Predictive reduced order models of unsteady chaotic flows using transformer architecture

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Reduced Order Models (ROMs) provide computationally efficient approximations of complex physical systems, enabling rapid prototyping and multiple-query scenarios in flow simulations. Model order reduction is achieved by constraining the solution space to a low-dimensional manifold defined by a reduced basis, where the system's dynamics are approximated. Recent advances in machine learning, particularly nonlinear neural network-based dimensionality reduction techniques, have shown promise in enhancing ROM performance. However, existing state-of-the-art approaches often struggle to accurately capture the underlying dynamics in the reduced space, particularly for systems exhibiting multiple fixed points or chaotic behavior. These limitations stem from poor generalization and limited predictive accuracy over long time horizons.

Building upon a recent work [1], which demonstrated that combining dimensionality reduction with Transformer architectures can effectively capture dynamics around limit cycles or multiple equilibria, we extend this approach to more complex dynamical regimes, including turbulence and chaos. Our method incorporates stochasticity in the latent variable representation, enabling stable long-term predictions. To achieve this, we leverage both the Stochastic Transformer architecture [2] and Diffusion Transformers [3], and evaluate their performance in producing accurate and stable roll outs. Our results demonstrate improved predictability and robustness in reduced-order modeling of high-dimensional chaotic systems.

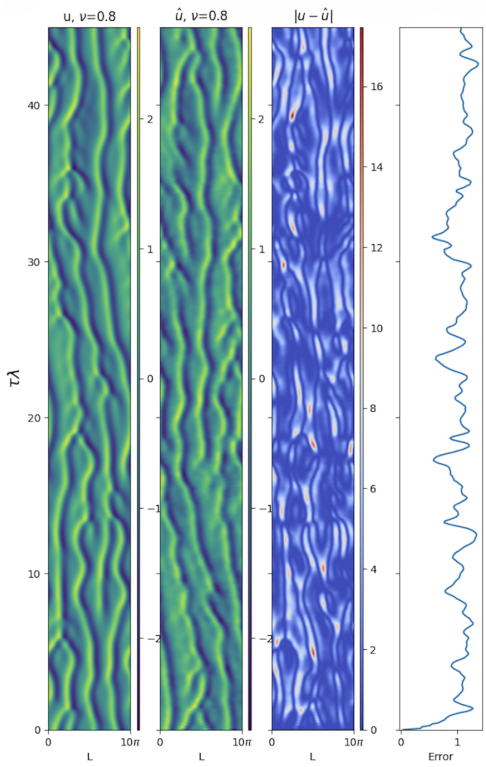

Figure 1: Kuramoto-Sivashinsky System; from left to right, Ground truth, Prediction, Absolute error, Evolution of total error over time.

References

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[3] W. Peebles and S. Xie. Scalable diffusion models with transformers. *2023 IEEE/CVF International Conference on Computer Vision (ICCV)*, pages 4172–4182, 2023.