Spring 2024 Medical Imaging with AI: Syllabus and Schedule

Schedule	Syllabus	Lecture Slides	Piazza

Course Description:

This course introduces the foundation for understanding, manipulating, and analyzing medical images. The topics include introducing AI concepts and tools to students, understanding and manipulating various types of medical data, data harmonization, biomedical image registration, segmentation, and disease localization. We will discuss how to develop resilient algorithms for various confounders common in the medical imaging domain, jointly analyze medical image data with other data modalities, and create an explainable AI method specifically for medical imaging applications.

Prerequisites: Linear Algebra, probability, and prior coursework in machine learning and programming experience in Python. Familiarity with Deep Learning is a big plus.

Lecture:

ENG EC500
M/W 10:10am-11:55am, SOC-B59

Instructor:

Kayhan Batmanghelich
office hours: Momday 12pm-1pm
Location: outside PHO 421

Teaching Assistant:

Li Sun (lisun@bu.edu),
Office hours: Thursday 3PM-4PM
Location PHO 4th floor

Graders/Additional Staff:

Shuyue Jia (brucejia@bu.edu)
Susan Zhang (szha@bu.edu)

How to Contact Us: Please use Piazza for all communication; if your question is only directed to the instructors, please make a post to “Individual Student(s) / Instructor(s)” and select “Instructors".

Piazza: https://piazza.com/bu/spring2024/ec500

We will be using piazza for online discussions, questions, and posting assignments.

Gradescope: We will be using Gradescope to submit and grade assignments.
Gradescope link: https://www.gradescope.com/courses/707758, Entry Code:WBZX8R

Schedule*

	Topic (Instructor)	Details	Homework
Mon Jan 22	Course overview, basic concepts, visualization tools	What is medical imaging? syllabus & course logistics, basic ideas of pixel/voxel, metadata, some tours of visualization	

		tools, various data types, various packages **Resources**: • ITKSNAP: https://www.youtube.com/watch?v=-tjVN5GwjKg •	
Wed Jan 24	Medical Image Modalities I	MRI, CT, X-ray, Ultrasound, Histopathology images **Resources**: • CT:http://capone.mtsu.edu/phys4600/Syllabus/CT/Lecture_5/lecture_5.html • Physics of CT: https://www.youtube.com/watch?v=PI6vgzg5l7E •	HW1 out (machine learning prereq)
Mon Jan 29	Medical Image Modalities II	MRI, CT, X-ray, Ultrasound, Histopathology images (continue) **Resources**: • NMR Basics: https://www.youtube.com/watch?v=TQegSF4ZiIQ • High level physics of MR: https://youtu.be/Yubg0cmXSQg?si=wXR8_mmdyswwME8b **More Resources**: • This is great if you want to learn more about image formation: https://www.youtube.com/watch?v=Uyf3A87q7g4&t=14s •	
Wed Jan 31	Dealing with Medical Images	Bias Field correction, Histogram Normalization, denoising, Masking **Resources**: • Original N3 paper (bias field correction) is uploaded to the Resource section in Piazza. • Improved version (called N4) is uploaded to the Resource section in Piazza. **More Resources**: • I briefly mentioned B-Spline. If you want to learn more watch this 3 videos (each 5 min): https://youtu.be/YMl25iCCRew?si=wCc9WvgUwnsQpTtx •	
Mon Feb 5	Math/ML Review I	Probability, distributions, maximum likelihood, empirical risk minimization	
Wed Feb 7	Introduction to Deep Learning I	Generalization, train/validation/test splits, optimization, loss, basics of deep learning, backpropagaiton	HW1 Due
Mon Feb 12	Project Pitch I and II		
Wed Feb 14	Project Pitch III and IV		
Mon Feb 19	NO CLASS		
Wed Feb 21	Introduction to Deep Learning II	Popular architecture (CNN and family), classification, regression	Project Proposal Due Template How to make a group submission
Mon Feb 26	Introduction to Deep Learning III	Residual Neural Networks, Attention Layers, Transformers	

