Deep Learning in Geophysical Fluid Dynamics
Fall 2021, AOS 551

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Class: Tuesdays and Thursdays 11:00 am - 12:20 pm
Classroom: Guyot Hall 154
Office hours: Thursdays 1-2pm

Summary:
Course provides a survey of the rapidly growing field of physics-informed deep learning, which integrates known physics principles with neural networks to predict the behavior of a physical system. It both introduces the background knowledge required to implement physics-informed deep learning and provides practical in-class coding exercises. Students gain experience applying this emerging method to their own research interests, including topics in geophysical fluid dynamics (atmospheric, oceanic or ice dynamics) or other nonlinear systems where the same technique applies. Students develop individual projects throughout the semester.

Grading scheme: A-F, P, AUD
Participation – 10 %
Oral presentations – 30 %
Paper in lieu of final - 60%

Schedule:
Lectures 1-4: Basics of neural networks (back propagation, universal function approximation)
Lectures 5-8: Physics-informed neural networks (PINN)
Lecture 9: Inferring hidden parameters in fluid dynamics
Lecture 10: Example of PINN applying to ice dynamics
Lecture 11-13: Student presentations of selected papers
Fall break (10/16-24)
Lecture 14-15: Automatic differentiation, collocation points, meaning of equation weights, optimal weights, high-frequency function approximation
Lecture 16-17: Discovering governing equations from data
Lecture 18-20: Basics of convolutional neural networks (CNN) and application to fluid modeling
Lecture 21: No Free Lunch: How ML can be used (or mis-used) to uncover dynamical regimes in the ocean and beyond. Guest lecturer: Dr. Maike Sonnewald
Thanksgiving break (11/24-28)
Lecture 22- 24: Student presentations on course projects.
Reading period (12/7-14)
Final exam period (12/15-21)
Final paper due on 12/21 5pm

For the **course project** the students should apply the method taught in class to their research fields involving geophysical fluid dynamics (atmospheric, oceanic or ice dynamics) or other nonlinear systems where the same technique applies.

Students should submit a **final paper** (due on 12/21 5pm) that summarize the course project. The final paper should not be longer than 10 pages.

SAMPLE READING LIST:

1. Raissi, M., Perdikaris, P. and Karniadakis, G.E., 2019. Physics-informed neural networks: A deep learning framework for solving forward and inverse problems involving nonlinear partial differential equations. *Journal of Computational Physics*, *378*, pp.686-707.
2. Raissi, M. and Karniadakis, G.E., 2018. Hidden physics models: Machine learning of nonlinear partial differential equations. *Journal of Computational Physics*, *357*, pp.125-141.
3. Raissi, M., Yazdani, A. and Karniadakis, G.E., 2020. Hidden fluid mechanics: Learning velocity and pressure fields from flow visualizations. *Science*, *367*(6481), pp.1026-1030.
4. Brunton, S.L., Proctor, J.L. and Kutz, J.N., 2016. Discovering governing equations from data by sparse identification of nonlinear dynamical systems. *Proceedings of the national academy of sciences*, *113*(15), pp.3932-3937.
5. Rudy, S.H., Brunton, S.L., Proctor, J.L. and Kutz, J.N., 2017. Data-driven discovery of partial differential equations. Science Advances, 3(4), p.e1602614.