Course name: **Imaging in Medicine: Applications**
Course number: **Medical Physics 574**
Instructor: **Sean Fain** / **Diego Hernando**
Session: **Spring 2019**
Credits: **3**

Overview:
This course covers topics in medical imaging and image processing, including image reconstruction, registration, and segmentation. These topics provide a deeper understanding of medical imaging systems, and are important for both the characterization of existing systems and for the development of novel imaging techniques. The course will begin with an overview of optimization problems and techniques, which have general applications in imaging and beyond. Subsequently, we will cover image reconstruction, registration, and segmentation. This course will combine a theoretical framework with computational examples and exercises.

Learning objectives:
Upon completion of this course, students should be able to:
- Distinguish various types of optimization problems (linear vs nonlinear, convex vs non-convex, etc)
- Distinguish formulations from algorithms
- Cast an image reconstruction problem as an optimization problem
- Understand the connection between errors/noise in signal space and artifacts in reconstructed images
- Implement computational solutions to image reconstruction problems
- Learn typical image transforms and deformations, cost functions, and optimization methods for rigid, affine, and deformable image registration
- Learn basic processing methods for segmenting, encoding, and measuring digitized structures in images.

Prerequisites:
Undergraduate calculus and matrix algebra (this will be used heavily in the first half of the course). In addition, this course requires a working knowledge of signal analysis (particularly Fourier transforms in continuous and discrete domains) in one and multiple dimensions, as well as probability, stochastic signals, and noise.

Course credit information:
This class meets for three 50-minute class period each week over the fall/spring semester and carries the expectation that students will work on course learning activities (reading, writing, problem sets, studying, etc) for about 2 hours out of classroom for every class period. This syllabus includes additional information about meeting times and expectations for student work.

Course contents:

1. Fundamentals of Optimization	
Theory	***Computation***
1. Motivation for studying optimization a. Imaging b. Therapy 2. Formulations a. Constrained vs unconstrained b. Linear vs non-linear c. Convex vs non-convex d. Continuous vs discrete	• Linear and non-linear least-squares • Total least squares • Optimization examples from ○ Imaging ○ Therapy • Regularized formulations ○ L1 ○ L2

3. Algorithms a. Closed form vs iterative b. Optimality conditions c. Various types of iterative algorithms d. Convergence: global vs local, speed of convergence 4. Applications a. Image reconstruction b. Image registration c. Image segmentation d. Therapy examples	• Compare algorithms ○ Gradient Descent ○ Newton's method ○ Quasi-Newton methods ○ Stochastic Gradient Descent

2. Image Reconstruction	
Theory	***Computation***
1. Basics of image reconstruction a. Noise and resolution 2. Reconstruction challenges a. Noise b. Artifacts c. Incomplete sampling 3. Image reconstruction as optimization a. Formulations b. Algorithms	• Basic reconstruction techniques • Reconstruction artifacts • Noise and resolution tradeoffs • Regularized formulations ○ L1 ○ L2

3. Image Registration	
Theory	***Computation***
1. Transforms for 2D-2D, 2D-3D and 3D-3D: Introduction to transformation matrices, rigid, affine, elastic grid transforms 2. Metrics for mono- and multimodal registration: Mean squared error, Pearson correlation, mutual information, entropy 3. Numerical optimization techniques (for image registration): gradient descend, Powell, evolutionary	• Introduction to the registration pipeline and basics of ITK (and C++) • Examples exploring sensitivity and performance of various methods to SNR

4. Image Segmentation	
Theory	***Computation***
1. Thresholding: Examples in 2D and 3D digital subtraction angiography a. Otsu Threshold b. Gaussian mixture (histogram fit) 2. Image classifiers: k-means, Bayesian, Machine-Learning 3. Watershed: Application in cell segmentation (microscopy) 4. Level sets: Vessel segmentation in retina fundus Images 5. Active contour models: Organ segmentation in CT or MRI 6. Sensitivity and performance of various methods to SNR	• Image processing examples for each method presented at left.

Texts:

No single textbook will be followed in this course. Relevant books include:

- D. P. Bertsekas, Nonlinear Programming, 1999, Athena Scientific, Belmont, MA.
- Z-P. Liang and P. Lauterbur, Magnetic Resonance Imaging: A Signal Processing Perspective, 2000, IEEE Press, New York, NY
- C. R. Vogel, Computational methods for inverse problems, 2002, SIAM, Philadelphia, PA
- K. Castleman, Digital Image Processing ISBN 0-13-211467-4
- Gonzalez and Woods, Digital Image Processing, Pearson/Prentice Hall, 2008.

Related courses:

Medical Physics/BME 573: Medical Image Science: Mathematical and Conceptual Foundations