Workshop on advanced NUmerical MEthods for Real-world Applications (NUMERA)
Department of Mathematics, University of Bari Aldo Moro
15 June 2026, Bari, Italy

INTERPRETABLE LATENT DYNAMICS VIA GRAPH CONVOLUTIONAL NETWORKS

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ABSTRACT

Graph Neural Networks (GNNs) have emerged as powerful tools for nonlinear Model Order Reduction (MOR) of time-dependent parameterized Partial Differential Equations (PDEs). However, existing methodologies struggle to combine geometric inductive biases [1] with interpretable latent dynamics [2], overlooking dynamics-driven features or disregarding geometric information, respectively.

In this work, we address this gap by introducing Latent Dynamic Graph Convolutional Network (LD-GCN), a purely data-driven, encoder-free architecture that learns a global, low-dimensional representation of dynamical systems conditioned on external inputs and/or parameters [3]. The temporal evolution is modeled in the latent space and advanced through time-stepping, allowing for time-extrapolation, and the resulting trajectories are consistently decoded onto geometrically parametrized domains using a GNN. Our framework enhances interpretability by enabling the analysis of latent trajectories and supports zero-shot prediction through interpolation in the latent space.

The methodology is mathematically validated via a universal approximation theorem for encoder-free architectures, and numerically tested on complex computational mechanics problems involving physical and geometrical parameters, including the detection of bifurcating phenomena for Navier–Stokes equations.

REFERENCES

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