Information-Theoretic Methods in Machine Learning

EEL 6935

Class Periods: Tuesday, 10:40 AM - 11:30 AM, Thursday 10:40 AM - 12:35 PM

Location: TUR2354

Academic Term: Spring 2024

Instructor:

Yuheng Bu

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Office Hours: Thursday (4:00-4:50 pm) MALA 3123

Supervised Teaching Student:

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Office Hours: TBD

Course Description

(3 credits)

The interplay between information theory and machine learning is a constant theme in the development of both fields. This course will discuss how techniques rooted in information theory play a key role in understanding the fundamental limits of statistical inference and supervised learning problems regarding generalization error and sample complexity. In particular, we will start from traditional statistical inference, which provides us with the basic intuition about the essence of information-theoretic methods, i.e., connecting mathematically defined information measures with operational meaning. Towards the end, we will also discuss the recent trend of using information-theoretic methods in characterizing the generalization error of learning algorithms.

Course Pre-Requisites / Co-Requisites

Required: EEE 5544 Stochastic Methods for Engineering 1

Nice to have but not required: EEL 5840 Fundamentals of Machine Learning

If you are unsure about your mathematical skills, feel free to reach out to the instructor at buyuheng@ufl.edu with a description of your background and how this course would be useful to you.

Course Objectives

Information theory, established by Shannon, was initially developed to understand the fundamental limit of a communication system. In this course, we will discuss some state-of-art research on how information theory can be applied to interpret and characterize a machine learning algorithm.

Upon completing the course, the student will master the following topics:

- Information measures, f-divergence, and their applications to statistical inference
- Information-theoretic generalization error bounds
- Information bottleneck interpretation of deep learning
- Ability to adapt an information-theoretic way of think in understating learning systems

This course is excellent for students who want to gain state-of-the-art knowledge in the theoretical aspect of machine learning, deepen their understanding from a rigorous perspective, and inspires the design of new algorithms using the information-theoretic method.

Materials and Supply Fees

N/A

Required Textbooks and Software

- Course notes developed by the instructor

Recommended Materials

- Elements of Information Theory
- Joy A. Thomas and Thomas M. Cover
- 2nd Edition
- ISBN number: 0471241954

- [Lecture notes on Information Theory](#)
- Yury Polyanskiy and Yihong Wu

Course Schedule

Week 1:	Introduction
	Information measures
	Entropy, Conditional entropy
	KL-divergence, Conditional divergence
	Convexity
	Homework 1
Week 2:	Mutual information, chain rule
	Sufficient statistics
	Data processing inequalities
Week 3:	Extremization, saddle point
	Variational characterizations
	Homework 1 due
Week 4:	**Traditional Information Theory and Communication**
	Entropy and Lossless Compression
	Mutual information and Channel coding
	Rate distortion and Lossy compression
	Homework 2
Week 5:	Moment generating function
	Large deviations
Week 6:	Hypothesis testing Asymptotic
	Stein and Chernoff exponents
	Homework 2 due
Week 7:	Information Geometry
	I-projection
	Homework 3
Week 8:	**Information-theoretic generalization error bounds**
	Information-theoretic stability
Week 9:	Information-theoretic Generalization error bounds for noisy, iterative algorithms
	Tightening information-theoretic bounds
	Homework 3 due
	Midterm exam
Week 11:	Exact characterization of generalization error Gibbs algorithm using information measure

Gibbs algorithm

Week 12:   Generalization error of transfer and meta learning

Week 13:   Model selection

Week 14:   Special topic: Modal decomposition
              Universal features

Week 15:   Special topic: Information bottleneck

Week 16:   Student project presentations

Attendance Policy, Class Expectations, and Make-Up Policy
Excused absences must be consistent with university policies in the Graduate Catalog (https://catalog.ufl.edu/graduate/regulations) and require appropriate documentation. Additional information can be found here: https://gradcatalog.ufl.edu/graduate/regulations/

Evaluation of Grades
This class has no final exam. Students will deepen their understanding by scribing lecture notes and research papers assigned as pre-lecture and post-lecture readings.

