IOWA STATE UNIVERSITY
Department of Mechanical Engineering

ME 600 Seminar

Amin Ghadami

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Title:
Tackling Surprises in Complex Systems:
Data-driven Forecasting of Critical Transitions Based on Invariants of Nonlinear Dynamics

Abstract:
Complex systems, ranging from systems examined by engineering to others related to climate sciences and ecology, are susceptible to transitions leading to drastic re-organization or collapse. Such an unexpected transition is usually undesirable because it is often difficult to restore a system to its pre-transition state once the transition occurs. Identifying the stability, resilience, and risk of critical transitions is a fundamental step toward implementing appropriate management strategies and the design of complex systems. It is exceedingly difficult to know if a system comes close to critical transitions because typically there are no easily noticeable changes in the system dynamics that can be observed until it is too late and the transition has occurred. Furthermore, accurate models of many physical and engineered systems are often not available due to assumptions and uncertainties as well as due to parameter variations over time, and predictions based on incomplete models have limited accuracy. Thus, a significant challenge emerges. How could we forecast such transitions before they occur? The answer lies in a combined use of invariants in nonlinear dynamics and data-driven methods that together can predict such catastrophic events.

In this talk, I introduce a unique set of data-driven approaches to forecast critical points and post-critical dynamics using measurements of the system response collected only in the pre-transition regime. The proposed data-driven approaches root in the theory of dynamical systems and underlying mechanism of critical transitions which eliminates reliance on massive data for predictions. Based on observations of the system response to natural and controlled perturbations, the method discovers the system's stability, resilience, and equilibriums in current and upcoming conditions. The application of this finding will be demonstrated for monitoring and design of a variety of natural and engineered systems, including aeroelastic systems (flutter of 2D airfoils and 3D wings), traffic flow systems (onset of traffic jams), and population dynamical systems (dynamics of yeast populations).

This seminar counts towards the ME 600 seminar requirement for Mechanical Engineering graduate students.