

Biomedical Image Analysis – Fall 2025 Syllabus

1. Course Description

This advanced graduate course covers the theoretical and practical fundamentals of modern quantitative image analysis that apply to the major modalities in biomedical imaging. The course combines in-depth examination of image registration and segmentation techniques that are now considered classical with an overview of modern approaches based on deep learning. Students will work with real-world imaging datasets as part of their Python-based programming assignments. After completing the course, students will be prepared to pursue independent study and research in biomedical image analysis.

2. Course Objectives

After completing this course, you should:

- Understand the basic principles that underlie the most widely used tools of medical image analysis, such as deformable registration, intensity-based and model-based segmentation.
- Know how to formulate common image analysis tasks as energy minimization problems that can be solved using numerical optimization.
- Be able to independently write code that implements 3D medical image processing and analysis algorithms in Python and the deep learning framework PyTorch
- Have experience using advanced image analysis software packages and libraries
- Be prepared for independent research in image analysis

3. Course Staff

Instructor:

Paul Yushkevich, Ph.D.
Professor
Department of Radiology
Richards Building, Room D605
Email: *please use Ed Discussion!*

Teaching Assistants:

Chinmayee Athalye,
Nidhi Mundada, Anindro Bhattacharya
Ph.D. Students
Department of Bioengineering
Email: *please use Ed Discussion!*

We will use Ed Discussion for content and assignment related questions!

4. Basic Information

Official Course Time: Mondays and Wednesdays, 3:30 – 5:00 PM EST
Location: 114 Fagin Hall
TA Office Hours: Tue 4:00-5:00pm and Thu 9:30-10:30am
[Holman Biotech Commons](#) (room varies, [see schedule](#))
Instructor's Office Hours: By Appointment
Course Materials: <https://canvas.upenn.edu/>
Ed Discussion: <https://edstem.org/us/courses/83713/discussion>

5. Academic Integrity and Plagiarism

We will strictly adhere to the University of Pennsylvania Code of Academic Integrity, which can be found at the link below. If during the semester you find that you are struggling with your workload or have other factors impeding your ability to complete assignments, please do not resort to cheating. Contact the instructor (and/or your academic advisor) and together we will work to find a solution.

<https://catalog.upenn.edu/pennbook/code-of-academic-integrity/>

It is important to recognize and avoid plagiarism. Plagiarism means including someone else's work as part of your own without proper attribution. For example, using phrases or sentences from some other source without quoting and citing the original source; paraphrasing someone else's ideas without citing; using source code written by someone else in a programming assignment without clearly acknowledging it; even using figures in a presentation without providing credit to the source of these figures. Using text, code, or media generated by AI models like ChatGPT without citation and acknowledgement also constitutes plagiarism. Plagiarism is unacceptable on any of the assignments in the course, including programming assignments, writing assignments, oral presentations, and all other assignments. If you are unsure if something you wrote might be considered plagiarism, check with the instructor before submitting it.

Suspected violations of the academic code, including suspected plagiarism and cheating, will be referred upon discovery to the Center for Community Standards and Accountability.

6. If You Are Struggling in this Class...

BE5370 is a challenging course. If you find yourself struggling in this class, you are probably not alone, and it is ok to feel this way. Be kind to yourself and ask for help!

- Do not hesitate to reach out to me or the TAs if you are falling behind on coursework, or if there are aspects of the course that contribute negatively to your wellbeing. The earlier you let us know, the easier it will be for us to find a way to help.
- Remember to take advantage of all resources at your disposal. These include Ed Discussion messages addressed to the TAs and your peer students, office hours, lecture recordings, and your assignment group partners.
- Penn Wellness offers virtual services by professional counselors who are really good at helping students address stress related to the pandemic. No issue is "too small" or "too insignificant" and it is better to ask for help sooner rather than later. They can be reached 24/7 at 215-898-7021 or via their website <https://wellness.upenn.edu/>

7. Prerequisites

Math. This class will draw on many areas of applied mathematics. At the minimum, you should have a solid grasp of multivariate calculus (MATH 241 is required) and linear algebra. Experience in at least some of the following areas is very valuable for the course: probability and statistics, differential equations, curve/surface geometry, and numerical methods. Although some mathematical background will be presented during the course, students are expected to fill the gaps in their mathematical background on their own.

Programming. The course involves a large programming component and programming experience is necessary to complete the course. **Programming assignments will use Python and mathematical libraries PyTorch and NumPy.** If you have not programmed in Python before, you will need to catch up in the first two weeks of the semester. Links to Python primers for MATLAB users will be provided on Canvas.

