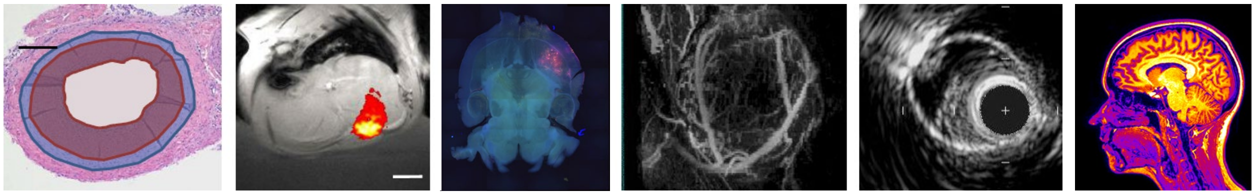
BE 128: Introduction to Biomedical Imaging and Systems

Syllabus 2024



Class Information:

Lecture: T,Th 2:15 – 3:30 pm
Lecture Location: SEC, room 1.307

Lab: ~every other week *see note re: times
Lab location: Varies by week *(~half in Cambridge and half in Allston)*

Instructor:

Linsey Moyer, Ph.D.
Email: lmoyer@seas.harvard.edu

Office Hours: see canvas
Office Location: SEC LL1.240

Teaching Fellow:

TBD

Office Hours: see canvas

Course Description:

Non-invasive techniques for analyzing and visualizing a wide range of systems, from nano-sized devices up to the human body, are critical in research, industry, and healthcare. The course is designed as an introduction for students who want to gain both hands on training as well as an introduction to the physics and image reconstruction techniques involved in generating biomedical images. It is also useful for students in life sciences and engineering disciplines who may need to use imaging to assess their products, devices, or organisms. The course will introduce the fundamentals of the major imaging modalities including, but not limited to: electron microscopy, optical microscopy, x-ray, computed tomography, ultrasound, magnetic resonance imaging, and nuclear imaging, as well as an overview of *in vivo* imaging and molecular imaging. The fundamentals of each imaging system will coincide with examples of studies from the current literature that explore the applications of these imaging systems to bioengineering, electrical engineering, materials science and clinical research questions. Through the laboratory component, students will gain experience working with many of these imaging modalities and will have the chance to utilize them in a final project.

Prerequisites:

- Required: Physics (electromagnetism such as PS12b, AP50b, PS3, or Phys 15b), calculus at the level of Math 1b or higher, some experience with MATLAB (use of other coding languages is allowed).
- Helpful, but not required: Knowledge of basic biology, physiology (ES 53 or similar), signals and systems (BE 110, ES 125, ES 155, etc.), Math 21b or other linear algebra.

Course Materials:

No textbook purchase is required, but we will be using some of these texts which are available for free via HOLLIS:

- Fundamentals of Medical Imaging, 3rd, Ed., Paul Suetens, Cambridge University Press 2017
- The Essential Physics of Medical Imaging, 3rd Edition, J. T. Bushberg, J. A. Seibert, E. M. Leidholdt, J. M. Boone, Lippencott Williams & Wilkins 2012
- Radiation Biology of Medical Imaging, Kelsey et al, Wiley & Sons 2014

Additionally, these texts are available for free online in Harvard's HOLLIS database:

- Medical Imaging Physics, Hendee and Ritenour, Wiley-Liss, 2002
- The Mathematics of Medical Imaging - A Beginner's Guide, Feeman, Springer 2010

Other useful texts which are not available via HOLLIS:

- Medical Imaging: Signals and Systems, Prince and Links, Prentice Hall 2005

Course Objectives:

<u>After completing the course, you should be able to:</u>

- Explain methods of image acquisition and formation.
- Describe the types of energy used for each modality and how the energy is generated.
- Derive the spatial and temporal limitations, and resolution of each modality.
- Identify what improves or degrades resolution.
- Determine which imaging modalities would be best to determine molecular, anatomical, or physiological information.
- Compare and contrast the possible bioeffects of each modality. Describe the FDA limits if they exist.
- Differentiate how biomedical imaging is used clinically and in biomedical research.
- Differentiate the advantages of each method for a range of industrial, clinical, and research applications.

