A Derivative-Free Approach to the Inverse Modeling of an Oil Reservoir

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Abstract: Numerical models used nowadays in oil reservoir characterization are increasing in complexity, due in part to the progressive decline of the world oil reserves. There is a greater need to model the complex spatial heterogeneity and fluid flow in the subsurface. With more involved models we expect that, once properly calibrated, better forecasts and depletion strategies can be made. This calibration process requires in essence the solving of an inverse problem.

In the oil industry there are two main trends within model inversion. The first one, based on filtering, can be efficient from a computational point of view, but it relies heavily on the linearity of the models. In order to deal with nonlinear cases, not infrequent in oil reservoir characterization, a purely optimization approach can be adopted. The inversion problem is formulated as minimizing the mismatch function between observations and the output of the numerical models. These observations are functions of space and time. If the level of uncertainty in the data acquisition is known, this information can be included in the mismatch function. The optimal search is carried out by adjusting model parameters, typically one or more for each of the grid-points of the reservoir discretization. The model inversion optimization problem is of a large-scale nature, with a nonlinear and nonconvex objective function, that often involves time-expensive simulations. Additionally, this problem is generally ill-conditioned, because the number of degrees of freedom usually is larger than the number of observations available.

In this work we present a robust and fairly efficient methodology to deal with these difficulties in the framework of oil reservoir characterization. The ill-conditioned character of the optimal search can be attenuated in two ways. By principal component analysis (PCA) the optimization search space can be projected to a subspace of much smaller dimension, while keeping consistency with prior spatial geological features already known for the reservoir under study. The number of optimal solutions can be reduced further by increasing the diversity of the data observed. In this research we combine flow production measurements (localized around wells and of high temporal periodicity) with seismic data (spatially distributed and of lower temporal periodicity). This data integration methodology can be extended to any observable for which a numerical model is available.

The numerical models in the optimization process frequently consist of complex simulators, and therefore, invasive techniques to extract analytic derivative information are either not possible or prone to a time-consuming implementation. Besides, cross-disciplinary data integration in the model inversion makes this difficulty more evident. The drastic reduction in the number of optimization variables obtained by PCA allows the use of numerical derivatives of the cost function. Within a distributed computing framework these approximate derivatives can be calculated efficiently. In our scheme we also consider several derivative-free algorithms. These methods, besides being mathematically sound and amenable to being parallelized, have been observed to perform robustly when noise is present in the objective function.

In this talk we will present the spatio-temporal model inversion scheme described above and illustrate its application to oil reservoir description by means of examples extracted from realistic cases.

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