Wed Feb 28	Medical Image Classification and Regression	Popular Classification and regression architectures, handing 3d images, Augmentation	HW2 out
Mon Mar 4	Object Detection and Localization	Formulation, handling imbalanced data **Resources**: • Object detector: https://youtu.be/TB-fdISzpHQ?si=DmFNhej5UfEj9BX2 •	
Wed Mar 6	Classical Medical Image Segmentation	Region growing, Level set, Metrics for evaluation	
Mon Mar 11	NO CLASS		
Wed Mar 13	NO CLASS		
Mon Mar 18	Modern Medical Image Segmentation	Unet, Transformer-based model	HW2 due HW3 out
Wed Mar 20	Basics of Image Registration I	Moving and fixed spaces, interpolation, affine, rigid, non-linear transformation **Resources**: • Chapter 13: Parametric Image Registration • Chapter 14: Non-parametric Image Registration (up to section 14.3	Project Status Report Due Thu 11:59pm Template
Mon Mar 25	NO CLASS		
Wed Mar 27	Basics of Image Registration II	Deformable Image Registration **Resources**: • Chapter 13: Parametric Image Registration Chapter 14: Non-parametric Image Registration (up to section 14.3	
Mon Apr 1	Modern Image Registration	Deep Learning based image registration	
Wed Apr 3	Uncertainty	Calibration, Conformal Prediction (?), How to estimate uncertainty in segmentation and classification	HW3 due HW4 out
Mon Apr 8	Unsupervised Learning I	Self-supervised Learning	
Wed Apr 10	Unsupervised Learning II	VAE, GANs, Diffusion Models	
Mon Apr 15	NO CLASS		
Wed Apr 17	Interpretability I	Feature attribution, Counterfactual methods	HW4 due
Mon Apr 22	Interpretability II	Feature attribution, Counterfactual methods continues …	
Wed Apr 24	Help with **project** [email to take slot]	Come to my office to discuss your project.	
Mon Apr 29	Project Presentations	Work on your projects	
Wed May 1	Project Presentations	Send slides (or slide link) to my email	Slides due Tue

	Final Project reports/code due (No lecture)	Upload your reports on GradeScope, **use the template** [Sample Projects: reports, slides]	Apr 29, 11:59pm [Slide Template] Report Due Wed 11:59pm MIDNIGHT [ReApril port Template]

*schedule is tentative and is subject to change.

Syllabus

Course Prerequisites

This is an upper-level undergraduate/graduate course. All students should have the following skills:

- Calculus, Linear Algebra
- Probability & Statistics
- Ability to code in Python
- Background in machine learning (e.g., EC 414, EC 503, CS 542)

Textbook

We use chapters from two sets of books. One is for deep learning, and one is for medical imaging. For deep learning, the books are online and free. For medical imaging, I will distribute copies of the chapter through Piazza.

Deep Learning Books

- Ian Goodfellow, Yoshua Bengio, Aaron Courville. Deep Learning. MIT Press, 2016.

This book is available online, and need not be purchased. Another recent book is

- Aston Zhang, Zack C. Lipton, Mu Li, and Alexander Smola. Dive into Deep Learning, 2020.

Medical Image Analysis

- Editors: Alejandro Frangi, Jerry Prince, Milan Sonka, Medical Image Analysis, Paperback ISBN: 9780128136577, eBook ISBN: 9780128136584

Other Useful Resources

Deep Learning and Pytorch

This course involves coding and, more specifically, using PyTorch. We strongly recommend all students become fully comfortable with PyTorch. There are many resources online to learn PyTorch. Here are some:

- https://www.coursera.org/learn/deep-neural-networks-with-pytorch
  There are many resources online to learn Deep Learning. Here are some resources for online courses
- http://cs231n.stanford.edu/ CS231n: Convolutional Neural Networks for Visual Recognition
- http://web.stanford.edu/class/cs224n/ CS224n: Natural Language Processing with Deep Learning
- http://rll.berkeley.edu/deeprlcourse/ CS 294: Deep Reinforcement Learning
- http://distill.pub/ Very nice explanations of some DL concepts

MONAI

MONAI is a PyTorch platform for applying Deep Learning to medical images.

