BIOE 580: Foundations of Imaging Science

- **Semester**: Spring 2026
- **Credit hours**: 4
- **Time**: 03:00 PM - 04:50 PM MW
- **Location**: 2018 Campus Instructional Facility
- **Co-requisites**:
  - BIOE 485 Computational Mathematics for Machine Learning and Imaging;
  - BIOE 483 Biomedical Computed Imaging Systems;
  - Or instructor approval.

Instructor

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Office Hours: Email Appointment

Course Description

This course provides a comprehensive introduction to the fundamental principles of image formation and image quality assessment, which are essential for the principled application of artificial intelligence in biomedical imaging. Imaging systems are analyzed using both deterministic frameworks based on linear operator theory and statistical frameworks that introduce stochastic models for objects and images. Methods for objective assessment of image quality (OAIQ) are introduced, including classification tasks, receiver operating characteristic (ROC) analysis, numerical observers, and estimation theory.

Course Objectives

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

- Distinguish between physical objects and their corresponding images.
- Model imaging systems using linear vector spaces and linear operator theory.
- Compute and interpret the singular value decomposition of linear imaging operators.
- Characterize the null space of linear imaging operators.
- Analyze representation error arising from discrete imaging models.
- Formulate stochastic descriptions of objects and images.
- Identify and explain sources of randomness in measured image data.
- Explain the role and importance of OAIQ in medical imaging.
- Apply signal detection theory and estimation theory to quantify OAIQ.
- Evaluate the performance of imaging systems and computational methods using numerical observers.

Required Resources

No textbook is required. However, the following references may be helpful:

- Harrison H. Barrett and Kyle J. Myers, ***Foundations of Image Science*** (optional)
- Charles Bouman, ***Foundations of Computational Imaging*** (optional)

Additional Requirements

Students are expected to have access to a modern computer capable of running recent versions of Python and the following libraries: NumPy, SciPy, Matplotlib, and Pillow. This is required for completing the homework assignments.

Course Policies

Lectures

- Class meetings will consist primarily of lectures (see the course schedule and attendance policies below).
- The midterm exam and final project presentation will be administered during regular class hours.

Homework

- There will be 4–6 homework assignments, each consisting of 3–4 multi-part exercises.
- Assignments will include a combination of analytical ("by hand") calculations, computational exercises implemented in Python, and short-answer questions.
- Both real and synthetic biomedical image data will be used for analysis and discussion.

Exams and Final Project

- **Midterm Exam**: The midterm will be an in-class written exam consisting of short-answer and short-calculation problems, focusing on key imaging science concepts covered in the course.
- **Final Project**: The final assessment will be a coding-based project. Students will implement a project design provided by the instructor, applying concepts learned throughout the course, and will analyze and present their results in a detailed *individual* written report.

Attendance and Participation

- Students are expected to attend at least 80% of scheduled class meetings.
- Active and meaningful participation during class is expected.
- Brief quizzes or polls may be given in class or online via Canvas for engagement and participation purposes. These will not be graded for correctness.

Additional Policies

- In general, no make-up exams will be given, and homework deadlines are firm.
- Exceptions due to special circumstances will be considered on a case-by-case basis at the discretion of the instructor.
- Students should notify the instructor as promptly as possible if special consideration is required.

Grading & Assessment

The overall course grade will consist of **67% homework** and **33% assessments** (midterm exam and final project). Grades will be assigned on an absolute scale and will not be curved. Final course grades will be rounded to the nearest whole number. Any concerns regarding individual assignments or grades should be communicated to the instructor promptly.

Scale (%)

Grade	Range	Grade	Range	Grade	Range
A+	[97, 100]	C+	[77, 80)	F	[0, 60)
A	[93, 97)	C	[73, 77)		
A-	[90, 93)	C-	[70, 73)		
B+	[87, 90)	D+	[67, 70)		
B	[83, 87)	D	[63, 67)		
B-	[80, 83)	D-	[60, 63)		

Additional Course Polices

In general, homework deadlines will be firm. Special circumstances regarding absence or forbearance will be handled on a case-by-case basis at the discretion the instructor or program director. Please inform the instructor promptly if additional consideration is required.

