UCLA Samueli School of Engineering

Mechanical & Aerospace Engineering Departmental Seminar

Friday, June 9, 2023, 12 PM – 1 PM
Klug Room (Boelter Hall 8500)

Data-driven reduced-order modeling and control flows with complex chaotic dynamics

Michael D. Graham
Steenbock Professor of Engineering and Harvey D. Spangler Professor
Department of Chemical and Biological Engineering
Department of Mechanical Engineering
University of Wisconsin-Madison

ABSTRACT: Fluid flows often exhibit chaotic or turbulent dynamics and require a large number of degrees of freedom (a high state-space dimension) for accurate simulation. Nevertheless, because of the fast damping of small scales by viscous diffusion, these flows can in principle be characterized with a much smaller number of dimensions, as their long-time dynamics relax to a finite-dimensional surface in state space called a manifold. Classical data-driven methods for dimension reduction, such as Proper Orthogonal Decomposition (POD), approximate this manifold as a flat surface, but for complex flows, this linear approximation is severely limited. We describe a data-driven reduced order modeling method, which we call Data-driven Manifold Dynamics" (DManD), that finds a nonlinear coordinate representation of the manifold using an autoencoder and then learns an ordinary differential equation (ODE) for the dynamics in these coordinates. Exploitation of symmetries substantially improves performance. We apply DManD to spatiotemporal chaos in the Kuramoto-Sivashinsky equation (KSE), chaotic bursting dynamics of Kolmogorov flow, and transitional turbulence in plane Couette flow, finding dramatic dimension reduction while yielding good predictions of short-time trajectories and long-time statistics. We also introduce an autoencoder architecture that provides an explicit estimate of manifold dimension as well as an orthogonal coordinate system for the manifold. DManD can be combined with a clustering algorithm to generate overlapping local representations that are particularly useful for intermittent dynamics. As an example of its utility, we apply DManD to drag reduction in wall turbulence. Deep reinforcement learning (RL) control can discover control strategies for high-dimensional systems, making it promising for flow control. However, it learns by interacting with the target system, which can be very costly. We mitigate this expense by obtaining a low-dimensional DManD model from data for the open-loop system, then learn an RL control policy using the model rather than the true system. For turbulent plane Couette flow in the transition regime, we accurately represent the turbulent dynamics with 25 degrees of freedom, as compared to the 100,000 degrees of freedom of the direct simulation. We then use the model to very rapidly train an RL control policy that is highly effective in laminarizing the flow.

BIO: Michael D. Graham is the Steenbock Professor of Engineering and Harvey D. Spangler Professor of Chemical and Biological Engineering at the University of Wisconsin-Madison, and also has an appointment in Mechanical Engineering. He received his B.S. in Chemical Engineering from the University of Dayton in 1986 and his PhD. from Cornell University in 1992. After postdoctoral appointments at the University of Houston and Princeton University, he joined the Chemical Engineering faculty at the University of Wisconsin-Madison in 1994. He chaired the department from 2006-2009. Professor Graham's research interests include the rheology and dynamics of complex fluids; blood flow in the microcirculation; swimming microorganisms; and instabilities and turbulence in Newtonian and complex fluids. He is author of two textbooks: *Microhydrodynamics, Brownian Motion, and Complex Fluids* (Cambridge, 2018) and *Modeling and Analysis Principles for Chemical and Biological Engineers* (Nob Hill, 2013, with James B. Rawlings). Among Professor Graham's professional distinctions are the Best Student Paper Award from the Environmental Division of AIChE in 1986, a CAREER Award from NSF in 1995, the François Frenkiel Award for Fluid Mechanics from the American Physical Society Division of Fluid Dynamics (APS/DFD) in 2004, the Stanley Corrsin Award from APS/DFD in 2015, and a 2018 Vannevar Bush Faculty Fellowship from the US Department of Defense. He has presented many named and plenary lectures, including the inaugural William R. Schowalter Lecture at the 2019 AIChE Annual Meeting. Professor Graham was an Associate Editor of the Journal of Fluid Mechanics from 2005-2012 and Editor-in-Chief of the Journal of Non-Newtonian Fluid Mechanics from 2013-2015. He is Past President of the Society of Rheology.

Pizza will be served

Host: Sam Taira MAE, ktaira@seas.ucla.edu