Boston University
Department of Electrical and Computer Engineering
ENG EC 517 Introduction to Information Theory
Fall 2023

Course Information

Motivation and overview: The field of information theory was pioneered by Claude Shannon, beginning with his landmark paper "A Mathematical Theory of Communication" in 1948. This theory elegantly captures the fundamental limits of efficient data compression and reliable transmission, and serves as the basis for digital communications networks. Subsequent efforts have revealed that information theory plays a fundamental role in many other disciplines, including statistics, machine learning, theoretical computer science, and physics. In this course, we will cover both the classical applications of information to compression and communication, as well as modern applications to high-dimensional statistics and machine learning. Our focus will be on measures of information and developing explicit connections between these abstract, probabilistic quantities and sharp characterizations of the performance limits for complex systems dealing with high-dimensional, noisy data. Bits are now well-known as the "currency" of information and this course will put this notion on sound mathematical footing.

Prerequisites: This course assumes a strong foundation in undergraduate probability and linear algebra as well as "mathematical maturity" for reading and writing proofs. Unlike most engineering classes, homework problems will consist of proofs, rather than calculations of numerical quantities based on provided formulas.

Logistics:

Instructor:	Prof. Bobak Nazer Office: PHO 439 Email: `bobak@bu.edu` Web: `https://bobaknazer.github.io` Phone: (617)-358-5858
Office hours:	Wednesdays 9:00 – 10:00am in PHO 439
Lectures:	Monday and Wednesday 12:20 – 2:05pm in PSY B35
Website:	`http://learn.bu.edu`
Homework Submission:	`https://www.gradescope.com`
Discussion Board:	`https://edstem.org/us/courses/46359/discussion/`

Textbooks:	T. M. Cover and J. A. Thomas *Elements of Information Theory*,
	Wiley-Interscience, 2nd ed. 2006. **Free PDF download with BU login:**
	`http://onlinelibrary.wiley.com.ezproxy.bu.edu/book/10.1002/047174882X`
	
	Y. Polysankiy and Y. Wu, *Information Theory: From Coding to Learning*,
	Cambridge University Press, forthcoming. **Free PDF draft online:**
	`https://people.lids.mit.edu/yp/homepage/data/itbook-export.pdf`

Grading:	Homework: 25% (approximately weekly) Midterm exam: 25% Lecture Scribing: 25% Final Project: 25%

Tentative List of Topics: This semester we will be attempting a novel approach to covering the material. A typical course would first focus on learning information measures, then compression and communication, and perhaps one or two lectures on advanced topics. Instead, we will try to spend each lecture introducing a new information-theoretic concept and then immediately connecting it with an application. We will also try to shift the emphasis towards more modern topics, especially those drawn from high-dimensional statistics and machine learning. The list below represents a tentative plan, and will be refined as the semester progresses.

- Binary Entropy → Compressing Binary Strings
- Entropy, Joint Entropy → Secret Sharing
- Typicality → Lossless Compression (Upper Bound)
- Converse → Lossless Compression (Lower Bound)
- Binning → Distributed Compression (i.e., Slepian-Wolf)
- Total Variation → Binary Hypothesis Testing, Neyman-Pearson
- Kullback-Leibler Divergence → Mismatched Compression
- Method of Types → Binary Hypothesis Testing: Many-Sample Asymptotics
- Mutual Information → Reliable Communication (Lower Bound)
- Fano's Inequality → Reliable Communication (Upper Bound)
- f-Divergences → Composite Hypothesis Testing, Community Detection
- Bayes Risk, Minimax Risk, Sufficient Statistics → (Scalar) Gaussian Location Model
- Maximum Likelihood Estimation → Distribution and Entropy Estimation (Upper Bound)
- Fisher Information, Cramer-Rao → Distribution and Entropy Estimation (Lower Bound)
- Information Radius and Diameter → Almost Exact Community Recovery
- Le Cam's 2-point Method, Joint Range of f-Divergences → Uniform Location Model
- Packing, Covering, Metric Entropy → Sparse Gaussian Location Model
- Soft Packing, Rate Distortion → Vector Quantization
- Linear Regression, Principal Component Analysis
- Differential Privacy

Homework: Each student must submit an original set of solutions to Gradescope by the due date. Requests for late submissions and/or extensions will not be entertained (except under exceptional circumstances which must be discussed with the instructor).