<u>As a participant in this course you will be able to engage in the following:</u>

- Learn how to use a range of imaging systems through hands-on and virtual experiments.
- Use ImageJ and/or MATLAB to perform modality-specific image reconstruction or analysis.
- Compare and contrast the advantages and disadvantages of imaging across spatial scales.
- Through your final project, compare and contrast two imaging modalities as they are applied to a single research question.

Schedule: (Slight changes may occur to the lecture order due to guest speaker availability.) This course includes classroom-based lectures, problem solving, and simulations as well as interactive laboratory exercises.
*Note: Labs are held outside of class time. The times are TBD. Please keep both Tuesday 3:30-5 and Fri. 9am -12pm open. Once enrollment has finalized on Nov. 15th we will know whether we are using the Tuesday or Friday time.

The labs are dependent on core facility staff and we may need to move a lab from time to time. We ask that students keep the same weekly time slot free in case a lab needs to be rescheduled. Labs will be held approximately every other week. See Canvas for specific dates (which will be updated after enrollment concludes on Nov. 15th).

For each of the first four modalities we will devote approximately one week to studying the devices and image acquisition methods including a laboratory exercise. The subsequent week will focus on image reconstruction or processing and the biomedical applications.

Problem sets will be due every other week (see canvas for specific deadlines), and labs will be due the opposite weeks. Refer to the Canvas site for the full list of all assignments and due dates.

Week 1: Introduction to Biomedical Imaging
– Course introduction, and overview of biomedical imaging
– Review of signals and systems, Fourier transforms; MATLAB for basic signal processing, display; image rendering in MATLAB and ImageJ
– Lab 0 (Optional attendance) 3:30-4:30 pm: ImageJ and MATLAB for image manipulation

Week 2: Ultrasound Physics and Imaging
– Introduction to ultrasound physics, instrumentation, and acoustic propagation
– Ultrasound image acquisition & reconstruction, imaging limits;

Week 3: Ultrasound Bioeffects, and Applications
– Acoustic imaging of blood flow and contrast agents; Ultrasound bioeffects and therapies
– Lab 1: Ultrasound imaging of cysts, blood flow, and phantoms
– Guest lecture on high intensity focused ultrasound, microbubbles; therapeutic applications

Week 4: X-Ray Planar Imaging
– X-ray physics and instrumentation
– Radiation dose and bioeffects

Week 5: X-ray Computed Tomography
– Computed tomography, image reconstruction including back-projection and radon transform
– Lab 2: Micro-CT lab for viewing biological samples and electronics
– Applications of x-ray and CT imaging, radiotherapy

Week 6: Magnetic Resonance Physics and Imaging
– Intro to nuclear spin, decay, resonance, magnetization, relaxation and instrumentation; bioeffects
– Encoding spin directions and pulse sequences, and slice selection

– MR signal acquisition, basic image reconstruction with k-space analysis

Week 7: Magnetic Resonance
– Lab 3: MRI of anatomy, MR angiography, and fMRI demo
– Guest lecture on fMRI and new MR applications

Week 8: Optical Imaging Introduction
– Introduction to optics: refraction, resolution, depth of field, and magnification; phase contrast
– Intro to microscopy, instrumentation *(Guest lecture)*

Week 9: Optical Imaging Applications
– Microscopy advances and techniques; image analysis; Systems (IVIS) and bioluminescence
– Lab 4: Phase and fluorescence microscopy; unicellular & multicellular organisms, and histologically stained tissues
– Optical In-Vivo Imaging

Week 10: SEM/TEM
– Introduction to SEM; electron physics and instrumentation *(Guest lecture)*
– SEM and TEM comparison; Intro to nuclear imaging physics

Week 11: Nuclear Imaging (PET/SPECT) and Molecular Imaging
– Positron Emission Tomography (PET/SPECT): physics, instrumentation applications
– Lab 5: Electron microscopy of insects, nanoparticles, biofilm, and bacteria
– PET/SPECT bioeffects, image reconstruction and analysis of SNR; molecular imaging

Week 12: Final Exam & Theranostics
– Molecular imaging comparison; theranostics introduction
– Theranostics and wrap up

Week 13: Wrap-up
– Final exam Theranostics and wrap up.