- This is a link to MONAI tutorials. There are too many of them: https://github.com/Project-MONAI/tutorials
- I recommend making yourself comfortable with the following:
  - https://github.com/Project-MONAI/tutorials/blob/main/2d_classification/mednist_tutorial.ipynb
  - https://github.com/Project-MONAI/tutorials/tree/main/2d_segmentation/torch
  - https://github.com/Project-MONAI/tutorials/blob/main/modules/nifti_read_example.ipynb
  - https://github.com/Project-MONAI/tutorials/tree/main/3d_segmentation/torch

SimpleITK
SimpleITK is python package we use to manipulate images and perform some basic image processing on medical images. We have a basic level of familiarity with it:

- This is a link to SimpleITK tutorials. There are too many of them: https://simpleitk.org/TUTORIAL/
- I recommend the following two:
  - Introduction: https://youtu.be/YBA-OST6t6E
  - Foundations: https://youtu.be/kbkv4L0U45w

Deliverables/Graded Work

There will be five homework assignments, each consisting of written and/or coding problems and a final project. Homework grade will be based on a randomly selected subset of questions (the same for everyone). The worst homework grade will be dropped. The project will be done in teams of 3-4 students and will have several deliverables, including a proposal, progress update(s), final report, and a final in-class/virtual presentation. The course grade consists of the following:

- HomeWorks (hw1 and weighted* sum of 2-4) 50%
- Project (including all components) 45%
- Class/Piazza participation 5%

*About the weighting: We sort the scores of HW2, HW3, and HW4 and apply this formula: 30% (HW1) + 30% (1st score) + 30% (2nd score) + 10% (3rd score)

Software/Hardware

Programming assignments and projects will be developed in the Python programming language. We will also use the pytorch deep learning library for some homeworks and for the project. Students are expected to use the Shared Computing Cluster (SCC) and/or their own machines to complete work that does not require a GPU. For the projects, we will provide GPU resources.

If you do not already have a CS account and would like one, you should stop by the CS undergraduate lab (EMA 302) and activate one. This process takes only a few minutes and can be done at any time during the lab's operating hours: <http://www.bu.edu/cs/resources/laboratories/undergraduate-lab/>

Late Policy

Late work will incur the following penalties

- Project deliverables: 20% off per day up to 2 days
- Homework 20% off per day, up to 3 days
- We will automatically down weight the lowest-scoring homework (except hw1). See the grading policy for more details.

Academic Honesty Policy

The instructors take academic honesty very seriously. Cheating, plagiarism and other misconduct may be subject to grading penalties up to failing the course. Students enrolled in the course are responsible for familiarizing themselves with the detailed BU policy, available here. In particular, plagiarism is defined as follows and applies to all written materials and software, including material found online. Collaboration on homework is allowed, but should be acknowledged and you should always come up with your own solution rather than copying (which is defined as plagiarism):

> **Plagiarism**: Representing the work of another as one's own. Plagiarism includes but is not limited to the following: copying the answers of another student on an examination, copying or restating the work or ideas of another person or persons in any oral or written work (printed or electronic) without citing the appropriate source, and collaborating with someone else in an academic endeavor without acknowledging his or her

contribution. Plagiarism can consist of acts of commission-appropriating the words or ideas of another-or omission failing to acknowledge/document/credit the source or creator of words or ideas (see below for a detailed definition of plagiarism). It also includes colluding with someone else in an academic endeavor without acknowledging his or her contribution, using audio or video footage that comes from another source (including work done by another student) without permission and acknowledgement of that source.

Religious Observance

Students are permitted to be absent from class, including classes involving examinations, labs, excursions, and other special events, for purposes of religious observance. In-class, take-home and lab assignments, and other work shall be made up in consultation with the student's instructors. More details on BU's religious observance policy are available here.