Aeroseminars

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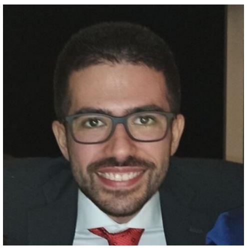
Sala Ferrari (2nd Floor DIMEAS), 10 October at 11:30 a.m.



Quantized Reduced-Order Models in Fluid Dynamics

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Abstract:

Over the past few decades, Reduced-Order Modelling (ROM) has become a cornerstone in computational science and engineering. The central idea is to approximate high-dimensional data in a lower-dimensional space or manifold and to model the temporal dynamics within this reduced representation. This can be achieved using classical projection-based methods, such as Galerkin projection, which project the governing equations onto a reduced space, or data-driven approaches like Echo State Networks (ESNs), which directly learn the temporal evolution from data. Among the various ROM strategies, Cluster-Based Reduced-Order Modelling (CROM) has gained increasing attention for its ability to represent the statistical and dynamical features of complex flows. By discretizing the state space into clusters and modeling transitions between them, CROM provides an intuitive description of the system's evolution in terms of representative states. However, conventional CROMs are typically global in nature, which can limit their physical interpretability and accuracy when applied to nonlinear or chaotic systems characterized by highly geometrically complex solution manifolds. To address these challenges, we propose a quantized local reduced-order model (ql-ROM) framework. The key idea is to construct a collection of local ROMs, each describing the dynamics in a specific region of the solution manifold. Using cluster-based analysis, the manifold is partitioned into local patches defined by centroids, effectively creating a geometric map of the system. Within each cluster, a Galerkin Proper Orthogonal Decomposition (POD) ROM is developed around its centroid, while transitions between local ROMs are governed by a distance-based metric. The methodology is first demonstrated on low-dimensional dynamical systems, such as the Rössler attractor, and on canonical fluid-dynamic benchmarks like the Kolmogorov flow. It is then applied to the wake flow past the fluidic pinball, exploring periodic, quasi-periodic, and chaotic regimes. Finally, the same framework is employed to perform a local modal energy budget analysis of the minimal flow unit (MFU), providing new insights into the local balance of production, dissipation, and transfer mechanisms across the manifold. Our results highlight the potential of ql-ROMs to accurately capture complex flow behavior, potentially opening opportunities for applications in efficient flow control and real-time prediction of extreme events.

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