current axes which two of the three coordinates (x,y,z) have to be updated and display the slices again accordingly.



Useful matlab commands that you almost certainly will need:
`while, subplot, imagesc or imshow, axes equal, axes off, squeeze, colormap gray, caxis, plot, hold on, hold off, ginput, gca.`