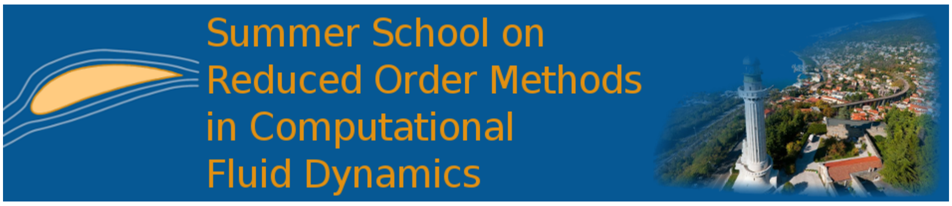

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Comparing Different Nonlinear Dimensionality Reduction Techniques for Data-Driven Unsteady Fluid Flow Modeling

Computational fluid dynamics (CFD) data are usually high dimensional, with millions of degrees of freedom in space and thousands of timesteps. The first step of reduced order modeling is to identify a new set of coordinates, a low dimensional embedding, that describe the underlying dominant structures in the data. This is usually done via Proper Orthogonal Decomposition (POD), which gives the best linear approximation. Several nonlinear dimensionality reduction (NDR) techniques, so-called manifold learning methods, have been developed in other branches of science, which have not yet been extensively used for fluid flow data. These methods can discover the nonlinear manifolds underlying the data, which can give a better representation than the linear hyper-plane obtained by POD. Herein, manifold learning techniques, e.g., Locally Linear Embedding (LLE), Kernel Principal Component Analysis (KPCA), and Laplacian Eigenmaps (LEM) are investigated for generating low dimensional embeddings for CFD data. Autoencoders are also implemented using deep neural networks. Simple unsteady flows (e.g., 2D flow around a cylinder) and more challenging biomedical flows (e.g., pulsatile blood flow in diseased arteries) were analyzed. Unlike POD, these methods need hyper-parameter tuning, but under the right circumstances, they can outperform POD. We compare data reconstruction between the methods and discuss the effect of hyperparameters. Data reconstruction is not straightforward with certain NDR techniques, which will be discussed. Another challenge is obtaining spatial and interpretable modes. We discuss the temporal vs. spatial arrangement of input data and its influence on NDR mode extraction. Finally, the modes are qualitatively compared between the methods. The results suggest that using these NDR methods instead of POD would be beneficial for building better reduced order models.

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