Imaging in Biomedicine

Instructor Information:

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Course Description

Welcome to Imaging in Biomedicine! Imaging technologies are essential in improving our understanding in biomedicine, from molecular biology to clinical trials. Via this course, you will learn about three different imaging modalities (optical microscopy, magnetic resonance imaging [MRI] and computed tomography [CT]). We focus on two aspects: 1) understanding the physical principles behind each modality and 2) illustrating how technological progress drives new scientific discoveries and better clinical outcomes. Ultimately, the course equips you with the perspective that biomedical images emerge from varied physical principles and serve as critical tools for advancing science and medicine.

Intended Learning Outcomes (ILOs)

By the end of this course, students will be able to…

- Explain principles behind 1) optical microscopy 2) CT and 3) MRI, and demonstrate understanding by reconstructing images from real-world data sets
- Choose the optimal imaging modality for a given biomedical process across spatial scales, from intracellular changes (< 1 micrometer) to whole-body imaging (~1 meter).
- Compare imaging modalities and explain how they can be used complementarily to deepen current understanding of biology
- Quantify patient benefits from advances in biomedical imaging by comparing clinical trials from the 2000s and the 2020s

Prerequisites

- Signal Processing 101 *or* a solid understanding of the Fourier transform. Comfort using either Python or MATLAB, as we will be reconstructing images from real raw data!
- Biology 101

Course Materials

- All course materials will be posted on Canvas two weeks before the corresponding class.
- Access to a computer is required for completing assignments. The institute has ample computing resources available; please contact the instructor if you need access.

What to Expect in This Course

This course is designed to guide your learning through a structured, three-part flow: **'Why'** (Context), **'How'** (Principles), and **'What'** (Applications). We aim to equip you with both the theoretical knowledge and the practical ability to understand different imaging modalities in biomedicine.

- **Active Participation is Essential (The 'Why'):**
    - **Goal:** To establish the real-world contexts and scientific/clinical needs that drive the use of a specific imaging technology *before* covering the technical details.
    - **In Class:** Class time will begin with active discussions. We expect you to come prepared to share your ideas, relevant experiences, or research insights regarding *why* a particular imaging technology is needed. Relevant questions will be made available prior to class.(See **Active Learning in Assessments**).
    - **Instructor Role:** The instructor will facilitate and summarize the class discussion. We will revisit these summaries later in the course to connect principles with context.
- **Chalkboard Physics (The 'How' - Principles):**
    - **Goal:** To build a deep, step-by-step understanding of the fundamental physics and principles required to generate images.
    - **In Class:** The instructor adopts a classic chalkboard style. This method is highly effective for learning physics because it forces a sequential understanding of every essential step in image formation.
    - **Preparation:** All principles and derivations covered on the chalkboard will be made available in a PDF format (typed) prior to class. Please feel free to review them and prepare questions.
- **Hands-on Image Reconstruction (Demonstrating Understanding):**
    - **Goal:** To bridge the gap between principles and practical application by having you actively reconstruct images.
    - **PSets:** Problem Sets (PSets) will challenge you to use the principles learned in class to generate images from raw data on a computer.
    - **Rationale:** Reconstructing images is a vital part of learning. It provides an immediate opportunity to identify and correct any misunderstandings of the underlying physics.
- **Case Studies and Current Advancements (The 'What' - Applications):**
    - **Goal:** To learn how each imaging modality is currently used in scientific and clinical settings.
    - **In Class:** The instructor will use a PowerPoint presentation format to cover applications.
    - **Optional Reading:** Course materials will include optional reading on recent advancements. While these are *not* included in assessments, they are provided to illustrate that the fields we study are rapidly evolving and continually enabling new discoveries.
- **Giving and Receiving Feedback:**
    - Throughout the course, there will be dedicated opportunities for you to provide feedback on the teaching style, pacing, and materials, ensuring the course remains effective for your learning.
    - The course is designed to help you develop two complementary competencies: (1) understanding the physics behind major imaging modalities, and (2) understanding how these modalities advance modern biology and medicine. These areas draw on different skill sets, and it is normal for students to find one more challenging than the other. Like any skill, both can be learned—and learned more effectively with timely feedback. You will receive written feedback on PSets assignments highlighting gaps between your current understanding and the Intended Learning Outcomes (ILOs).

