Biomedical Image Analysis – Fall 2018 Syllabus

# Course Description

This course covers the theoretical and practical fundamentals of modern quantitative image analysis that apply to all of the major and emerging modalities in biological imaging and in vivo biomedical imaging. While traditional image processing techniques will be discussed to provide context, the emphasis will be on advanced algorithms for image registration, image segmentation, and statistical shape analysis. Students will work with real-world imaging datasets as part of their course assignments.

# Course Objectives

These are the main educational goals of BE537:

* To instill an understanding of the theoretical Bayesian framework upon which most modern biomedical image analysis methods are based;
* To provide an in-depth understanding of specific image segmentation and registration algorithms through a combination of classroom and hands-on learning;
* To prepare students for independent research involving image analysis by exposing them to the field and requiring them to complete a major research project;
* To improve students’ oral and written scientific communication skills through course presentations and high-quality written reports.

# Course Staff

Instructor: Teaching Assistants:

Paul Yushkevich, Ph.D. Ahmed AlyAssociate Professor Ph.D. StudentDepartment of Radiology Department of Bioengineering6th Floor Richards Building, Room 605 6th Floor Richards BuildingEmail: [pauly2@pennmedicine.upenn.edu](mailto:pauly2@grasp.upenn.edu) Email: *please use Piazza!*

***We will use Piazza for content and assignment related questions!***

# Basic Information

Course Times MW 3-4:30

Location Towne 303

Final Exam Wednesday, Dec 11, 3pm (during the last scheduled class)

Final Presentations Tuesday, Dec 18, 3-5pm (during the official final exam time)

TA’s Office Hours TBD

Instructor’s Office Hours By appointment

Course Materials <http://canvas.upenn.edu>

Piazza Site [https://piazza.com/upenn/fall2018/be537/home](https://piazza.com/class/jk9zzrwsl3g1j7?cid=4)

# Academic Integrity - THIS IS IMPORTANT!!!

All students must read, understand and adhere to the University of Pennsylvania Code of Academic Integrity, which can be found at the link below:

<http://www.upenn.edu/academicintegrity/index.html>

**In particular, be certain that you understand fully what is 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 Office of Student Conduct (OSC). Once the matter has been referred to the OSC, it is handled between the OSC and the student, and the instructor has no way to reverse the referral or influence the OSC decision. Violations of the academic integrity code in the course can result in serious sanctions, such as suspension from the University.

*Before any assignment can be turned in for a grade, you will need to complete the plagiarism quiz located under the Academic Integrity tab on Canvas.*

# Texting Policy

Please try to not get distracted with electronic devices during class. If you have pressing family/personal matters and expect an urgent text message, leave your phone on your desk. Otherwise, please put it away during class. Please don’t hide the phone under the desk, it is obvious to the instructor and very distracting.

# Course Outline

The course is organized into four modules: Introduction, Registration, Segmentation, and Shape Analysis. The main topics covered in each component are listed below.

Module 1. Introduction

* Introduction to biomedical image analysis
* Review of signal and image processing
* Review of biomedical imaging modalities and applications

Module 2. Registration

* Review of variational calculus and numerical optimization
* Transformation models (rigid, affine, deformable, diffeomorphic) in 1-D and N-D
* Image similarity metrics (mutual information, cross-correlation)
* High-dimensional deformable registration (optical flow, Demons, LDDMM)
* Groupwise registration and atlas building
* Graph-based deformable registration (time allowing)
* Deformation-based and voxel-based morphometry (time allowing)

Module 3. Segmentation

* Edge and feature detection
* Pattern theory and Bayesian statistics
* Statistical image segmentation (clustering, mixture models, Markov random fields)
* Graph-based segmentation
* Multi-atlas and patch-based segmentation
* Active snakes, active contours and level sets

Module 4. Shape Analysis and Other Topics

* Geometric object representations and shape spaces
* Active shape and appearance models
* Medial representations
* Deep Learning in Image Segmentation and Registration

# 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.

Computing. Computer programming experience and basic knowledge of a Unix-like command line environment are strongly recommended. Programming assignments require MATLAB programming. If you have not programmed in MATLAB before you will need to learn this in the first 1-2 weeks of the semester.

