MDPH 704: Computational methods in Medical Physics (3 credits)

COMP 766: Advanced Topics Applications (4 credits): Applications of Computer Vision and Machine Learning to Medical Imaging

Coordinator: Peter Savadjiev.

Lecturers Peter Savadjiev and Guest lecturers TBA

Prerequisites

The following courses (or their equivalents) are pre-requisites or co-requisites: COMP 551 and either COMP 558 or ECSE 415. Otherwise, the permission of the course coordinator is required.

In addition, students should be comfortable with undergraduate-level calculus, linear algebra, probability theory, statistics. They should be comfortable with scripting and/or object oriented programming languages, as well as with mathematical/statistical platforms such as Matlab or R.

Learning objectives

By the end of the course, students are expected to be able to:

- Understand how to adapt and apply current computer vision and machine learning algorithms to clinical imaging data, which come with unique properties and constraints.
- Discuss strengths and limitations of different classes of algorithms
- Implement, test and evaluate representative algorithms

Topics to be covered:

Introduction and Background

- Week 1:
  - Clinical context and needs: risk stratification, prognosis, prediction, therapy
  - Image Biomarkers. Currently used imaging biomarkers in clinical practice
  - Overview of modern applications of computer vision and machine learning to medical image analysis. Mismatch between clinical needs and current technological progress: lessons to be learned from a lean business model.
  - History of computerized medical image interpretation
- Week 2: Introduction to medical image processing pipelines.

Part 1: Model-driven medical image analysis

- Weeks 3 and 4: Generative models in medical image analysis. Active appearance models, Mixtures of Gaussians, atlas-based models, shape-based models, computational anatomy. Example applications.

Part 2: Data-driven medical image analysis

- Week 5: Discriminative models in medical image analysis. Image representation via sets of features. Traditional radiomics feature sets: first-order, second order and higher order texture descriptors. Wavelet-based descriptors. Standardization of the features' definitions and the algorithms that compute them.
- Weeks 6 and 7: Feature selection, model building and classification in radiomics. Applications.
- Week 8: Compressed sensing, sparse coding and dictionary learning with applications to medical image acquisition and analysis.

Part 3: Deep-learning models for medical image analysis

- Weeks 9 and 10: Deep Radiomics: CNNs for medical image analysis. Review of CNNs, example applications, strengths and limitations of the CNN approach.
- Week 11: Compositional hierarchical models (CHMs): deep alternatives to the CNN approach. Introduction, definition of CHMs, algorithms for model construction and learning, example applications.

Part 4: Clinical applications

- Week 12: Applications specific to radiotherapy: Automatic target delineation, Image-guided adaptive Radio Therapy, In situ outcomes assessment
- Week 13: Multimodal analysis approaches combining imaging and non-imaging data (such as text reports, physiological variables, genomic variables etc)

Grading scheme:

Since there is a difference in credits awarded between MDPH 704 and COMP 766, there will be two separate grading schemes, one for students registered in MDPH 704 and one for those registered in COMP 766.

For MDPH704:
Assignments 40%, Midterm exam: 20%, Final exam: 40%

For COMP 766:
Students registered in COMP 766 will have to do a research project, in addition to assignments and exams. This project will involve selecting a topic of relevance to the course material, performing a literature review, implementing a relevant algorithm, and discussing its strengths and limitations.
For COMP SCI students, the grading scheme will be as follows:
Assignments 25%, Course project 25% Midterm exam: 20%, Final exam: 30%

Assignments:

There will be three assignments. Each assignment will be a combination of theory questions, a paper critique, and an implementation of a representative algorithm on test data provided by the instructor.
The first assignment will cover the course introduction and Part 1.
The second assignment will cover Part 2.
The third assignment will cover Parts 3 and 4.

Course project

The course project will follow the main stages of a writing a research paper. It will involve:

- Assembling a literature review on a selected topic
- Implementing an algorithm within the selected topic area.
- Applying the algorithm on appropriate dataset(s), either provided by the instructor or obtained via public databases
- In depth discussion of the results

It is expected that the course project will involve a total of approximatively 40 hours of work. A written report of the project will be submitted. Maximum length: 8 pages, following a standard journal template to be provided by the instructor.

Reading list:

Simon Prince (2012) Computer Vision: Models, Learning and Inference. Cambridge University Press. http://www.computervisionmodels.com/

Trevor Hastie, Robert Tibshirani, Jerome Friedman (2016) The elements of statistical learning: data mining, inference and prediction. Springer, 2nd edition. https://web.stanford.edu/~hastie/Papers/ESLII.pdf

A bibliography of scientific articles to be provided by the instructor