Solving Subsurface Inverse Problem on the MapReduce Platform: A Langevin Dynamics Approach for Geosteering Inversion

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Azimuthal resistivity LWD tools are widely used in geosteering worldwide due to its azimuthal sensitivity and relatively large depth of investigation. In recent years a new generation of extra-deep EM geosteering tool with a much larger depth of detection has emerged on the market. As the new tools can see much further than the first generation, the earth model to be inverted will have more detailed layer structures. Hence the associated inverse problem becomes much more challenging with increased complexity and uncertainty in the inverse problem. Traditional deterministic methods, such as the Gauss-Newton method for solving the Geosteering inverse problems, can easily get stuck in the local optima. In addition, the sparsity of observed data, noise and incomplete knowledge of the formation introduce many uncertainties into the problem. Stochastic optimizations, such as Bayesian inverse and Markov chain Monte Carlo (MCMC) methods, are in general better at searching for global optimal solutions and handling uncertainty quantification, whereas they are computationally expensive due to frequent requirement on forward model computation by the Bayesian inference.

A distributed scheme for large-scale geosteering inversions is proposed in this work. First, a Hybrid Monte Carlo (HMC) sampling method governed by the Langevin dynamics is used for its potential to sample much more efficiently than the popular random-walk Metropolis. Avoidance of random-walk behavior leads to higher acceptance rate and low autocorrelation among continuous runs. Second, we implement the multiple chains HMC on a MapReduce platform to take the parallel computing advantage provided by a distributed computation environment. The multiple chains method, which launches multiple sampling sequences on different initial earth parameters such as layer resistivity and depth-to-boundary, improves its chances in locating the optimal result by exploring the parallel computing capacities. Third, we adopt the parallel tempering scheme to prevent the Markov chain from oscillating within a local region. Parallel tempering allows multiple chains to exchange configurations and enables the samplers to explore the phase space in a more flexible way.

In the end, we will demonstrate improved efficiency and accuracy of the proposed statistical inversions framework with several synthetic geosteering examples.