

Physics-Informed Machine Learning

EEL 6935

Class Periods: TBD

Class Location: TBD

Academic Term: Fall 2023

Website: TBD

Instructor

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Course Description

This course looks to integrate physical properties and laws of nature into state-of-the-art data analysis, machine learning, and signal processing techniques. We address three critical data science and machine learning challenges in analyzing and understanding complex, physical systems and materials:

- (1) collecting enough data is often impossible for practical and financial reasons
- (2) capturing the data diversity for informed decision-making can be impossible due to insufficient laboratory conditions or lack of observations (i.e., rare events)
- (3) data-driven analytics are not as explainable as physics-based techniques

These challenges make sophisticated data analytics and machine learning inapplicable in many fields. We expand state-of-the-art analytics into these physics-driven applications, focusing on both theory and practical applications.

We begin the course by exploring the geometric (or linear algebra based) perspective of data and physical laws. We discuss this perspective because it forms the basis for much of modern machine learning. In the second half of the course, you will help direct the course. You will learn these subjects through hands-on projects and research and present them to your peers, utilizing the tools developed in the first half of the course. Students from various disciplines are encouraged to join the course to provide the class with both machine learning as well as a physics application perspective of the topics discussed. However, all students are expected to have a robust mathematical maturity and programming experience in MATLAB or Python.

Course Pre-Requisites / Co-Requisites

- Programming experience in MATLAB and / or Python required
- Fundamentals of Machine Learning (EEL 5840) or equivalent recommended
- Foundations of Digital Signal Processing (EEE 5502) or equivalent recommended

Course Objectives

At the conclusion of this course, you should be able to:

- Describe data science concepts from a geometric perspective
- Describe physical laws (e.g., partial differential equations) from a geometric perspective
- Derive and create a state-of-the-art physics-informed machine learning framework
- Apply cutting-edge physics-informed machine learning techniques to real world problems

Recommended Materials

- Foundations of Signal Processing by Martin Vetterli, Jelena Kovacevic, and Vivek Goyal
 - Freely downloadable from: <http://fourierandwavelets.org/>
- Course notes (Author: Joel B. Harley)

Recommended Software

- MATLAB and/or Python

Course Schedule

DATE	LECTURE	READING	ASSIGNMENTS
Week 1: Introduction			
TUE	Aug 22	No Class	--
THU	Aug 24	Introduction, Policies, Vector Spaces	FSP 1-2
Week 2: The Most Important Linear Operations			
TUE	Aug 29	Orthogonality, Norms	FSP 2
THU	Aug 31	Linear Operators, Projections	FSP 2
Week 3: Data Representations			
TUE	Sep 05	Bases	FSP 3
THU	Sep 07	Eigenvalue Decomposition	FSP 3
Week 4: Extracting Knowledge from Data			
TUE	Sep 12	Singular Value Decomposition	FSP 3
THU	Sep 14	Tensor Data Science – Kronecker products and sums	--
Week 5: Linear Algebra and Optimization			
TUE	Sep 19	Optimization and a little Matrix Calculus	--
THU	Sep 21	Project Presentations	--
Week 6: The Physics-Informed Learning Setup			
TUE	Sep 26	What is physics-informed Machine Learning?	Paper
THU	Sep 28	Approximating Partial Differential Equations	Paper
Week 7: The Physics-Informed Decomposition Algorithm			
TUE	Oct 03	Physics-Informed Decomposition: Estimating Physics	Paper
THU	Oct 05	Physics-Informed Decomposition: Obtaining Solutions	Paper
Week 8: The Physics-Informed Decomposition Application			
TUE	Oct 10	Physics-Informed Decomposition: Extension into Tensor Spaces	Paper
THU	Oct 12	Physics-Informed Decomposition: Interpretability	Paper
Week 9: Project Discussion			
TUE	Oct 17	Project Discussions	--
THU	Oct 19	Review	--
Week 10: Exam			
TUE	Oct 24	Mid-Term Exam	--
THU	Oct 26	Student Presentation: TBD	--
Week 11: Student Presentations			
TUE	Oct 31	Student Presentation: TBD	--
THU	Nov 02	Student Presentation: TBD	--
Week 12: Student Presentations			
TUE	Nov 07	Student Presentation: TBD	--
THU	Nov 09	Student Presentation: TBD	--
Week 13: Student Presentations			
TUE	Nov 14	Student Presentation: TBD	--
THU	Nov 16	Student Presentation: TBD	--
Week 14: Student Presentations			
TUE	Nov 21	Student Presentation: TBD	--
THU	Nov 23	Thanksgiving Holiday (No Class)	--
Week 15: Student Presentations			
TUE	Nov 28	Student Presentation: TBD	--
THU	Nov 30	Student Presentation: TBD	--
Week 15: Poster Presentations			
TUE	Dec 5	Poster Presentations	--
THU	Dec 7	Reading Day (No Class)	--

