Contribution ID: **10** Type: **Contributed talk**

Sparse identification of delay equations with distributed memory

Tuesday, 27 January 2026 11:15 (30 minutes)

Data-driven model discovery has become a powerful approach for identifying governing equations of dynamical systems using temporal data. The Sparse Identification of Nonlinear Dynamics (SINDy) algorithm, initially developed for ordinary differential equations (ODEs), has been extended to more general classes of problems, including partial differential equations (PDEs), stochastic differential equations (SDEs) and delay differential equations (DDEs) with discrete delays. However, its application to systems with distributed delays and renewal equations remains unexplored.
Distributed delays involve integration over a continuum of past states and are at the core of renewal-type integral equations. Related models are prevalent in biological and ecological applications, to describe in particular structured populations and epidemics. They portrait memory dependent dynamics but are challenging to identify due to the inherent complexity of delay kernels and renewal processes. Building on the integral formulation of SINDy for ODEs, we propose a novel extension of the SINDy framework to recover the (possibly nonautonomous) kernel of distributed delays through the use of quadrature formulas. As such the new approach aims at providing a sparse interpretable model rather than just a black-box right-hand side.
We demonstrate the efficacy of the new method first on academic examples and then by applying it to the transmission dynamics of Severe Fever with Thrombocytopenia Syndrome (SFTS), an emerging tick-borne disease. We use real data on reported human cases and daily temperature from Dalian, China. The technique successfully discovers a parsimonious integral model that not only accurately predicts the outbreaks but also identifies an interpretable, temperature dependent kernel. This study validates our extended SINDy framework as a powerful tool for uncovering and forecasting the dynamics of complex environmental and epidemiological systems governed by memory effects.

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Session Classification: Session 3