Assessments

- Assessments aim to 1) provide students feedback on their learning progress toward ILOs and 2) evaluate whether ILOs have been achieved. The assessment consists of Problem Sets (30%), an imaging technology analysis (30%), a final quiz (30%), and participation + active learning (10%).
- **Problem set (PSets, 30%):**
  - **Structure:** There are 6 PSets in total, with Unit 1 and 2 each having three PSets. In each PSet, one half will be a more traditional style that can be answered with numbers or short paragraphs. The other half will involve reconstructing images from raw data.
  - **Purpose and Relevance**: Traditional-style PSets are an effective format for you to communicate your understanding of the materials. However, it is challenging for both the instructor and students themselves to identify any misunderstandings of the materials in the traditional PSet format. Image reconstruction provides an opportunity to demonstrate that your understanding of the imaging principles is complete enough (or error-free enough) to generate interpretable images from raw data.
  - **Support:** For the office hour a week before each PSet is due, the instructor will join with the TAs.
  - **Trivia:** At the end of each PSet, we will provide you with instructions on how to generate cool .gif files that summarize your reconstructed images. This is not evaluated, but it is a great way to show your peers what you learned in Imaging in Biomedicine!
- **Imaging technology analysis (30%)**
  - **Submission:** Three short analyses (700 words each) of new imaging technologies
  - **Due date**: Within one week after the last class of Unit 1
  - **Description**: In this assessment, you will analyze three new imaging technologies using the concepts from Unit 1. Six technologies will be provided to you, each with a conference abstract (~6 pages) and a recorded oral presentation (~10 minutes). You will select three of these technologies and analyze each one through:
    - The framework of information generation, collection, and decoding
    - The common trade-offs in microscopy (e.g., resolution vs. field of view, speed vs. signal-to-noise ratio)
  - **Purpose and Relevance:** New imaging technologies are developed and presented every day. Being able to evaluate their strengths and limitations is a critical skill whether you are:
    - A clinician deciding if a technique is relevant in practice
    - A biologist considering if a technique applies to your research
    - A clinical trial designer designing secondary endpoints
    - A researcher developing new imaging technologies

    Although this evaluation is a challenging task in the real world, this assignment will give you structured practice in building this important skillset. Note that a part of the previous problem sets adopts similar structures, but with more guidelines; please be sure to incorporate the feedback you received for PSet 2 and PSet 3.
  - **Alignment with Course ILOs:** This assessment directly supports the following Intended Learning Outcome:

    ● Analyze and evaluate new microscopy technologies through the framework of information generation, collection, and decoding, and their expected trade-offs.
  - **Assessment Design and Grading:**
    - A detailed rubric will guide your analysis.
    - You are encouraged to choose three technologies that are substantially different from each other; doing so can earn you extra credit. The rubric defines what are considered substantially different in detail.
    - Examples of exceptional, satisfactory, and poor responses will be provided for reference.

    - All analyses should be concise (700 words or fewer, each)
- **Final quiz (30%)**
    - The quiz serves as a tool to evaluate whether you have achieved the intended learning outcomes (ILOs). The total quiz score is 150 points, broken down into three equal sections of 50 points each.
    - **Conceptual (50/150):** This section primarily evaluates your understanding of the principles behind the imaging technologies we studied.
    - **Reconstruction (50/150):** This section will present you with sample images containing various artifacts and ask you to propose plans to fix them. Completing the problem sets on your own and experimenting with different solutions will prepare you for this portion of the final quiz.
    - **Modalities and Justification (50/150):** This section will present five research/clinical trial scenarios where you need to choose appropriate imaging modalities and justify your selections. You will be asked to choose three out of the five scenarios, and only those three chosen scenarios will be graded.
- **Participation + Active learning (10%)**
    - Student participation is important because it 1) helps build a sense of community, 2) offers a deeper engagement with the class material, and 3) allows lecturers to improve and adapt their teaching methods to better meet student needs.
    - Active learning is one way students can participate (detailed in the next paragraph) and will be used to track participation and attendance.
    - We use active-learning activities to help everyone engage with the material. Expect brief polls (including simple yes/no questions), think-pair-share discussions, and short exercises where you compare viewpoints with a peer and try to persuade each other in a 5-minute conversation. These activities are designed to deepen understanding and provide immediate, low-risk practice. While they may involve elements of scientific communication, that is not an intended learning outcome for this course and you will not be graded based on the quality of your scientific communication; these are tools to promote learning, not to evaluate your progress. I expect you to participate thoughtfully and listen to your peers respectfully.

