Reduced-order Modeling in the Age of AI

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Classical model order reduction (MOR) methods compute a reduced-order model (ßurrogate") of a large-scale mathematical model that describes some technical, physical, chemical, biological, social or other real-world process. This mathematical model is often obtained from a discretization, e.g., via finite differences or finite elements, of some partial differential operators. The dominating projection-based MOR approach identifies a linear low-dimensional subspace V of the state space and some projector P_V onto this space. The model is then projected onto V, and an approximation of the original state of the model can be constructed from an appropriate linear combination of the basis vectors spanning V. From a machine learning perspective, projection-based MOR is nothing else but an autoencoder, where V is then the latent space, P_V the encoder and the construction of the approximate full-order state vector the decoder. The advantage of this interpretation is that we can now use different approaches for the different elements of an autoencoder. The encoder can select a nonlinear manifold for the latent space, the model describing the states in the latent space can be based on learning the model description from data, and the decoder can also be a nonlinear map. Allowing nonlinear maps for the encoder and the decoder paves the way for new methods that overcome the problem of slowly decaying Kolmogorov n-width limiting the practicality of projection-based MOR for problems with transport-dominated character, while learning the model in the latent space from data allows for non-intrusive methods that do not need to access the full-order model in order to identify a reduced-order surrogate. Based on these observations, we will discuss some of the approaches that extend the field of MOR into the era of Artificial Intelligence by using the generalized MOR philosophy of autoencoders and by making use of deep and machine learning approaches to identify nonlinear encoders and decoders as well as latent space models.