Final Project Presentations – During finals period (Date set by the College)

Course Requirements and Evaluation:
In this class it is expected that you will take an active part in the learning process. In some ways, this may make the course more challenging; however, I hope this approach will make the course much more fun and interesting as well. Because of the interactive nature of this course, attendance and participation will be necessary for you to completely achieve the course goals. Attendance and participation will not be directly graded; however, your performance in the class and on other forms of evaluation, including in-class assignments will reflect your level of participation and attendance. It is your job to come prepared to class, ask questions, participate, <u>and take detailed notes</u>. Much of the material that we cover is not in the textbook. Class time will be used for implementing ideas from the texts and reading assignments, for practicing problems

not found in the book, for laboratory exercises, and for discussion. Condensed powerpoint slides will be available on the Canvas site, but full sets of notes will not be posted.

In order for you to be prepared to participate, you should complete any assigned readings, problem sets, or pre-class exercises before class. These will always be posted on the Canvas course site ahead of time. In order for everyone to succeed in this class you should 1) arrive on time, ready to focus on the day's objectives; 2) keep track of your assignments and due dates. These will also be listed on Canvas. You are responsible for informing me ahead of time if you will need to miss class and are responsible for looking at the syllabus to find out what you missed and when assignments are due.

Teaching and learning is a two-way street, so you can expect certain things from me as well. I will make myself available to help you and to answer questions. I strongly encourage you to attend my office hours or make an appointment to see me for specific or general guidance in the course. I will provide you with feedback on your assignments and exams in a timely fashion. Finally, I will ask you for feedback throughout the course. I will take your feedback seriously, and work to incorporate your ideas on how to improve the course.

Evaluation for this course will be based upon the successful completion of assignments and participation in the course. You will complete reading assignments and use online imaging simulators to prepare you for lecture. You'll also work through problem sets and mini projects on image analysis through the lab component. Another course requirement is a group imaging project. You will work in groups of two to three (depending on total course enrollment) on a project where you will need to answer a research question by using two or more imaging modalities. We will cover the details of the project and its requirements in class and more information is available on the Canvas course site. A final exam designed to test your conceptual understanding of the course topics will be given.

This course is designed as an introduction to biomedical imaging and as such, we will only skim the surface of each of the respective fields of imaging. Entire courses on each imaging modality are commonly taught at the graduate level. While we will not have time to cover all of the interesting details of the methods and applications of each imaging modality you are encouraged to explore a topic in more depth through a final project.

Course policies:

The tenets of our/my approach to the classroom:

- *Adopt a Humanistic Approach to Science and Engineering*
- *Recognize that the Culture of Science Is Shifting Toward Collaboration and Inclusion*
- *Understand that Experiences, Perspectives, Personalities, and Worldviews Vary*
- *Realize that People Are Imperfect and Make Mistakes*
- *Take Appropriate Steps to Make Amends If You Make a Mistake*
- *Adopt a Mindset of Continuous Growth and Improvement*

Diversity and Inclusion – We, the instructional team including Dr. Moyer, and the teaching assistants would like to create a learning environment for our students that supports a diversity of thoughts, perspectives and experiences, and honors your identities (including race, gender, class, sexuality, religion, ability, etc.) To help accomplish this:

- If you have a name and/or set of pronouns that differ from those that appear in your official Harvard records, please let us know.
- As a participant in course discussions and lab groups you should also strive to honor the diversity of your classmates.
- We (like many people) are still in the process of learning about diverse perspectives and identities. If something was said in class (by anyone) that made you feel uncomfortable, please talk to us about it.
- You can also submit anonymous feedback (which will lead to us making a general announcement to the class, if necessary, to address your concerns). If you prefer to speak with someone outside of the course, the SEAS Committee on Diversity, Inclusion, and Belonging is an excellent resource.
- If you are struggling for any reason in this course, please reach out to us. The instructional team want to be a resource for you.

Missed work – At the start of the semester it is recommend that each student identify a "study buddy" to get missed notes. Lecture slides will be available on Canvas regularly and office hours will be available regularly via zoom. It is expected that students will first catch up with a peer before bringing questions to office hours. Unless it is a quick logistical question students should plan to bring questions to office hours and discuss among their peers. Learning is a collaborative endeavor and research consistently shows that students learn better in social setting than in isolation. Please plan to work collaboratively with peers throughout the course.

Class attendance is essential for successful completion of the course but we also understand that illnesses, travel and other issues arise. Much of the material that we cover is not in the textbook. Class time will be used for implementing ideas from the texts and reading assignments, for practicing problems not found in the book, for laboratory exercises, and for discussion. Condensed powerpoint slides will be available on the Canvas site, but full sets of notes will not be posted. You are responsible for making up any notes with a fellow classmate and/or coming to office hours.

