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Advanced Subsurface Characterization using Deep Generative Prior and Reduced Order Modeling

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Subsurface applications like geologic carbon storage and geothermal energy recovery require near-real-time, accurate forecasting for safe and optimized operations. In this presentation, we develop and test an improved data assimilation framework that combines deep generative models as priors in the latent space for parameterization with deep learning-based reduced-order models for rapid thermo-hydro-mechanical prediction during subsurface operations. This framework enables accurate approximation of physical system parameters including permeability, porosity, thermal conductivity, and fault fields.

Our approach employs multiple generative models: variational autoencoders (VAEs) for near-Gaussian-type heterogeneous fields, and both generative adversarial networks (GANs) and latent-space based diffusion models (DMs) for fault/fracture fields. The data assimilation process operates in a latent space of significantly reduced dimensionality compared to the physical parameter space (e.g., « 1M DOF), enabling more effective sampling and improved convergence. During history matching with observation data (e.g., bottom hole pressures at injection wells and pressure, saturation, and temperature at monitoring wells), we update the low-dimensional latent variables, which serve as inputs to the generative models. The resulting outputs are then used in fast reduced-order models for multi-phase flow prediction.

We validate our framework using real CO2 demonstration data from the Illinois Basin Decatur Project (IBDP) site and field-scale stimulation and circulation tests from the Utah FORGE site. The results demonstrate the framework's capabilities in subsurface property estimation, including uncertainty quantification, prediction accuracy, and computational efficiency for future operations.

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References

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