The homework problem sets will contain some proofs omitted in the lecture, and some extension of the topics covered in class. Each problem set will also contain one coding question using python/MATLAB simulation.

The midterm will assess the theoretical concepts' understanding from the course's first half. The in-class sessions will walk students through problems similar to those in the midterm.
Final project: report on a research paper or a standalone research project.

Assignment	Total Points	Percentage of Final Grade
Class participation	100	10%
Homework Sets (3)	100 each	30%
Midterm Exam	100	30%
Final Project	100	30%

Grading Policy
The following is given as an example only.

Percent	Grade	Grade Points
93.4 - 100	A	4.00
90.0 - 93.3	A-	3.67
86.7 - 89.9	B+	3.33
83.4 - 86.6	B	3.00
80.0 - 83.3	B-	2.67
76.7 - 79.9	C+	2.33
73.4 - 76.6	C	2.00
70.0 - 73.3	C-	1.67
66.7 - 69.9	D+	1.33
63.4 - 66.6	D	1.00
60.0 - 63.3	D-	0.67
0 - 59.9	E	0.00

More information on UF grading policy may be found at:
[UF Graduate Catalog](#)
[Grades and Grading Policies](#)

Students Requiring Accommodations
Students with disabilities who experience learning barriers and would like to request academic accommodations should connect with the disability Resource Center by visiting https://disability.ufl.edu/students/get-started/. It is important for students to share their accommodation letter with their instructor and discuss their access needs, as early as possible in the semester.

Course Evaluation
Students are expected to provide professional and respectful feedback on the quality of instruction in this course by completing course evaluations online via GatorEvals. Guidance on how to give feedback in a professional and respectful manner is available at https://gatorevals.aa.ufl.edu/students/. Students will be notified when the evaluation period opens, and can complete evaluations through the email they receive from GatorEvals, in their Canvas course menu under GatorEvals, or via https://ufl.bluera.com/ufl/. Summaries of course evaluation results are available to students at https://gatorevals.aa.ufl.edu/public-results/.

In-Class Recording
Students are allowed to record video or audio of class lectures. However, the purposes for which these recordings may be used are strictly controlled. The only allowable purposes are (1) for personal educational use, (2) in connection with a complaint to the university, or (3) as evidence in, or in preparation for, a criminal or civil proceeding. All other purposes are prohibited. Specifically, students may not publish recorded lectures without the written consent of the instructor.

A "class lecture" is an educational presentation intended to inform or teach enrolled students about a particular subject, including any instructor-led discussions that form part of the presentation, and delivered by any instructor hired or appointed by the University, or by a guest instructor, as part of a University of Florida course. A class lecture does not include lab sessions, student presentations, clinical presentations such as patient history, academic exercises involving solely student participation, assessments (quizzes, tests, exams), field trips, private conversations between students in the class or between a student and the faculty or lecturer during a class session.

Publication without permission of the instructor is prohibited. To "publish" means to share, transmit, circulate, distribute, or provide access to a recording, regardless of format or medium, to another person (or persons), including but not limited to another student within the same class section. Additionally, a recording, or transcript of a recording, is considered published if it is posted on or uploaded to, in whole or in part, any media platform, including but not limited to social media, book, magazine, newspaper, leaflet, or third party note/tutoring services. A student who publishes a recording without written consent may be subject to a civil cause of action instituted by a person injured by the publication and/or discipline under UF Regulation 4.040 Student Honor Code and Student Conduct Code.

University Honesty Policy
UF students are bound by The Honor Pledge which states, "We, the members of the University of Florida community, pledge to hold ourselves and our peers to the highest standards of honor and integrity by abiding by the Honor Code. On all work submitted for credit by students at the University of Florida, the following pledge is either required or implied: "On my honor, I have neither given nor received unauthorized aid in doing this assignment." The Honor Code ([https://sccr.dso.ufl.edu/process/student-conduct-code/)](https://sccr.dso.ufl.edu/process/student-conduct-code/) specifies a number of behaviors that are in violation of this code and the possible sanctions. Furthermore, you are obligated to report any condition that facilitates academic misconduct to appropriate personnel. If you have any questions or concerns, please consult with the instructor or TAs in this class.

