Seminars on Machine learning for Fluid dynamics

Politecnico di Torino
Department of Mechanical and Aerospace Engineering (DIMEAS)

Title:

Nonlinear manifold learning of chaotic shear flows: the fluidic pinball configuration.

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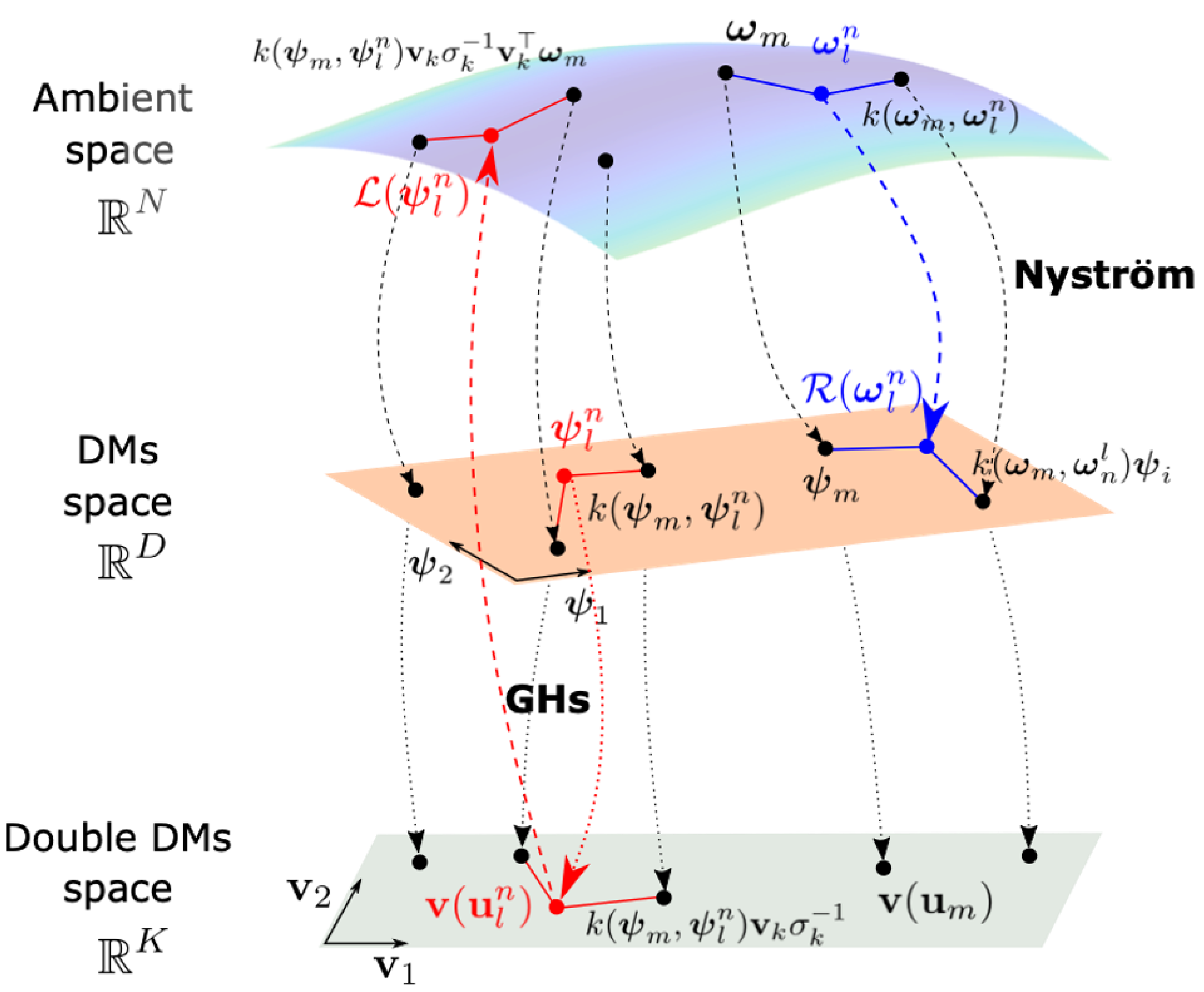

Keywords:

Manifold learning, chaotic shear flows, direct numerical simulation, diffusion maps.

Abstract

A parsimonious nonlinear manifold learning algorithm based on Diffusion Maps (DMs) is presented and employed to identify the low-dimensional manifold embedding the fluidic pinball dynamics. Two-dimensional direct numerical simulations of the incompressible Navier–Stokes equations are first performed to compute the viscous wake flow behind the fluidic pinball by varying the Reynolds number Re. Five different flow regimes are considered, spanning from steady symmetric (Re $<$ 18) to fully chaotic (Re $>$ 115) conditions. In the first step of the Diffusion Maps embedding, the minimum set of DMs reduced coordinates (eigenvectors) necessary to represent the flow dynamics in all the regimes is found by projecting the high-dimensional simulation data into the reduced low-dimensional space (restriction operation). The nonlinear manifold lying in the state-space spanned by the three leading DMs coordinates is thus obtained by varying the Reynolds number Re, and its shape discussed in connection with the different physical mechanisms at play across all the flow regimes. Then, the time series embedded into the manifold are lifted back to the original space by means of Geometric Harmonics (lifting operation), such as to evaluate the reconstruction error between the "ground truth" solution (i.e. high-fidelity simulation data) and the DMs "reconstruction". The performance of the DMs- based reconstruction is finally compared with a counterpart linear technique based on the Proper Orthogonal Decomposition (POD), which shows the superiority of the proposed approach in parsimoniously representing the nonlinear dynamics up to the chaotic regime. This work demonstrates that Diffusion Maps are a promising tool to identify a fully data-driven parsimonious reduced order surrogate model across all the flow regimes exhibited by the fluidic pinball configuration.

Bio

Alessandro Della Pia is a Postdoctoral Researcher at Scuola Superiore Meridionale (SSM), School for Advanced Studies, in Napoli (Italy). He earned his bachelor's and master's degrees in Aerospace Engineering at University of Naples "Federico II", where he also earned his Ph.D. in Fluid Dynamics. During his Ph.D. he worked on the numerical and experimental characterization of two-phase flows, developing also a collaboration with the Delft University of Technology, where he spent one year working as Visiting Researcher. He obtained in 2024 the GIMC (Gruppo Italiano di Meccanica Computazionale) Award for the best Ph.D. thesis in Computational Fluid Mechanics. Nowadays, his main research interest consists in reduced-order-modelling of bifurcating fluid flows, which he develops with prof. Costantinos Siettos' research group (https://www.siettos.net/) at SSM. He also collaborates with prof. Marios Kotsonis (https://www.tudelft.nl/staff/m.kotsonis/) from Delft University of Technology on the experimental characterization of two-phase flows, and with prof. Steven Weinstein from Rochester Institute of Technology on the numerical-theoretical investigation of plane liquid jets dynamics.