Data-Driven Methods for Dynamical Systems (L12)

Non-Examinable (Graduate Level)

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Dynamical systems are a ubiquitous tool for modeling time-dependent processes in science and engineering. Progress in machine learning methods in the past two decades has been tremendous, giving rise to the field of scientific machine learning which combines data-driven methods with physical modeling techniques. This course will cover some of the pivotal data-driven algorithms and model architectures that have influenced the field of dynamical systems, enabling more accurate model inference, forecasting, and analysis of dynamical data. Special focus will be given to partially observed systems resulting from incomplete measurements of the system state or scale separation. Topics will cover the three pillars of dynamical modeling:

- Regression and Modal Decomposition (system identification, control methods)
- Gradient Optimization Methods (neural/GP ODEs, adjoint sensitivity)
- Data Assimilation and Bayesian Methods (Kalman filtering and smoothing)

Prerequisites

This course requires an understanding of calculus, probability, linear algebra, numerical algorithms, and programming. Proficiency in one of Python or Julia programming languages is expected, class demonstrations and course examples sheets will require students to interpret and write code in of one of these languages. A deep mathematical understanding of dynamical systems and partial differential equations is not needed, but familiarity with them is helpful.

Literature

- General textbooks:
  1. S. Brunton, N. Kutz, *Data-Driven Science and Engineering,* Cambridge University Press. Also available at https://databookuw.com/
  2. K. Law, A, Stuart, K. Zygalakis, *Data Assimilation,* Springer
  3. E. Bach, R. Baptista, D. Sanz-Alonso, A. Stuart, *Machine Learning for Inverse Problems and Data Assimilation,* . Also available at https://arxiv.org/abs/2410.10523
- Online notes:
  1. Kevin Murphy, Scott Linderman, et al. *State Space Models: A Modern Approach*: https://probml.github.io/ssm-book/root.html#

Additional support

Three examples sheets will be provided and accompanying office hours will be offered.