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Optimized graph-based methods for subsurface flow simulations

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Numerical solution to partial differential equations (PDEs) requires a discrete formulation of the continuous problem. For many numerical methods, this discrete formulation can be thought of as a graph: in finite-volume methods for subsurface flow as considered here, the grid cells represent nodes, whereas cell interfaces represent edges, and their assigned *weights* (and model parameters) are determined by the underlying physical description and discretization.

Leapfrogging the discretization step, several authors have recently applied purely graph-based approaches for simulation of hydrocarbon reservoirs by treating the reservoir as a densely connected graph with wells as nodes, and edges connecting well-pairs [1, 2]. These network-type models are purely data-driven, and the weights are tuned so that model output (well curves) match observed or simulated fine-scale reference data. In this work, we follow a related approach based on Lie and Krogstad [3] in which the graph is constructed from a coarse representation of the high-resolution reservoir model.

Our method consists of two steps: (i) for a given simulation model, workflow, and computational budget, we optimize the coarse partition that determines the graph topology, and (ii) given the parameterized discretization graph, we optimize its node and edge parameters using adjoint methods so that the model best matches the reference data. The model training in step (ii) is performed in conjunction with step (i). The result is a highly efficient, graph-based method for simulation of subsurface flow, derived from physics and tuned to reference data.

We evaluate the method on a number of industry-relevant cases, including geothermal heat storage and hydrocarbon recovery, emphasizing accuracy (including operational conditions outside the training data), and efficiency (including computational cost of model training).

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