ECE 485 – Inverse Problems in Imaging – Syllabus – Spring 2026

Description:
This course teaches students the mathematical principles and computations that underpin modern imaging systems from an inverse-problems perspective. The course begins with linear and nonlinear regression to establish the broad base of linear algebra and optimization tools needed to solve inverse problems. Once this base has been established, the course will investigate a wide variety of inverse problems in medical (and non-medical) imaging: deconvolution (and blind deconvolution); compressed sensing and non-uniform FFTs (as used in MRI); phase retrieval and ptychography (from Fourier optics); X-ray computed tomography; refracted/bent-ray ultrasound tomography; electrical impedance tomography; diffraction tomography/full-waveform inversion; and aberration correction in ultrasound beamforming. By covering several different imaging modalities, we show how the mathematical theory is put into practice. This course emphasizes the direct translation of mathematical ideas into practical algorithms that reconstruct images from the raw data. Towards the end of the course, we discuss the clinical application of inverse problems and ultrasound tomography, in particular.

Course objectives:

- Teach students to formulate inverse problems for a variety of imaging modalities: blind deconvolution; compressed sensing and non-uniform FFTs (as used in MRI); phase retrieval and ptychography (from Fourier optics); X-ray CT; refracted/bent-ray tomography; electrical impedance tomography; diffraction tomography/full-waveform inversion; and aberration correction for ultrasound beamforming.
- Teach students how to develop regularization strategies (Tikhonov, sparsity-based, Bayesian) and assess their impact on stability and resolution.
- Teach students how to implement scalable solvers based on the theory of matrix-free forward and adjoint operators (e.g., gradient descent with momentum and Krylov-based conjugate gradients) on high-performance computing clusters.
- Teach students how to translate mathematical solutions based on forward/adjoint solvers into engineered imaging pipelines and their implementation in automatic differentiation software (e.g., JAX, PyTorch, TensorFlow), including hardware-level considerations (memory bandwidth, latency, checkpointing, and storage-rematerialization tradeoffs).

Pre-Requisites: No strict prerequisites.
Expecting basic background in *Linear Algebra* and *Signals & Systems* (e.g., Fourier transforms)
ECE 452 (Medical Imaging – Theory & Implementation) is highly recommended

Class Location: Imaging Sciences Department, 3rd Floor of URMC
Room 3.4326—Imaging Sciences Library—Main classroom for lectures on Tuesdays
Room 3.4451—Imaging Sciences Conference Room—Main classroom for lectures on Thursdays

Class Time: Tuesdays and Thursdays (11:30AM – 1:00PM)

Textbooks: None; students may read journal papers (accessible through UR subscriptions)

Grading: Homeworks (80% of final grade); Final Project (20% of final grade)

Tentative Lectures/Homeworks Scheduled for Spring 2026:

#	Lecture Date	Topic	Homework	Room
		Introduction and Course Overview		
1	01/20	Course Introduction	*HW1 Released*	3.4326
2	01/22	Linear Algebra Review		3.4451
		Linear Regression		
3	01/27	Introduction to Linear Regression	*HW2 Released*	3.4326
4	01/29	Statistical Approach to Linear Regression		3.4451
		Nonlinear Regression		
5	02/03	Nonlinear Regression	**HW1 Due**	3.4326
		Matrix-Free Methods		
6	02/05	Matrix-Free Methods	*HW3 Released*	3.4451
7	02/10	Variants of the Conjugate Gradient Method	**HW2 Due**	3.4326
		Introduction to Inverse Problems		
8	02/12	Regularization	*HW4 Released*	3.4451
02/16-02/20		***SPIE Medical Imaging Conference***	*NO CLASS THIS WEEK*	
9	02/24	Blind Deconvolution	**HW3 Due**	3.4326
10	02/26	Forward vs. Adjoint Operators	**HW4 Due**	**Zoom**
		Magnetic Resonance Imaging		
11	03/03	Physics of Magnetic Resonance Imaging	*HW5 Released*	3.4326
12	03/05	Magnetic Resonance Imaging	*HW6 Released*	3.4451
03/09-03/13		***SPRING BREAK***	*NO CLASS THIS WEEK*	
		Advanced Fourier Imaging		
13	03/17	Fourier Optics (Including Phase Retrieval)	**HW5 Due**	3.4326
14	03/19	Gridding / Non-Uniform FFT	*HW7 Released*	**Zoom**
		Linear Tomography—Mainly X-Ray Computed Tomography (CT)		
15	03/24	Linear Tomography—X-Ray CT (Part 1)	**HW6 Due**	3.4326
16	03/26	Linear Tomography—X-Ray CT (Part 2)		3.4451
		Introduction to Nonlinear Tomography		
17	03/31	Bent-Ray Ultrasound Tomography	*HW8 Released*	3.4326
18	04/02	Electrical Impedance Tomography	**HW7 Due**	3.4451
		Full-Waveform Inversion (FWI)		
19	04/07	Frequency-Domain FWI—General Approach	*HW9 Released*	3.4326
20	04/09	Frequency-Domain FWI—Plane-Wave Approach	**HW8 Due**	3.4451
21	04/14	Time-Domain FWI	*Project Released*	3.4326
		Overview of JAX for Final Project		
22	04/16	Automatic Differentiation Theory Behind JAX		3.4451
23	04/21	Practical Aspects of Using JAX	**HW9 Due**	3.4326
		Beamforming		
24	04/23	Introduction to Beamforming		3.4451
25	04/28	Aberration Correction Based on Tomography		3.4326
28	04/30	Final Presentations	**Project Due**	3.4451