Commitment to a Safe and Inclusive Learning Environment

The Herbert Wertheim College of Engineering values broad diversity within our community and is committed to individual and group empowerment, inclusion, and the elimination of discrimination. It is expected that every person in this class will treat one another with dignity and respect regardless of gender, sexuality, disability, age, socioeconomic status, ethnicity, race, and culture.

If you feel like your performance in class is being impacted by discrimination or harassment of any kind, please contact your instructor or any of the following:
• Your academic advisor or Graduate Program Coordinator
• Jennifer Nappo, Director of Human Resources, 352-392-0904, jpennacc@ufl.edu
• Curtis Taylor, Associate Dean of Student Affairs, 352-392-2177, taylor@eng.ufl.edu
• Toshikazu Nishida, Associate Dean of Academic Affairs, 352-392-0943, nishida@eng.ufl.edu

Software Use

All faculty, staff, and students of the University are required and expected to obey the laws and legal agreements governing software use. Failure to do so can lead to monetary damages and/or criminal penalties for the individual violator. Because such violations are also against University policies and rules, disciplinary action will be taken as appropriate. We, the members of the University of Florida community, pledge to uphold ourselves and our peers to the highest standards of honesty and integrity.

Student Privacy

There are federal laws protecting your privacy with regards to grades earned in courses and on individual assignments. For more information, please see: https://registrar.ufl.edu/ferpa.html

Campus Resources:

Health and Wellness

U Matter, We Care:
Your well-being is important to the University of Florida. The U Matter, We Care initiative is committed to creating a culture of care on our campus by encouraging members of our community to look out for one another and to reach out for help if a member of our community is in need. If you or a friend is in distress, please contact umatter@ufl.edu so that the U Matter, We Care Team can reach out to the student in distress. A nighttime and weekend crisis counselor is available by phone at 352-392-1575. The U Matter, We Care Team can help connect students to the many other helping resources available including, but not limited to, Victim Advocates, Housing staff, and the Counseling and Wellness Center. Please remember that asking for help is a sign of strength. In case of emergency, call 9-1-1.

Counseling and Wellness Center: https://counseling.ufl.edu, and 392-1575; and the University Police Department: 392-1111 or 9-1-1 for emergencies.

Sexual Discrimination, Harassment, Assault, or Violence
If you or a friend has been subjected to sexual discrimination, sexual harassment, sexual assault, or violence contact the **Office of Title IX Compliance**, located at Yon Hall Room 427, 1908 Stadium Road, (352) 273-1094, title-ix@ufl.edu

Sexual Assault Recovery Services (SARS)
Student Health Care Center, 392-1161.

University Police Department at 392-1111 (or 9-1-1 for emergencies), or http://www.police.ufl.edu/.

Academic Resources

E-learning technical suppor*t*, 352-392-4357 (select option 2) or e-mail to Learning-support@ufl.edu. https://lss.at.ufl.edu/help.shtml.

Career Connections Center, Reitz Union, 392-1601. Career assistance and counseling; https://career.ufl.edu.

Library Support, http://cms.uflib.ufl.edu/ask. Various ways to receive assistance with respect to using the libraries or finding resources.

Teaching Center, Broward Hall, 392-2010 or 392-6420. General study skills and tutoring. https://teachingcenter.ufl.edu/.

Writing Studio, 302 Tigert Hall, 846-1138. Help brainstorming, formatting, and writing papers. https://writing.ufl.edu/writing-studio/.

Student Complaints Campus*:* https://sccr.dso.ufl.edu/policies/student-honor-code-student-conduct-code/;https://care.dso.ufl.edu.

On-Line Students Complaints*: https://distance.ufl.edu/state-authorization-status/#student-complaint.*