Attendance and Participation Policies

Attendance & Participation:

While attendance is not graded, lectures will include regular homework help and in-class discussions and demonstrations on the subject material. While participation is not graded, it is an integral part of each class that can help you learn the material.

Slack Page:

We have a Slack page for the course: **TBD**. This is an *optional* resource for students to discuss the course amongst each other and occasionally with the Professor and TAs. This resource is intended to supplement office hours and student interactions. **No official communication / submission happens over Slack.** No assignments submissions will be accepted over Slack.

Online Course Recording:

Our class sessions may be audio visually recorded for students in the class to refer back and for enrolled students who are unable to attend live. Students who participate with their camera engaged or utilize a profile image are agreeing to have their video or image recorded. If you are unwilling to consent to have your profile or video image recorded, be sure to keep your camera off and do not use a profile image. Likewise, students who un-mute during class and participate orally are agreeing to have their voices recorded. If you are not willing to consent to have your voice recorded during class, you will need to keep your mute button activated and communicate exclusively using the "chat" feature, which allows students to type questions and comments live. The chat will not be recorded or shared. As in all courses, unauthorized recording and unauthorized sharing of recorded materials is prohibited.

Evaluation Methods and Criteria

The following section discusses the policies for each of the graded assessments in this course. You should look here first for answers to any general, course-related inquiries.

Homework (5 in total)

When: Assigned roughly once a week (see course schedule).

What: Two parts: (1) Analytical and theory problems that can be solved by hand and (2) coding problems solve thru MATLAB or Python.

Why: Homework guides you through the course material and presents you with questions that require time to think about and complete. Homework assignments are not meant to be completed in a single day.

Grading: Each of the three homework parts is graded separately. Homework is graded on a scale from 0 to 10. How points are assigned will vary with the assignment.

Late policy: Late assignments can be submitted one day late and can receive a maximum grade of 8/10.

Assignments will not be accepted after one day. This policy allows us to post solutions before an exam.

Submission: Homework will be submitted on canvas before class on the due date.

Mid-term Exam

When: There is one mid-term exam

What: Questions will be similar to homework concept problems

Why: Exams are an opportunity to show what you know about the course

Calculators/Open Book: Exams will be open book but time-constrained, so do not rely on them

Grading: Exams are graded on a 100-percentage scale.

Course Project

When: Projects will be worked on during the second half of the semester.

What: Students will choose projects presented by faculty, industry representatives, or others to complete. The project will be divided into three components: a project paper due at the end of the course, a project poster presentation due at the end of the course, and a project topic presentation during the second

half of the course. You will present a topic of your choice to the class. The presentation will either focus on a machine learning framework or application related to your project.

Why: The project is intended to give you an opportunity to apply the techniques learned in this course to a real problem given by top engineers. The poster and topic presentations give you the experience of presenting in front of an audience and diving deep into a subject.

Grading for Paper: Project reports are graded by the instructor on a 100-percentage scale.

