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Reduced order modeling of subsurface multiphase flow models using deep residual recurrent neural networks

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We present a reduced order modeling technique for subsurface multi-phase flow problems building on the recently introduced deep residual recurrent neural network (DR-RNN) [Nagoor Kani and Elsheikh(2017)]. DR-RNN is a physics aware recurrent neural network for modeling the evolution of dynamical systems. The DR-RNN architecture is inspired by iterative update techniques of line search methods where a fixed number of layers are stacked together to minimize the residual (or reduced residual) of the physical model under consideration. In this work, we combine DR-RNN with POD-Galerkin and discrete empirical interpolation method (DEIM) [Chaturantabut and Sorensen(2010)] to construct a reduced order model termed DR-RNN$^{\text{pd}}$. In DR-RNN$^{\text{pd}}$ ROM formulation, POD is used to construct an optimal set of reduced basis functions and DEIM is employed to evaluate the nonlinear terms independent of the full-order model size.

We demonstrate the accuracy and stability property of DR-RNN$^{\text{pd}}$ on two forward uncertainty quantification problems involving two-phase flow in subsurface porous media. The uncertainty parameter is the permeability field modeled as log-normal distribution. In the two test cases, full order model, standard POD-Galerkin ROM, and DR-RNN$^{\text{pd}}$ are solved for 2000 random permeability realizations to estimate an ensemble based statistics using Monte Carlo method. The obtained numerical results shows that DR-RNN$^{\text{pd}}$ provides accurate and stable approximations of the FOM in comparison to standard POD-Galerkin ROM. Moreover, DR-RNN$^{\text{pd}}$ has a fixed computational complexity $\mathcal{O}(r^2)$ per saturation update, where r is the size of the ROM.

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