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Application of Genetic Algorithms in Seismic Tomography

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In the earth sciences several inverse problems that require data fitting and parameter estimation are nonlinear and can involve a large number of unknown parameters. Consequently, the application of analytical inversion or optimization techniques may be quite restrictive. In practice, most analytical methods are local in nature and rely on a linearized form of the problem in question, adopting an iterative procedure using partial derivatives to improve an initial model. This approach can lead to a dependence of the final model solution on the starting model and is prone to entrapment in local misfit minima. Moreover, the calculation of derivatives can be computationally inefficient and create instabilities when numerical approximations are used. In contrast to these local minimization methods, global techniques that do not rely on partial derivatives, are independent of the form of the data misfit criterion, and are computationally robust. Such methods often use random processes to sample a selected wider span of the model space. In this situation, randomly generated models are assessed in terms of their data-fitting quality and the process may be stopped after a certain number of acceptable models is identified or continued until a satisfactory data fit is achieved. A new class of methods known as genetic algorithms achieves the aforementioned approximation through novel model representation and manipulations.

Genetic algorithms (GAs) were originally developed in the field of artificial intelligence by John Holland more than 20 years ago, but even in this field it is less than a decade that the methodology has been more generally applied and only recently did the methodology attract the attention of the earth sciences community. Applications have been generally concentrated in geophysics and in particular seismology. As awareness of genetic algorithms grows there surely will be many more and varied applications to earth science problems.

In the present work, the application of hybrid genetic algorithms in seismic tomography is examined and the efficiency of least squares and genetic methods as representative of the local and global optimization, respectively, is presented and evaluated. The robustness of both optimization methods has been tested and compared for the same source-receiver geometry and characteristics of the model structure (anomalies, etc.). A set of seismic refraction synthetic (noise free) data was used for modeling. Specifically, cross-well, down-hole and typical refraction studies using 24 geophones and 5 shoots were used to confirm the applicability of the genetic algorithms in seismic tomography. To solve the forward modeling and estimate the traveltimes, the revisited ray bending method was used supplemented by an approximate computation of the first Fresnel volume. The root mean square (rms) error as the misfit function was used and calculated for the entire random velocity model for each generation. After the end of each generation and based on the misfit of the individuals (velocity models), the selection, crossover and mutation (typical process steps of genetic algorithms) were selected continuing the evolution theory and coding the new generation. To optimize the computation time, since the whole procedure is quite time consuming, the Matlab Distributed Computing Environment (MDCE) was used in a multicore engine. During the tests, we noticed that the fast convergence that the algorithm initially exhibits (first 5 generations) is followed by progressively slower improvements of the reconstructed velocity models. Thus, to improve the final tomographic models, a hybrid genetic algorithm (GA) approach was adopted by combining the GAs with a local optimization method after several generations, on the basis of the convergence of the resulting models. This approach is shown to be efficient, as it directs the solution search towards a model region close to the global minimum solution.