CEE 598
Physics-Informed ML for Water and Environmental Engineering

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2025
Time: MW, 04PM-05:50PM
Location: 2015 Hydro

Course Description

This course covers several areas of scientific machine learning (ML), including how to (a) construct data-driven ML models, (b) constrain ML models with the laws of physics and engineering principles, and (c) apply physics-informed ML models to engineering problems. The main topics include physics-informed Deep Neural Networks, Gaussian process regression, and theory-guided machine learning. The focus is on flow, transport, and other processes key to water resources and civil and environmental engineering applications.

Course objectives:

- To understand how to leverage data, mathematical differential equation models, and machine learning methods to study civil and environmental engineering problems
- To explore the advantages and disadvantages of different physics-informed ML methods
- To understand how mechanistic models can improve data-driven ML methods
- To become familiar with software for training ML models subject to differential equation constraints
- To improve technical writing and communication skills

Prerequisites: CEE 498 Data Science for Civil and Environmental Engineering; CEE 498 Machine Learning for Civil Engineering; students are expected to know differential equations and linear algebra and be able to write computer programs for numerical computations in a language of their choice (e.g., C/C+, Matlab, Python).

ILLINOIS CANVAS: https://canvas.illinois.edu/
Illinois Canvas will be used to post course materials and homework assignments, etc.

Engineering Workstation Access: All students enrolled in the class should have an account on the College of Engineering Workstation (EWS) Labs. EWS has a wide variety of software (e.g., MATLAB) that you might want to use for computer assignments and the term project.

Course Notes: Course notes will be available on Canvas.

Reference Texts - available in the Engineering Library.

Bishop, Christopher M., and Nasser M. Nasrabadi. Pattern recognition and machine learning. Vol. 4. No. 4. New York: Springer, 2006.

Brunton, Steven L., and J. Nathan Kutz. *Data-driven science and engineering: Machine learning, dynamical systems, and control*. Cambridge University Press, 2022.

Carl Edward Rasmussen and Christopher K. I. Williams. Gaussian Processes for Machine Learning, MIT Press, 2005

Office Hours

Please email me if you would like to meet.

Grading

Homework Problem Sets You can work in teams (2 students)	**20%**
Paper presentation for 1 class ~ 30 min (or 2 classes if working as a team)	**20%**
Reviews of 9 papers presented by others	**20%**
Term Project	**40%**

1. Group project (2 students). The project should involve data-driven computations with physics constraints. Students select a topic of their choice (does not have to be related to water resources and environmental workflow engineering, can be in any area of civil and environmental engineering) in consultation with the instructor.

There is no final exam

DETAILED COURSE OUTLINE

(subject to adjustment due to time limits and student interest)

I. Overview of standard (purely data-driven) machine learning methods in Civil and Environmental Engineering (1-2 lectures)
   a. Fully connected feed-forward deep neural networks (NNs)
   b. Convolutional NNs
   c. Long short-term memory models
   d. Gaussian Process Regression

II. Overview of physics(process)-based models and numerical methods for solving the underlying equations (1-2 lectures)

III. Introduction to Physics-Informed Neural Network method (3 lectures)

a. Theory: approximation errors, existence, and convergence
b. Steady-state problems
c. Time-series modeling
d. Spatial time-evolving data

IV. Physics-Informed Deep Neural Network models (3 lectures)
V. Physics-Informed Convolutional Deep Neural Network models (3 lectures)
VI. Physics-Informed LSTM models (3 lectures)
VII. Neural ODE models (3 lectures)
VIII. Theory-guided Deep Learning methods (3 lectures)
IX. Physics-informed Gaussian process regression methods (3 lectures)
X. Physics-Informed Radial Basis Method (3 lectures)

JOURNALS

(very incomplete list)

Computational Methods in Applied Mechanics and Engineering
Journal of Computational Physics
Journal of Hydraulic Engineering, ASCE
Journal of Hydrology
SIAM Journal on Numerical Analysis
Advances in Water Resources
Water Resources Research