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Predicting Dynamic Co_2 Plume Migration in 3d Heterogeneous Reservoirs Using Hybrid Deep Learning Models

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Objectives/Scope: Physics-based numerical simulation of multiphase flow emulates the nonlinear physical process in the subsurface, yet the high computation expense makes it infeasible in applications like history matching and uncertainty quantification. This work presents a machine learning model for the dynamic non-linear mapping of multiphase flow in 3D heterogeneous porous media.

Methods, Procedures, Process: This work aims to provide a faster alternative to traditional simulators using a hybrid Wasserstein generative adversarial network with gradient penalty (WGAN-GP) and spatial and channel squeeze-and-excitation (scSE) block. Specifically, the WGAN can stabilize the training process, the gradient penalty is used to solve the gradient boosting and vanishing problems, the residual block's utilization in the generator alleviates the gradient vanishing problem and boosts information exchange across different layers, and the scSE can capture the high-frequency details and amplify the critical features of the images. A fine-tuned VGG network is also deployed to help the network to extract high-level features. The 3D domain is decomposed into 2D images to reduce the training expenses while maintaining the fluid flow continuity. An automated workflow is proposed, including dataset preparation, model training, and result screening.

Results, Observations, Conclusions: We demonstrate the WGAN-GP-scSE architecture using a complex 3D CO2-water multiphase flow problem. The model is trained from high-fidelity simulation data with a wide range of permeability, porosity, flow rate, and time step. The time step, represented by a constant valued image, enables the network to predict outputs at different times. The model performs prediction with a speedup of about 1000 times with a mean spatial error of 0.3% regarding the predicted gas saturation at different time steps compared with the traditional high-fidelity simulators. The WGAN-GP-scSE architecture is more accurate than the traditional CNN, Unet, and conditional GAN based surrogate model, especially it provides superior performance of gas saturation fronts prediction in highly heterogeneous porous media. The coupled physics does not limit the use of the WGAN-GP-scSE-based model, so it provides a framework for building surrogate models to study the subsurface fluid flow problems.

Novel/Additive Information: We propose a novel machine-learning approach using WGAN-GP-scSE to predict the CO2 plume migration in 3D heterogeneous reservoirs. This hybrid model is demonstrated to reliably forecast the dynamic CO2 plume migration with high efficiency and accuracy compared with the physics-based simulator and traditional machine learning approach, respectively.