- Contact us on Ed Discussion if you are unsure about your level of math and programming

8. Undergraduate Admittance Policy

Undergraduate students require permission to take the course. Undergraduate students must meet the course prerequisites and have the combined GPA of 3.5 or higher in Mathematics, Computer Science and Bioengineering courses. Please email the instructor with the following:

- Why this course is important to you;
- GPA calculated for the relevant courses (Math, CS, BE);
- Unofficial transcript with courses in these subject areas highlighted (as PDF attachment)

9. Course Organization and Reading Materials

Class time will be divided into instructor-led lectures and a few guest lectures. The lectures are organized into three modules: Introduction, Segmentation, and Registration. The suggested textbook for this course is

- Frangi, A., Prince, J. and Sonka, M. eds., 2023. [*Medical Image Analysis*](#). Academic Press.

However, the textbook is marked as optional, and if you decide not to get the textbook, there are papers listed for each reading assignment that you can read instead. The schedule at the end of the syllabus lists the tentative lecture topics and the assigned reading for each day, with a link to the PDF.

10. Course Format

The course will be held in person and there will be no support for remote participation. Some lectures may be recorded, but it is the students' responsibility to be present at lectures and participate in class in person. Students who are unable to come to class due to family emergency, illness, or conference travel can request access to prior years' lecture recordings by contacting us on Ed Discussions.

11. Homework and Grading

The homework assignments and grade breakdown for this semester are as follows:

Assignment	Weight	Description
Programming assignments	50%	Two programming assignments, submitted in phases, each weighted 25%.
In-class exams	25%	Two exams cover main material from lectures and programming assignments. The lower of the two grades is weighted 10% and the higher grade 15%.
Project/Presentation	25%	Small project and presentation conducted over the course of the semester, focused on medical image analysis software.

11.1. How to submit assignments

Homework assignments must be turned on Canvas using the GradeScope tool. For group assignments, only one person per group should submit the assignment.

11.2. Late homework policy

Unless noted otherwise, assignments are due by 3pm on the due date. Late assignments will be penalized:

- 2 points off if you miss the 3pm deadline.
- 2 points off for each 24-hour period after the deadline

Exceptions to the policy may have to be made when there are extenuating circumstances. However, for an assignment to be considered for an exception, the student must let the instructor or TA know why they will be turning in an assignment late ahead of the deadline.

11.3. Group assignment policies

The two programming assignments and the final project are group assignments.

Equal share of work. I expect all members of a group to do an approximately equal share of work on each assignment. If you find that a group member is not doing their fair share, you need to let me know as early as possible, so that there is an opportunity to intervene, and, in rare circumstances, adjust the grades of the team members. However, if you do not alert me ahead of submission deadline that there is a problem, I will not be able to adjust grades retrospectively.

Changing groups between assignments. The groups for the two Python assignment should be different. If two students were together in a group on the first assignment, they cannot be together in a group for the second assignment. However, they can be together in a group for the final project.

Getting assigned to groups. During the first week of class, you will have the opportunity to assign yourselves to groups on Canvas freely (under “People”). If at the end of this period you have not assigned yourself to a group, we will randomly assign you to a group. Students who join the class after the first week should contact the instructor and TAs to ask to be assigned to groups.

11.4. Guest lectures

Please make every effort to attend guest lectures and to participate by reading assigned materials and participating in the Q&A. Material from guest lectures is likely to be included on assessments.

11.5. Programming assignments

There will be two Python programming assignments (segmentation and registration).

- Assignments should be done in teams. For the first assignment, which is done in teams of three, we will assign students to teams in the first week.
- Teams should be changed between assignments. If you worked with someone on the first assignment, then you must do the other assignments individually or with another partner.

- If you work in a team, each of you is still expected to work on the entire assignment, as opposed to splitting the work in halves/thirds. This is so that all students in the group learn from the assignment and from each other. Consider coding together side-by-side or online.
- Assignments should be completed as Python interactive notebooks. You can use [Jupyter Lab](#) on your computer or a cloud-based service such as [Google Collaboratory](#). I have also applied for Google Cloud Service credits for the course (\$50 per student) to facilitate GPU access.
- Turn in your assignments by uploading the **.ipynb** file on Canvas. Upload only one report per group.
- To get full marks for a programming assignment, you must complete all the required parts of the assignment. However, the grade also considers the quality and clarity of the written text (included as Markdown cells in your notebook), quality of the figures and plots, code quality and documentation.
- Start working on the assignments as early as possible. The assignments are a major component of the grade and will take several weeks to complete. The assignments are divided into phases, and each phase should be turned in on its due date.
- If you get stuck, ask for help by posting a question on Ed Discussion. Most questions should be posted publicly (anonymously if you wish) so that the entire class can benefit from the answer and so that you can benefit from your classmates' insight.