Grading for Topic Presentation: Grading for topic presentation will be based on a rubric completed by the entire class and the instructor. A weighted average will be applied. The rubric is as follows:

Section	Requirement	Score	Out of
Presentation Structure	Presenter well motivated his or her topic. Comments:		10
	Presentation is well organized. Content is presented in a logical order with appropriate transitions. Comments:		10
	Presentation was delivered clearly, both orally and visually. Comments:		10
	The presenter was prepared – knew what he/she was going to present and had all of the material ready. Comments:		10
Presentation content	Presenter taught me something new and interesting. Comments:		20
	Content was appropriate for the given audience. That is, we should have been able to understand it. Comments:		10
Total			70

Grading for Poster Presentation Grading for poster presentations will be accomplished by anyone and everyone who comes to your poster. Each audience member will be presented with a rubric to fill out. The grade will be based on a weighted average from the participants (based on position: e.g., faculty, graduate student, undergraduate student). Attributes will be graded on a scale from 1 to 5. The rubric is as follows:

Attribute	Grp. X	Grp. X	Grp. X	Grp. X
The work presented was high quality.				
Presenters well motivated their work.				
Posters were well organized. Content was presented in a logical order with appropriate transitions.				
Presentation was delivered clearly, both orally and visually.				
The presenters were prepared – knew the material well.				
The presenters taught me something new and interesting.				

Evaluation of Grades

Lecture-Based Assignments (First Half of Course)	
Assignment	Percentage
Homework (best 4 out of 5)	20%
Midterm Exam	30%
Project-Based Assignments (Second Half of Course)	
Assignment	Percentage
Project Paper	20%
Project Poster Presentation	15%
Project Topic Presentation	15%
Total	100%

Grading Policy

Percent	Grade	Grade Points
93.3 - 100.0	A	4.00
90.0 - 93.3	A-	3.67
86.6 - 90.0	B+	3.33
83.3 - 86.6	B	3.00
80.0 - 83.3	B-	2.67
76.6 - 80.0	C+	2.33
73.3 - 76.6	C	2.00
70.0 - 73.3	C-	1.67
66.6 - 70.0	D+	1.33
63.3 - 66.6	D	1.00
60.0 - 63.3	D-	0.67
00.0 - 60.0	E	0.00

More information on UF grading policy may be found at:

<http://gradcatalog.ufl.edu/content.php?catoid=10&navoid=2020#grades>

<https://catalog.ufl.edu/ugrad/current/regulations/info/grades.aspx>

Course & University Policies

Modifying Syllabus by Class Vote

When: If you and/or other students believe the course would be improved by a change in the syllabus and I agree that it would be a reasonable change. **What:** The proposed change will be put to an anonymous vote with the entire class. If the majority of the class agrees to this change, it becomes part of the syllabus. **Why:** In previous years, changes to the syllabus have been necessary due to unforeseen consequences of certain policies. The class vote ensures the entire class agrees with the change.

Collaboration

Healthy collaboration: To solve homework assignments, healthy discussion and collaboration amongst classmates is encouraged. Healthy collaboration includes:

- Discussing and explaining general course material
- Discussing assignments for better understanding
- Providing assistance for general programming and debugging issues

If another student contributes substantially to your understanding of a problem, you should *cite* this student to let myself and the teaching assistants be aware of your similar interpretations of a problem. You will not be judged negatively for citing another student.

Cheating and plagiarism: While collaboration is encouraged, you are *expected to submit your own work*. Submitting work completed by another student is considered plagiarism and will be dealt with according to university policy. In general, if you do not fully understand your solution, the work is not your own. Examples of plagiarism or cheating include:

- Copying (or allowing someone to copy), even partially, an assignment solution or program from the course
- Submitting material, particularly code, using material taken from another source without proper a citation
- Obtaining solutions to assignments or exams through inappropriate means

Note that I may elect to use a plagiarism detection service in this course, in which case you will be required to submit your work to such a service as part of your assignment.

Consequences: If you are suspected of dishonest academic activity, university policy to is immediately report the activity to the Student Conduct & Conflict Resolution office to have paper trails and ensure students receive fair representation. Once reported, the Student Conduct & Conflict Resolution office will review the report act on it.

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/>) 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 support, 352-392-4357 (select option 2) or e-mail to Learning-support@ufl.edu.
<https://lss.at.ufl.edu/help.shtml>.

Career Resource 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: <http://www.distance.ufl.edu/student-complaint-process>.