* *Contact me immediately if you are unsure that your level of preparation is adequate for the course*

# Undergraduate Admittance Policy

The course is work-intensive and historically has been ranked in the top 75% of BE graduate courses for difficulty. 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)

# Reading Materials

There is no textbook for this course. Reading assignments will largely consist of published conference and journal papers. Reading materials are available on Canvas, under Modules.

# Course Organization and Assignments

Class time will be divided into instructor-led lectures and a few guest lectures. Lecture notes and presentation slides will generally be available on Canvas after each lecture. Students will complete several assignments outside of class, detailed below.

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| **Assignment** | **Weight** | **Description** |
| Programming  Assignments | 42% | Three MATLAB programming assignments, which may be done individually or in groups of two. |
| Team Project | 40% | Larger independent project involving image analysis. Includes a proposal, progress reports, final report and final presentation. |
| Quizzes | 18% | A quiz will be held after the due date of each programming assignment. It will consist of a few multiple-choice questions covering lecture topics and an open question related to the programming assignment. |

* 1. How to submit assignments

Homework assignments must be turned on Canvas using the Assignment tool.

* 1. Late homework policy

Unless noted otherwise, assignments are due by 3pm on the due date. Late work will only be accepted without a penalty in the presence of previously communicated serious extenuating circumstances (e.g., illness, family emergency). You must inform the instructor or TA of the circumstances ahead of the deadline.

Late penalties are as follows:

* 3 points off if you miss the 3pm deadline.
* 2 points off for each 24-hour period after the deadline
* Missing an oral presentation will result in a zero grade on the presentation
  1. Guest lectures

There are guest lectures that may be given by faculty members at Penn or visiting scientists. It is essential that you make every effort to attend these guest lectures and to participate by reading assigned materials and asking questions. Material from guest lectures is likely to be tested on quizzes.

* 1. Programming assignments

There will be three programming assignments in the course:

1. An introductory assignment to introduce you to working with images in MATLAB
2. Image registration assignment
3. Image segmentation assignment

Here are some guidelines for the programming assignments:

* Assignments can be done individually or in groups of two
* Groups must be changed between assignments. If you worked with someone on the first assignment, then you should do the second assignment individually or with another student.
* If you work in a group, each of you is still expected to work on the entire assignment, as opposed to dividing the work into parts. This is so that both students in the group learn from the assignment.
* *The quizzes will be heavily focused on material covered in the programming assignments, so not doing a part of the assignment can hurt you on the quiz.*
* Upload the report PDF, source code and results using the Assignment tool on Canvas. Only one report should be uploaded per group.
* Start working early and anticipate possible programming roadblocks.

TA Availability:The role of the TA/instructor is to answer questions about the material presented in the course, provide general advice, but *not to help individual students and groups with homework*. Please post any assignment-related questions to Piazza instead of emailing the TA directly. This way the entire class will benefit from the answer.

Discussing with Peers.It is acceptable to discuss homework assignments with other students in the class at the general level. However, it is not acceptable to 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.

* 1. Quizzes

Three 30-minute quizzes will be held soon after the due date of the programming assignments. Quizzes will include

* Multiple-choice questions testing your understanding of the main concepts covered in the lectures;
* A longer question on the topics covered in the programming assignment.

The best way to prepare for the quizzes is to attend class regularly, make sure you understand the key concepts of each lecture, ask questions if you do not understand something, and make sure you complete the programming assignments in their entirety.