Collaboration policy: While you may discuss homework problems with other students for clarifying your understanding, you are required to solve homework problems on your own. Contact the instructor if you are not sure whether the extent of your collaboration with other students is acceptable.

Midterm Exam: There will be an in-class midterm exam, towards the end of October or beginning of November. Further details will be communicated as the class progresses.

Lecture Scribing: Each student will be responsible for writing up the lecture notes for (at most) two lectures. The writeup should capture the introduction and motivation, all of the presented equations and proofs, intuition, helpful figures and illustrations, and any pertinent references. Typesetting will be done in LaTeX via the Overleaf platform, and detailed examples will be provided. Scribed lectures will be due two weeks after the original lecture is delivered.

Final Project: The goal of the project is to investigate an information theory topic beyond the scope of the class. Topic suggestions and overall expectations will be provided as the semester progresses. Note that the focus of the project will be on the theoretical underpinnings of a concept or application, rather than on numerical simulations. Projects can be in groups of up to two people. The project grade will be based on a final report and an in-class presentation. The report will be in the style of a scribed lecture (as if the topic were actually presented as part of the class).

General Policies:

- *Plagiarism:* All of the writing for scribed lectures and the final project **must be your own.** (Writing out what I say in class or reusing what I provide via draft lecture notes is acceptable.) Grading will be very generous with respect to typos and grammatical errors, and writing can be in "bullet point" style to make it easier. However, plagiarism (even of a single sentence) from textbooks and other lecture notes, papers, etc. will not be tolerated, and could result in an automatic zero on the assignment.

- *Academic misconduct:* The student handbook defines academic misconduct as follows:

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  Academic misconduct is conduct by which a student misrepresents their academic
  accomplishments, or impedes other students' opportunities of being judged
  fairly for their academic work. Knowingly allowing others to represent your work
  as their own is as serious an offense as submitting another's work as your own.
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  This basic definition applies to EC517. If you are ever in doubt as to the legitimacy of an action, please talk to an instructor immediately. The penalty for academic misconduct at BU is severe. For further information on the BU Academic Code of Conduct, visit the following website:
  `https://www.bu.edu/academics/policies/academic-conduct-code/`

- *Incomplete grades:* Incomplete grades will not be given to students who wish to improve their grade by taking the course in a subsequent semester. An incomplete grade may be given for medical reasons if a doctor's note is provided. The purpose of an incomplete grade is to allow a student *who has essentially completed the course* and who has a legitimate interruption in the course, to complete the remaining material in another semester. Students will not be given an opportunity to improve their grades by doing extra work.

- *Drop dates:* Students are responsible for being aware of the drop dates for the current semester. Drop forms will not be back-dated.

- *Inclusion:* This class is to be a place where you will be treated with respect, and it welcomes individuals of all ages, backgrounds, beliefs, ethnicities, genders, gender identities, gender expressions, national origins, religious affiliations, sexual orientations, ability – and other visible and non-visible differences. All members of this class are expected to contribute to a respectful, welcoming, and inclusive environment for every other member of the class.

- *Accommodations for Students with Documented Disabilities:* If you are a student with a disability or believe you might have a disability that requires accommodations, requests for accommodations must be made in a timely fashion to Disability & Access Services, 25 Buick Street, Suite 300, Boston, MA 02215; 617-353-3658 (Voice/TTY). Students seeking academic accommodations must submit appropriate medical documentation and comply with the established policies and procedures.
  `http://www.bu.edu/disability/accommodations/`