WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

Course name:	**Imaging in Medicine: Applications**
Course #:	**Medical Physics 574 / Biomedical Engineering 574**
Instructors:	**Sean Fain, PhD, Professor (sfain@wisc.edu)**
	Diego Hernando, PhD, Assistant Professor (dhernando@wisc.edu)
Office hours:	**Mondays 10:00AM-11:00AM**
Assistant:	**Martin Wagner, PhD**
Session:	**Spring 2019**
Credits:	**3**
Lectures:	**MWF 9:55AM – 10:45AM**
Location:	**WIMR 1022**
Canvas URL:	**https://canvas.wisc.edu/courses/141098**

Instructional mode: **Face-to-face**
Course designations and attributes: **Graduate level, general education**

Course description:

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.

Homework: Homework sets will be due every 2-3 weeks, and will include both theoretical derivations and proofs, as well as computational exercises.

Exams: There will be two exams: one midterm and one final exam.

Course project: There will be one course project, focused on deepening knowledge into one or more of the concepts studied in class. This project may be aligned with the student's own graduate research interests, but it may not be something the student is already working on prior to the course.

Grading: Homework problems will count for 25% of the final grade. The midterm exam will count 20%. The final exam grade will count for 25%. The course project will count for 25%. In-class participation and quizzes will count for the remaining 5%.

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:

<table>
<tr><th colspan="2">1. Fundamentals of Optimization</th></tr>
<tr><th>Theory</th><th>Computation</th></tr>
<tr><td>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
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</td><td>• Linear and non-linear least-squares
• Total least squares
• Optimization examples from
    ○ Imaging
    ○ Therapy
• Regularized formulations
    ○ L1
    ○ L2
• Compare algorithms
    ○ Gradient Descent
    ○ Newton's method
    ○ Quasi-Newton methods
    ○ Stochastic Gradient Descent</td></tr>
</table>

<table>
<tr><th colspan="2">2. Image Reconstruction</th></tr>
<tr><th>Theory</th><th>Computation</th></tr>
<tr><td>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</td><td>• Basic reconstruction techniques
• Reconstruction artifacts
• Noise and resolution tradeoffs
• Regularized formulations
    ○ L1
    ○ L2</td></tr>
</table>

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 or required 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

Academic Integrity:

By enrolling in this course, each student assumes the responsibilities of an active participant in UW-Madison's community of scholars in which everyone's academic work and behavior are held to the highest academic integrity standards. Academic misconduct compromises the integrity of the university. Cheating, fabrication, plagiarism, unauthorized collaboration, and helping others commit these acts are examples of academic misconduct, which can result in disciplinary action. This includes but is not limited to failure on the assignment/course, disciplinary probation, or suspension. Substantial or repeated cases of misconduct will be forwarded to the Office of Student Conduct & Community Standards for additional review. For more information, refer to studentconduct.wiscweb.wisc.edu/academic-integrity/.

Accommodations for Students with Disabilities:

McBurney Disability Resource Center syllabus statement: “The University of Wisconsin-Madison supports the right of all enrolled students to a full and equal educational opportunity. The Americans with Disabilities Act (ADA), Wisconsin State Statute (36.12), and UW-Madison policy (Faculty Document 1071) require that students with disabilities be reasonably accommodated in instruction and campus life. Reasonable accommodations for students with disabilities is a shared faculty and student responsibility. Students are expected to inform faculty [me] of their need for instructional accommodations by the end of the third week of the semester, or as soon as possible after a disability has been incurred or recognized. Faculty [I], will work either directly with the student [you] or in coordination with the McBurney Center to identify and provide reasonable instructional accommodations. Disability information, including instructional accommodations as part of a student's educational record, is confidential and protected under FERPA.” http://mcburney.wisc.edu/facstaffother/faculty/syllabus.php

Diversity & Inclusion:

Institutional statement on diversity: “Diversity is a source of strength, creativity, and innovation for UW-Madison. We value the contributions of each person and respect the profound ways their identity, culture, background, experience, status, abilities, and opinion enrich the university community. We commit ourselves to the pursuit of excellence in teaching, research, outreach, and diversity as inextricably linked goals.

The University of Wisconsin-Madison fulfills its public mission by creating a welcoming and inclusive community for people from every background – people who as students, faculty, and staff serve Wisconsin and the world.” https://diversity.wisc.edu/