* 1. Course team project

The course project will give you first-hand experience in biomedical imaging analysis in the “real” world. The project is the largest component of the course, and you should expect to spend a significant amount of time working on it during the semester. The ideal project would have some practical value and an open-ended structure, allowing you to pursue further graduate research in the imaging field. The following guidelines apply:

* Each project will be performed by a team of 3-4 students.
* Each project will involve analysis of biomedical imaging data and will be related to at least one of the topic areas covered in the course.
* Each project will have a clinical sponsor (typically a faculty member in the School of Medicine) who will provide the team with the data and will help set overall objectives.
* Each project will also have a technical sponsor. The technical sponsor will be a student, postdoctoral fellow or faculty member with significant image analysis expertise. Her or his role will be help the team learn necessary background material to implement the project and to regularly advise the students on their implementation.
* About 7 project ideas will be announced and presented during the second week of the course, followed by a sign-up period. Sign-up will be on the first come basis.
* Once project teams have been formed, the teams are responsible for arranging to meet with the sponsors on a regular basis, as needed to develop the proposal and implement the project.
* Most projects will require some outside of the classroom learning, such as learning new algorithms and software, or jumping ahead to material covered later in the course. The technical sponsor’s role will be to direct this learning.

The components of the project are:

* A written proposal outlining project goals, significance, and proposed approach (may be revised once).
* Short half-way progress report
* Final written report
* Final oral presentation
  + 1. Proposal

In September, teams will submit a short project proposal. You will be provided with a template for preparing the proposal. A copy of the proposal must be submitted to the sponsors. The proposal will be assigned a grade counting towards the total grade for the project.

* + 1. Proposal Revision

The proposal will be reviewed, and some groups may be asked to revise their proposal (usually to provide additional details). The revised proposal is due in October and will be graded on its responsiveness to the questions raised.

* + 1. Project Management

Use a group project management tool (such as Asana or Trello) to manage tasks in your project. After turning in your proposal, create tasks and sub-tasks, assign them to team members, set due dates, and keep track of progress. This will help you ensure progress throughout the semester, and to keep track of effort done by each member of the team. Also consider using a communication tool like Slack or Piazza for project-related communication (instead of email).

Infrequently, a situation arises when some members of a group feel that others have not done their fair share of the project. When this is brought to my attention, I will ask each group member to provide a detailed report of their own effort and the effort of their teammates. Grades may be adjusted to reflect inequity of effort between team members. Please do your fair share of the project and keep records of your efforts.

If any conflicts or issues between team members arise, they should be brought to the instructor’s attention as early as possible. For example, if a student stops responding to email or fails to show up for group meetings, this may impact the entire group’s ability to complete the project and hurt everyone’s grade. Little can be done to remedy this situation after the fact; so it is best to let the instructor know as soon as the problem occurs.

* + 1. Progress Report

Students must submit one progress report in November. A template for preparing the progress report will be provided. The progress report will be sent to the sponsors, who will provide a mid-project evaluation.

* + 1. Final Deliverables

Projects are due at the beginning of the final exam period. The students submit the following materials:

*Report*

A report laid out as a regular research paper, organized into Introduction, Background, Materials and Methods, Results, Discussion, and Conclusion sections, and including a list of references. The length of the report, including figures and references, should be 6-8 pages in the NIH format. Do not exceed 12 pages.

*Presentation*

Students will present their project and its findings during the final exam period. The length of the presentations will be determined based on the number of student projects.

*Data and Code Archive*

Students must provide the instructor and sponsor with a CD or thumb drive containing the data, results, and programs (source code and binaries) developed for the project. If the data used in the project is human subject data, IRB policies may preclude uploading data or require data to be de-identified. Converting images to the NIFTI format (and removing the skull for brain scans) is a good simple way to de-identify data.

* + 1. Grading of the project

Several criteria will be used to assign a grade for the project.

