Medical Physics 574 - Imaging in Medicine: Applications

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Lecture 1

Course Overview

Course name: Imaging in Medicine: Applications

Course number: Medical Physics 574

Instructors: Diego Hernando, PhD, and Sean Fain, PhD

Session: Spring 2019

Credits: 3

1.1 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.

1.2 Learning objectives

Upon completion of this course, students should be able to:

- Distinguish various types of optimization problems (constrained vs unconstrained, 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.

1.3 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.

1.4 Related courses at UW

This course's materials build upon and complement the materials covered in Medical Physics 573 (Hernando/Fain).

1.5 Motivation

Why take this course?

- Learn mathematical foundations for understanding medical imaging and therapy planning concepts
- Become better at research: reading papers, solving problems, and writing papers

1.6 Course Structure

This course will consist of a combination of:

- White board lectures.
- Presentations with real-world examples to illustrate mathematical concepts.
- In-class discussions.
- Homework.

  - Proof-based exercises. These are pen-and-paper type questions, typically dealing with the fundamental properties of the concepts studied in class.
  - Computational exercises. *Important note: The examples given in class will be mostly based on Matlab, with a subsection of the course performed in ITK/VTK.*

- Course project.

1.7 Grading

- Midterm exam: 20%
- Final exam: 25%
- Homework sets: 25%
- Course project: 25%
- In-class participation: 5%

1.8 Online Interaction

1.8.1 Canvas

This course will rely on Canvas for important communication, content distribution, and assignments. Make sure you are familiar with Canvas (`http://canvas.wisc.edu`) and able to access this course's materials.

1.8.2 Poll Everywhere

We will also use Poll Everywhere for real-time questions. This is free and available at `http://polleverywhere.com`. Make sure you can access it. The goal of this live polling will be to assess students' understanding of the material, without direct grade impact.

We will do a test during the first lecture, located at `http://pollEV.com/diegoh314`. Note that this poll will only be active during the lecture (ie: you will not be able to access it until our first lecture).

1.9 Expectations

You can expect the instructors:

- To highlight the importance of the course materials, both the mathematical and computational aspects

- To work to ensure that all students have a chance to learn the material, given adequate effort on the students' part.
- To assign homework that adequately covers the material and meets the learning objectives of the course while adhering to the time expectations for a 3 unit course.
- To assign exams that accurately reflect the material covered in class and assigned in homework.
- To start and end class on time.

We can expect you:

- To come to class on time.
- To be attentive and engaged in class.
- To spend an adequate amount of time on each homework set, making an effort to solve and understand each problem.
- To engage with both the mathematical and computational sides of the material.
- To seek help when appropriate.

1.10 Course Project

1.10.1 Project Rules

This will be a team-based project, with 2-4 members per team. Please come talk to me if you are not sure who to work with. All members of the team are expected to contribute to the project. The lecture on March 25 (right after Spring Break) will be devoted to project pitches, where each team will describe to the class and to the instructors what their project is. Final project presentations will take place around the last week of class (specific date TBD). Students are expected to find teams within the first month of classes, discuss potential project ideas with the instructor(s) before Spring Break (either in person or over email), and work on their projects as a team (ie: where everyone contributes) during the remainder of the semester.

1.11 Ideas for course projects

The choice of specific course project is up to each team, although it needs to be approved by the instructors to ensure thematic relevance and feasibility. A typical course project would be focused on implementing and replicating the results from a published paper that proposed some new method, or evaluated an existing method for image reconstruction or processing. A reasonable addition to such project (beyond replicating the original paper) would include evaluating the failure modes of the method, eg: as SNR or other artifacts become worse. Note that this evaluation is often not included on technical development papers (which are focused on showcasing the potential success of the method). Also, there are many areas of optimization and image reconstruction and processing that are important and deep, and would be appropriate for a course project. If one of these areas is relevant to your research, or interesting to you, these may be good topics:

- Optimization:
  - Duality theory and applications
  - Simulated annealing algorithms
  - Simplex algorithm
  - Conjugate gradient (CG) algorithm
  - Graph-based optimization problems and algorithms
  - Stochastic gradient descent
  - Computational/theoretical comparison of existing algorithms
- Application of existing techniques in image reconstruction or image processing to specific problems in your research area. In addition to replicating a previously published paper, projects may include characterization of a technique, comparison of several techniques, development or optimization of a technique, etc. However, each team should make sure to define a project that is realistic in terms of time and resources. If unsure, come talk to the instructors and we can help with this. Specific types of applications include the components of this course, ie:
  - Image reconstruction
  - Image registration
  - Image segmentation

  as well as other imaging applications such as regularized parameter estimation.

Prior approval will be required for the selected topic. Criteria for approval will include the relevance to the course, feasibility, and the novelty relative to the student's prior work. If you do not have a team after a few weeks of lectures, try talking to your classmates first and, if you still do not have a team, come talk to the instructor(s). If your team does not have ideas for projects and Spring Break is approaching, try googling highly cited papers in image reconstruction and processing published over the past 15 years. If that does not work, come talk to the instructors and we will provide ideas.

1.12 Discussion Items

- Office hours (Diego)
- Students have laptops available to bring to class?
- Background: Matlab
- Background: Matrix algebra
- Background: Research interests