ESE 559 Topics in Systems & Control:

Data-Integrated Frameworks for Systems Analysis and Control Design

Fall 2021 (**Classroom Instruction**)

Website: https://wustl.instructure.com/courses/68025 (**Canvas webpage**)
The Canvas course webpage will be the main access point through which you will be able to navigate yourself through all relevant course resources.

Description: Modeling and control approaches of the past decades are usually concerned with analytically described control systems with relatively mild complexity, which allows for a highly successful treatment by rigorous systems theoretic methods. Recent years, however, have witnessed a significant shift towards the consideration of far more complicated control systems in which purely analytical approaches are infeasible.

This is a research-focused course that will introduce and explore systematic approaches towards augmenting the core foundations of systems and control theoretic frameworks with data-integrating capabilities to efficiently harness the vast amounts of valuable operational data and computing resources in order to solve challenging control tasks that escape the traditional setting. The starting point for these new developments are specific macroscopic considerations of dynamical systems associated with transfer operators and Koopman operators. After reviewing these operator-theoretic frameworks, we will explore a family of sample-based approaches that emerge out of the macroscopic viewpoint. These sample-based approaches not only mitigate drawbacks of the original operator-theoretic approaches but also facilitate more direct and efficient data-integrated paths for elucidating important features of dynamical systems with applications to control and estimation.

Prerequisites: ESE 415 Optimization,
ESE 551 Linear Dynamic Systems,
ESE 553 Nonlinear Dynamic Systems

Lectures: Tuesdays and Thursdays 4–5:20pm.

Instructor Zoom Office Hours: Fridays 4–5pm, or by appointment.

TA Zoom Office Hours: Wednesdays 4pm-5pm, or by appointment.

Course outline

A Macroscopic View of Dynamical Systems via Operator-Theoretic Approaches: Review of theoretical and computational aspects of the Frobenius-Perron operator (also referred to as a transfer operator) and the Koopman operator.

Sample-Based Methods for Assessing Macroscopic Features of Dynamical Systems: Data-driven methodologies for the prediction of system trajectories from snapshot data; Novel flow clustering and its interpretation as a computational nonlinearity measure; computationally defined quantitative observability measures for nonlinear systems; sample-based approaches to computations of invariant sets and stability analysis.

Efficient Integration of Data to Aid in Particularly Challenging Dynamic Tasks: Data-driven iterative nonlinear optimal control schemes originating from the novel data-centric modeling perspective; data-integrated motion planning under complicated constraints that cannot be analytically modeled and are given as point sets.

Vertically Integrated Data-Driven Joint Modeling and Control Methodologies: Control strategies operating on purely data-defined models; the use of delay coordinates as a proxy for the state in the context of complex and large-scale control systems with measured outputs but no prior understanding of what constitutes the state

Specific Course Objectives

The course highlights the new aspects Prof. Zeng's research agenda and will expose the attending students to a truly interdisciplinary set of topics spanning nonlinear dynamics, engineering, and computational mathematics. Through considering practical problems and constructive computational approaches, the students will be effectively prepared to go on to tackle the vast rapidly emerging challenges for complex systems of the 21st century. The findings and results of Prof. Zeng's group and other researchers working in this field will be continuously integrated into the course.

Course Materials

There is no single course textbook for this course as the results and contents of the theory of this rapidly evolving new direction are still being fully fleshed out in ongoing research. Relevant materials and resources (lecture notes by Prof. Zeng and research papers) will be made freely available on the Canvas course webpage.