* Quality of the initial proposal (15%)
* Responsiveness of the revised proposal to sponsor/instructor comments (15%)
* Mid-project progress evaluation (15%)
* Scientific quality of the final report (25%)
* Scientific quality of the final presentation (15%)
* Ability to meet the goals outlined in the proposal (15%)

The grade for each project will be assigned based on the sponsor evaluation and independent evaluation by the instructor. Typically, all students will receive the same grade on the project, but sponsors will have leeway to assign different grades to different students if there is a clear imbalance in the amount of work performed by different team members. *Be sure to do your fair share of the project!*

* + 1. The Sponsor’s Role

The sponsors play a crucial role in the success of each project. The following guidelines apply to the sponsors:

* The sponsors are responsible for framing the project for the students, providing necessary data, background information, and resources, and for helping the instructor evaluate the students’ work.
  + In particular, the technical sponsor is responsible for ensuring that the project if technically feasible and must point students to the image analysis literature, tutorials, etc., that provide the necessary knowledge for the students to be successful.
* A sponsor’s role is that of a teacher or mentor. The sponsor may not directly contribute to the project (e.g., by writing or debugging code; by writing parts of reports or editing them; or by solving image analysis related problems for the students).
* The sponsors must make themselves available for meeting with the students regularly (at least once a week during the initial phase when students are writing and revising their proposal, and at least once every two weeks afterwards).
* The clinical sponsor must make sure that any data provided for this project is shared in a way consistent with relevant IRB and HIPAA protocols, i.e., through de-identification.
* If the project requires computing cluster or other resources that students don’t readily have access to, it is the sponsors’ responsibility to make these resources available to the students in a timely manner.
* If a publication is anticipated, the sponsors should discuss authorship and timing with the students as early as possible.

# Tentative Schedule for the Semester

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| --- | --- | --- |
| **Date** | **Lecture Topic** | **Assignments Due** |
| Wed, Aug 29 | Course Introduction |  |
| Mon, Sep 3 | LABOR DAY |  |
| Wed, Sep 5 | Project Teaser Day |  |
| Mon, Sep 10 | Detre Guest Lecture: Intro to Brain Imaging |  |
| Wed, Sep 12 | Image and Signal Processing Review I | Online Plagiarism Quiz |
| Mon, Sep 17 | Image and Signal Processing Review II |  |
| Wed, Sep 19 | Calculus of Variations and Optimization I |  |
| Mon, Sep 24 | Calculus of Variations and Optimization II |  |
| Wed, Sep 26 | Introduction to Registration I | Project Proposal |
| Mon, Oct 1 | Introduction to Registration II |  |
| Wed, Oct 3 | Rigid and Affine Registration |  |
| Mon, Oct 8 | Optical Flow and Non-Linear Registration | MATLAB-1 |
| Wed, Oct 10 | Diffeomorphic Registration I | Quiz 1 |
| Mon, Oct 15 | Diffeomorphic Registration II |  |
| Wed, Oct 17 | Atlases and Groupwise Registration | Revised Project Proposal |
| Mon, Oct 22 | Edge and Feature Detection |  |
| Wed, Oct 24 | Pattern Theory and Bayesian Statistics |  |
| Mon, Oct 29 | Statistical Image Segmentation I |  |
| Wed, Oct 31 | Statistical Image Segmentation II |  |
| Mon, Nov 5 | Graph-Based Segmentation | MATLAB-2 |
| Wed, Nov 7 | Multi-Atlas and Patch-Based Segmentation | Quiz 2 |
| Mon, Nov 12 | Geometry of Curves and Surfaces |  |
| Wed, Nov 14 | Active Contours and Level Sets I |  |
| Mon, Nov 19 | Active Contours and Level Sets II | Project Progress Report |
| Wed, Nov 21 | THANKSGIVING |  |
| Mon, Nov 26 | Geometric Representations and Shape Spaces |  |
| Wed, Nov 28 | Active Shape and Appearance Models |  |
| Mon, Dec 3 | Medial Representations | MATLAB-3 |
| Wed, Dec 5 | Deep Learning in Image Segmentation | Quiz 3 |
| Mon, Dec 10 | Deep Learning in Image Registration |  |
| Tue, Dec 18 | PROJECT PRESENTATIONS | Final Project Report / Presentation |