Problem sets / reports – It is the sole responsibility of each student to generate and write-up their own problem sets and lab reports. Although you may compare ideas and discuss general strategies of solving problems from the lab or problem sets, there is to be no direct copying of work, and no sharing of MATlab files or figures. Copying of any part of the tutorials or work from another student will result in a zero for the assignment.

Academic Honesty – All students are expected to maintain an environment of academic integrity. Use of materials from past versions of this course is considered a violation of academic honesty. Any and all cheating will result in a zero grade for that assessment. Repeated violations of academic integrity may result in dismissal from the course or failure of the course. Always remember that if you need help with any part of the coursework you are always encouraged and welcome to talk to Linsey or the teaching fellow.

Generative Artificial Intelligence statement: We expect that all work students submit for this course will be their own, or through collaborative work with other students. In instances when collaborative work is assigned, we expect for the assignment to list all team members who participated.

AI is becoming part of our lives and education. That being said, learning cannot be achieved without cognition, and we must all strive to ensure that our cognitive abilities are not being weakened by GAI. To that end and to make sure that you meet the learning objectives and avoid any copyright issues we have the follow GAI rules in place for this course:

- We specifically forbid the entering of any course materials (homework questions, lab questions, textbook material, answer keys, transcripts of lectures, or any other material available through canvas or other means in this course may not be entered into any GAI. This is a copyright issue.
- You may use GAI to help you debug code and generate code, but you are responsible for checking the validity of said code.
- You may use it to help look up information that may assist you in becoming more familiar with a topic, but please beware that hallucinations are common in current GAI. You are responsible for checking the validity of any information. We recommend using the textbooks as much as possible before trying GAI.
- Violations of this policy will be considered academic misconduct.

Please note that the A.I. policy for this course reflects our specific goals. We fully understand that different courses in the College will have a wide range of policies based on the particular goals of those courses, and we hope that you'll reach out to us if—at any point—you're unclear about what our policy is or why.

We want to make sure you have access to as much support as possible and that you are sure what that support is, and where to find it. Here are some of the people, places, and other resources you can (and should!) reach out to:

- Us! Our course will have regular office hours, and you should come to those at any stage of completion of your problem sets or labs.
- Your peers – we encourage collaboration and peer to peer learning.

- Our Canvas site has many links to resources as well as a signals & transforms guide created by past TFs!
- Your textbooks are free online and available via HOLLIS.
- MATLAB online help: https://www.mathworks.com/help/matlab/

Regrading – If you think a grading mistake has been made on your assignment please bring it up with the instructor (Linsey) within one week after the assignment has been returned (or grades posted). No grade changes will be made after that. This policy is here to streamline grading and ensure feedback is received in a timely manner.

Assignments and Grading Guidelines:

Lab reports and problem sets:

Assignments will include both problem sets and lab reports (one per week). Some assignments will require the use of MATLAB or ImageJ. Both are available at no cost to students. Problem sets and lab experiments will be designed for each imaging modality which amounts to about 11 assignments. These will be due at the beginning of the class on the listed due date.

All written lab reports should be uploaded via Canvas as a PDF. If you have hand-written any portion of the lab report you must scan it and save it as a PDF before submitting it. One lab report can be omitted or the lowest grade of the six will be dropped.

In Class Assignments:

Students will be asked to participate in a variety of in class assessments in the form of quizzes, short analyses, designing of experiments, or simulations. These activities are designed as practice to gauge understanding of the current objectives.

Final Exam:

The final exam will cover all of the course material. It will consist of a combination of short answer questions and mathematical analysis questions.

Final Project:

The goal of the project is for you to explore applications of biomedical imaging through your group's own mini research endeavor. This is your chance to design your own imaging experiment. Students are welcome to bring along something from their research or hobbies to scan/image. You will be required to select your topic for approval no later than Week 7. These projects will be due during reading period, and should result in a 10-12 minute presentation. More details will be given during class and can be found on the course Canvas site.

Grading:

In class assignments	10% (grade will largely be based upon completion – this is an easy way for you to gain points)
Lab Reports:	25%
Problem Sets:	25%
Final Project:	20%
Final Exam:	20%