TA Availability: The main role of the TAs is to provide clarifications, answer questions about course material, and provide general guidance about the programming assignments. The TAs cannot be expected to directly help individual students write or debug code. Please post all your assignment-related questions on Ed Discussion and make these posts visible to the whole class. This way others in the class will be able to provide insight on your questions and everyone will benefit from the TAs answers.

Discussing with Peers. It is acceptable to discuss homework assignments with other students in the class at the general level. However, you may not share your code with other groups, or incorporate code from another group into your own. The rules regarding plagiarism apply, and any code copied or modified from another source must be marked as such with the appropriate acknowledgement given. If in doubt, ask us.

Discussing with AI chat bots. Treat chat bots like fellow class members: it is ok to ask general questions, use bots to help you locate functions or make sense of documentation, but it is not ok to have a chat bot write code or text for you. Remember that material in the programming assignment will likely be covered on the exams.

11.6. Exams

Exams covering segmentation and registration modules will focus on the material covered in lectures and programming assignments. They will include multiple choice or short answer problems, free response questions, and derivations. These must be completed on paper in class. Electronic devices may not be used during the exam. You may bring a one-page cheat sheet for the exam. You may use both sides of the paper, and the cheat sheet may be hand-written or typed, but it should be readable without a magnifying glass.

11.7. Software Project

The software project involves preparing a demo and a recorded presentation about an impactful tool or software technology related to medical image analysis. There are two submissions for the software project:

- Proposal (mid-semester): each team should select three potential software tools to present and rank them in order of preference. We will assign a tool to each team to minimize overlap.
- Final submission: submit a Jupyter notebook with your demo and a recording of your presentation. The presentations will be viewed by the whole class during the two-hour period designated for the final exam.

12. Tentative Lecture Schedule: Subject to Change!

Please check for updated versions of the syllabus on Canvas for updates.

Date	Lecture Topics	Reading Assignment (read before the lecture)	Homework Handed Out and Due
Wed, Aug 27	Course Introduction Discuss course objectives, assignments. Discuss quantitative image analysis and its applications.		
Mon, Sep 01	LABOR DAY – NO CLASS		
Wed, Sep 03	Introduction to Segmentation I Applications of segmentation in medical imaging; types of segmentation approaches; segmentation from the Bayesian perspective	- Pham et al., "Current methods in medical image segmentation" - Cheng et al., "Deep learning: an update for radiologists"	HW1 Handed Out
Mon, Sep 08	Introduction to Segmentation II Bayesian segmentation continued; hands-on introduction to ITK-SNAP, C3D, and Greedy	Ch. 1-2 in Prince & Links, "Medical Imaging Systems and Signals"	<i>Class selection period ends 9/09</i>
Wed, Sep 10	Statistical Segmentation I Statistical estimation; Gaussian mixture models; expectation-maximization algorithm.	Sridharan, "Gaussian mixture models and the EM algorithm".	
Mon, Sep 15	Statistical Segmentation II Spatial priors for statistical segmentation; Markov random fields.	Textbook Ch. 10 or Li, "Markov random field models in computer vision"	
Wed, Sep 17	Statistical Segmentation III Graph cuts for image segmentation.	Textbook Ch. 10 or Boykov et al., "Fast approximate energy minimization via graph cuts"	HW1 Phase I Due
Mon, Sep 22	Guest Lecture on Neuroimaging by Prof. John Detre History of brain imaging; basic MRI principles; MRI biomarkers in disease; functional, diffusion and perfusion MRI.	Ch. 3 in Prince & Links, "Medical Imaging Systems and Signals"	
Wed, Sep 24	Deep Learning and CNN Introduction Multilayer perceptron, convolutional neural networks, getting started with PyTorch.	Watch the introductory and convolutional neural nets lectures from the MIT 2022 Intro to Deep Learning Course.	
Mon, Sep 29	DL Segmentation I Review of the UNet architecture. Losses used for segmentation. Augmentation strategies for segmentation. Segmentation with geometric constraints.	- Textbook Ch 18 or Ronneberger et al., "U-Net: Convolutional Networks for Biomedical Image Segmentation" - Isensee et al., "nnU-Net: a self-configuring method for deep learning-based biomedical image segmentation"	
Wed, Oct 01	DL Segmentation II State-of-the art image segmentation networks; transformers; augmentation and self-supervised learning.	Taleb et al., "3D Self-Supervised Methods for Medical Imaging"	HW1 Phase II Due