Course Expectations and Policies

- **Late assignments:** We understand that life can sometimes get in the way, so here is our policy on late work. For problem sets, we will apply a deduction of -15% per day for that problem set for up to 3 days past the deadline. For the imaging technology analysis essay, the deduction is -10% per day for up to 3 days past the deadline. Please note that after 3 days, we won't be able to award credit, as we will be releasing the solutions and personalized feedback on the 4th day. However, we are happy to provide you with feedback for *any* assignment submitted within 7 days of the original deadline, because we believe that learning from the material is the most important part!

Academic integrity statement

In this course, I will hold you to the high standard of academic integrity expected of all students at the Institute. I do this for two reasons. First, it is essential to the learning process that you are the one doing the work. I have structured the assignments in this course to enable you to gain a mastery of the course material. Failing to do the work yourself will result in a lesser understanding of the content, and therefore a less meaningful education for you. Second, it is important that there be a level playing field for all students in this course and at the Institute so that the rigor and integrity of the Institute's educational program is maintained.

Violating the [Academic Integrity policy] in any way (e.g., plagiarism, unauthorized collaboration, cheating, etc.) will result in official Institute sanction. Possible sanctions include receiving a failing grade on the assignment or exam, being assigned a failing grade in the course, having a formal notation of disciplinary action placed on your MIT record, suspension from the Institute, and expulsion from the Institute for very serious cases.

Please review the Academic Integrity policy and related resources (e.g., working under pressure; how to paraphrase, summarize, and quote; etc.) and contact me if you have any questions about appropriate citation methods, the degree of collaboration that is permitted, or anything else related to the Academic Integrity of this course.[1]

Special Accommodations and Disability Support Services

If you need disability-related accommodations, I encourage you to meet with me early in the semester. If you have not yet been approved for accommodations, please contact Student Disability Services at sds-all@mit.edu.

I look forward to working with you to assist you with your approved accommodations.

Mental Health

As a student, you may experience a range of challenges that can interfere with learning, such as strained relationships, increased anxiety, substance use, feeling down, difficulty concentrating and/or lack of motivation. These mental health concerns or stressful events may impact your ability to attend class, concentrate, complete work, take an exam, or participate in daily activities.

Support for undergraduate and graduate students is available through the doingwell@mit site. Support for postdocs is available through MyLifeServices. For *urgent or after-hours concerns*, please visit DoingWell's page of 24/7 resources. These include:

- MIT Student Mental Health & Counseling Services - Clinicians on Call [617-253-2916],
- Urgent Care @MIT Medical [617-253-1311],
- ULifeline Crisis Text Line [Text: "START" to 741-741], and
- MIT Police [617-253-1212].

[1] Office of Student Citizenship, W20-507, (617) 258-8423

Course Calendar

Week	Topic	**Assessment** (M: Monday, W: Wednesday)
	Unit 1: Optical Imaging	
1	What is optical imaging and what do lenses do?	PSet 1 Out (W)
2	How to generate an image: Scanning and Camera	
3	Confocal microscopy	PSet 1 Due (M), PSet 2 out (W)
4	*in vitro* versus *in vivo* imaging	
5	Signal-to-noise ratio and Resolution	Pset 2 Due (W), PSet 3 out (W)
6	Label-free imaging	
7	Multi-modal imaging: A powerful tool to study biology	PSet 3 Due (M), Imaging Technology Analysis out (W)
	Unit 2: MRI and CT imaging	
9	Scale and absorption: Need for non-optical imaging in medicine	Imaging Technology Analysis Due (W)
10	Computed Tomography I: Principles	PSet 4 Out (M)
11	Computed Tomography II: Applications	PSet 4 Due (W)
12	Magnetic Resonance Imaging I: Principles	PSet 5 Out (M)
13	Magnetic Resonance Imaging II: Applications	PSet 5 Due (W)
14	How imaging benefits society: Clinical trials	PSet 6 Out (M)
15	Role of imaging in personalized medicine	PSet 6 Due (W)
Final Week		Final Quiz