Academic Integrity

In brief, an infraction of academic integrity is any one of the following:

- Cheating – using or attempting to use unauthorized materials
- Plagiarism – representing the words, work, or ideas of another as your own
- Fabrication – the falsification or invention of any information, including citations
- Facilitation – helping or attempting to help another commit an infraction
- Bribes, Favors, and Threats – actions intended to affect a grade or evaluation
- Academic Interference – tampering, altering or destroying educational material or depriving someone else of access to that material

It is the students' responsibility to refrain from infractions of academic integrity, from conduct that may lead to suspicion of such infractions, and from conduct that aids others in such infractions. "I did not know" is not an excuse. Please ask the instructor for clarification if you are unsure of their expectations. The complete text of the University of Illinois student code can be found online at http://studentcode.illinois.edu/article1/part4/1-401/. Additional relevant information may be found by searching "academic integrity" at the University of Illinois website (https://illinois.edu).

Students of various Schools, Colleges and Departments within the university may have additional rights, requirements or resources regarding academic integrity so students are encouraged to consult the information specific to their particular program.

Statement of Accessibility & Accommodation

To obtain disability-related academic adjustments and/or auxiliary aids, students with disabilities must contact the course instructor and the Disability Resources and Educational Services (DRES) as soon as possible. To contact DRES, you may visit 1207 S. Oak St., Champaign, call 333-4603, e-mail disability@illinois.edu or go to the DRES website. If you are concerned you have a disability-related condition that is impacting your academic progress, there are academic screening appointments available on campus that can help diagnosis a previously undiagnosed disability by visiting the DRES website and selecting "Sign-Up for an Academic Screening" at the bottom of the page.

Tentative Schedule

Lecture	Spring 2026	Topic	Note
1	Jan 21 (W)	Guest Lecture	
2	Jan 26 (M)	Introduction to Imaging Science in Medicine & Vector Spaces in Imaging	
3	Jan 28 (W)	Basis Vectors, Subspaces, and Products	
4	Feb 2 (M)	Mappings Between Spaces	
5	Feb 4 (W)	Inverse, Adjoint, and Projection Operators	
6	Feb 9 (M)	Generalized Functions and Fourier Transforms	Homework 1 Due
7	Feb 11 (W)	X-ray Propagation and the Radon Transform	
8	Feb 16 (M)	Eigenanalysis of Imaging Operators	
9	Feb 18 (W)	Singular Value Decomposition	
10	Feb 23 (M)	Moore–Penrose Pseudoinverse	Homework 2 Due
11	Feb 25 (W)	Pseudoinverses and Linear Equations	
12	Mar 2 (M)	Iterative Image Reconstruction	
13	Mar 4 (W)	Hallucinations in Image Reconstruction	
14	Mar 9 (M)	Review of Lectures 1-13	Homework 3 Due
15	Mar 11 (W)	**Midterm Exam**	
	Mar 16–20	**Spring Break**	No Classes
16	Mar 23 (M)	Discretization Operators and Representation Error	

Lecture	Spring 2026	Topic	Note
17	Mar 25 (W)	Linear Shift-Invariant Imaging Operators and the Point-Spread Function	
18	Mar 30 (M)	Random Variables in Imaging	
19	Apr 1 (W)	Covariance Matrix of an Ensemble of Images	
20	Apr 6 (M)	Stochastic Models for Objects and Data	Homework 4 Due
21	Apr 8 (W)	Statistical Decision Theory	
22	Apr 13 (M)	Binary Decision Task and ROC	
23	Apr 15 (W)	Ideal Observer	
24	Apr 20 (M)	Impact of Deep Learning-Based Image Super-Resolution on Binary Signal Detection Performance	Homework 5 Due
25	Apr 22 (W)	Optimal Linear Observer	
26	Apr 27 (M)	Estimation Tasks	
27	Apr 29 (W)	Review of Lectures 1-26	
28	May 4 (M)	**Final Project Presentation**	Final Project Report Due