Instructional Activities:

- **Lectures:** The lectures will be given during the class period (Tuesday and Thursday, 11:30 am – 1:00 pm ET). They will be in-person for students who can come but remote for students who cannot be there physically. All lectures will be recorded via Zoom and uploaded to Blackboard Ultra. See more details regarding delivery method below.
- **Message Boards:** Blackboard Ultra has both a Discussions and a Conversations feature that can be linked to specific assignments and lectures. Blackboard Ultra also has a feature that allows you to message instructors as well.
- **Faculty Office Hours:** Immediately after class on Thursdays 1:00-2:00 pm. Otherwise, an appointment can be arranged by email or Blackboard Ultra messages (preferred).
- **TA Office Hours:** A TA will have office hours at the posted time (TBD); in addition, appointments can be made for other times. If an emailed question can be answered by email, the TA will try to answer it within 24 hours.
- **Study groups:** Students experience greater success by joining small study groups. You can learn from the readings, from your teacher, from the TAs, and from your peers. An effective way to learn something more deeply is to explain it to another student.
- **Homework Assignments:** This is a graduate level course; therefore, students are expected to carefully articulate their entire thought process in each assignment and produce well-commented code. It is not sufficient that your code runs correctly. We also want to see the thought process (e.g., math, intermediate plots, etc.) that led to your answer. For each homework, you will submit a zip file containing the PDF of your solutions and your code. A well-organized and well-commented code will make it very clear which steps are applied where. This is the minimum level of organization expected from graduate students. Students should budget a minimum of 9 to 12 hours per week towards the homework assignments in this course.
- **Final Project:** Your final project will require you to implement an inverse problem in medical (or non-medical) imaging and its iterative solution using JAX (an automatic differentiation library written in Python). Using JAX will demonstrate how the theory of forward and adjoint operators is directly baked into forward- and reverse-mode automatic differentiation, and how these computations can be structured to solve inverse problems.

Delivery Method (Hyflex):

This course is delivered using a HyFlex model that ensures online and on-campus students receive the same high-quality instruction and equitable access to all course components. All class sessions are taught in person and are simultaneously streamed live via Zoom for distance-learning students. Each session is recorded and uploaded to Panopto to support asynchronous viewing. During live sessions, teaching assistants (TAs) monitor the Zoom chat and relay questions from distance learners to the instructor to maintain full participation and engagement. All course materials, announcements, assignments, and assessments are delivered through Blackboard to ensure consistency across modalities. Additionally, all office hours are held online so that both on-campus and remote students have equal access to instructor support.

Academic Honesty for ECE 485

Academic Honesty policies will be enforced. Read the University of Rochester's policies on Academic Honesty. In addition, specific to ECE 485 are the following policies.

Final Project

Although you may be assigned to groups to work together as a team, each of you will be asked to write up your own final report in your own words, documenting and describing the methodology and results. Additionally, you must present your work at your final presentation and must participate in the final presentation. Finally, all code necessary to reproduce the results shown in the final presentation and the final report must be made available with the final submission.

Homework

- In ECE 485, working together is encouraged, and advising one another on homework problems (e.g., giving hints, and collaborating on the thought process) is acceptable.
- However, each student should write up their own homework in their own words.
- Copying another's homework or copying from any other source or letting another copy your homework is plagiarism (falsely claiming someone else's work to be your own) and is forbidden.
- Think of the homework problems as practicing for the final exams. If you do not understand the thought process involved in each homework assignment, the final exam will be impossible

Distribution of lecture videos, lecture slides, homework

The lecture videos, slides from the lecture videos, and homework assignments and solutions are only for the students taking ECE 485 or by permission of the faculty. Posting them on a web site or allowing an unauthorized person to gain access to them is forbidden. These are all copyrighted materials. Unauthorized distribution will be considered a violation of academic honesty.