Uncertainty-Aware and parametrized reduced-order model constructed from sparse observations

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Abstract. Although high-fidelity simulations of complex flows provide accurate and predictive representations, their substantial computational cost severely limits their applicability to parametric studies, control design, and real-time forecasting. Reduced-order models (ROMs) alleviate this burden by evolving the dynamics in a low-dimensional subspace; however, classical ROMs often lose accuracy in strongly nonlinear regimes and exhibit poor generalization across varying operating conditions. These limitations are further exacerbated when only sparse measurements are available, as is commonly the case in experimental settings.

We present an uncertainty-aware, parameterized ROM in which deep learning architectures enable interpolation across operating conditions from sparse observations. The approach learns a compact latent representation of the flow together with a parameter-conditioned model for the latent dynamics. In particular, nonlinear encoders (e.g., variational autoencoders) map sparse sensor data to latent coordinates, while a sequence model (e.g., a Transformer) advances these coordinates in time conditioned on Reynolds as the varying parameter. The latent state is then decoded to reconstruct full-field quantities of interest. Uncertainty is quantified through probabilistic latent variables, providing confidence estimates for both temporal predictions and parameter interpolation. The resulting model supports fast rollouts, full-field reconstruction from sparse data, and reliability-aware predictions at unseen Reynolds numbers.

Keywords: Parametrised reduced-order models; Sparse observations; Uncertainty quantification; Deep Learning.
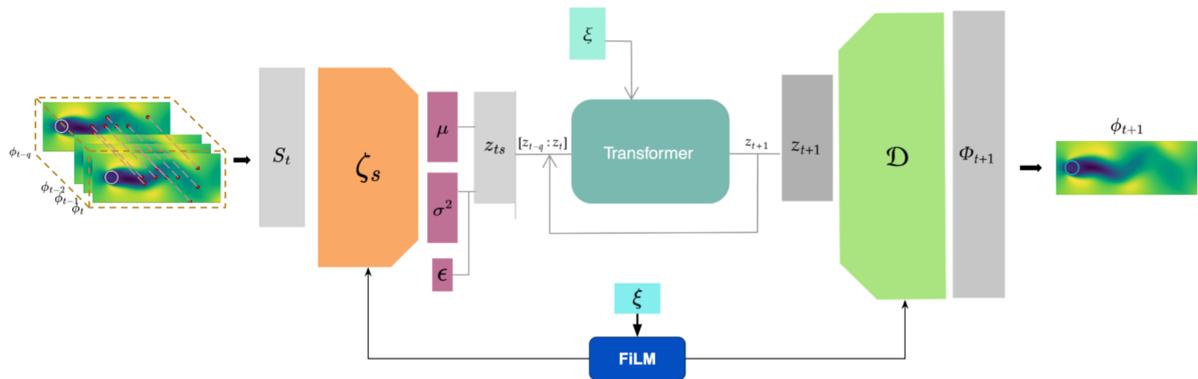

Figure 1: ROM architecture

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