Date	Lecture Topics	Reading Assignment (read before the lecture)	Homework Handed Out and Due
		Wachinger et al., “DeepNAT: Deep Convolutional Neural Network for Segmenting Neuroanatomy”	
Mon, Oct 06	Active Contour Segmentation I Formulating segmentation as a contour evolution problem; edge-based active contour models; level set method.	Textbook Ch. 9 or Caselles et al., “Geodesic active contours”.	Drop period ends
Wed, Oct 08	Active Contour Segmentation II Formulating segmentation as a contour evolution problem; edge-based and region competition active contour models; level set method.	Textbook Ch. 9 or Zhu and Yuille, “Region competition”	
Mon, Oct 13	DL Segmentation III Weakly supervised segmentation; segmentation with topological constraints; segmentations with geometric models.	- Hu et al., “Topology-Preserving Deep Image Segmentation” - Hoopes et al., “TopoFit: Rapid Reconstruction of Topologically Correct Cortical Surfaces”	Return from fall break
Wed, Oct 15	Guest Lecture on Geometric Representations by Prof. Alison Pouch Geometric object representations; shape spaces; Procrustes analysis; shape-based segmentation; applications in heart valve segmentation and shape analysis.	Textbook Ch. 8 and Ch. 11.1/11.2 or Heimann and Meinzer, “Statistical shape models for 3D medical image segmentation: A review”	HW1 Final Submission
Mon, Oct 20	Catch Up Day		
Wed, Oct 22	Intro to Registration I Overview of basic registration concepts; registration pipeline.	- Sec. 1-9 in Maintz & Viergever “A survey of medical image registration” - Viergever et al. “A survey of medical image registration – in review”.	
Mon, Oct 27	Exam: Segmentation Students must be present in person for the pen and paper exam.		HW2 Handed Out
Wed, Oct 29	Intro to Registration II Linear and non-linear transformations in 1D; Squared difference and normalized cross-correlation metrics.	Textbook Ch. 13 (preprint PDF on Canvas).	
Mon, Nov 03	Rigid and Affine Registration Rotation matrices; parameterizing rotations; exponential maps; quaternions; rigid registration; polar decomposition of affine transforms; affine registration.	- Taubin, “Representing rotations” - Shoemake & Duff, “Matrix animation and polar decomposition”.	Last day to withdraw
Wed, Nov 05	Deformable Image Registration I Parametric registration using radial basis functions; introduction to diffeomorphisms	Textbook Ch. 14.1-14.3 (preprint PDF on Canvas).	Software Project Proposal Due
Mon, Nov 10	Deformable Image Registration II Optical flow algorithm; optical flow as building block of deformable registration; diffeomorphic demons.	Vercauteren et al., “Diffeomorphic demons”.	
Wed, Nov 12	Deformable Image Registration III Large deformation diffeomorphic metric mapping (LDDMM).	Textbook Ch. 14.4 (preprint PDF on Canvas).	

Date	Lecture Topics	Reading Assignment (read before the lecture)	Homework Handed Out and Due
Mon, Nov 17	Multi-Modality Registration with Mutual Information Information; entropy; joint entropy; mutual information; mutual information-based metrics for image registration.	• Studholme et al., "An overlap invariant entropy measure of 3D medical image alignment". • Heinrich et al., "MIND: Modality-independent neighborhood descriptor for multi-modal deformable registration".	HW2 Phase I Due
Wed, Nov 19	Groupwise Registration Templates in medical imaging; Fréchet mean; unbiased population templates; detailed atlases of the human medial temporal lobe.	• Joshi et al., "Unbiased diffeomorphic atlas construction for computational anatomy".	
Mon, Nov 24	Deep Learning Registration I CNNs for linear, parametric non-linear, and non-parametric registration; Intro to representation learning.	• Textbook Ch. 19 or Dalca et al., "VoxelMorph: A learning framework for deformable medical image registration".	
Wed, Nov 26	THANKSGIVING BREAK – NO CLASS		
Mon, Dec 01	Deep Learning Registration II Image-to-image translation using generative adversarial models; joint registration and image-to-image translation.	• Park et al., "Contrastive Learning for Unpaired Image-to-Image Translation".	
Wed, Dec 03	Catch-Up Day		HW2 Phase II Due
Mon, Dec 08	Exam: Registration Students must be present in person for the pen and paper exam.		
Final Exam Period (TBD)	Software Project Presentations Students may attend in person or on Zoom.		Software Project Due