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Joint global optimization of tomographic data based on particle swarm optimization and decision theory

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In many near surface geophysical applications multiple tomographic data sets are routinely acquired to explore subsurface structures and parameters. Linking the model generation process of multi-method geophysical data sets can significantly reduce ambiguities in geophysical data analysis and model interpretation. Most geophysical inversion approaches rely on local search optimization methods used to find an optimal model in the vicinity of a user-given starting model. The final solution may critically depend on the initial model.
Alternatively, global optimization (GO) methods have been used to invert geophysical data. They explore the solution space in more detail and determine the optimal model independently from the starting model. Additionally, they can be used to find sets of optimal models allowing a further analysis of model parameter uncertainties.
Here we employ particle swarm optimization (PSO) to realize the global optimization of tomographic data. PSO is an emergent methods based on swarm intelligence characterized by fast and robust convergence towards optimal solutions. The fundamental principle of PSO is inspired by nature, since the algorithm mimics the behavior of a flock of birds searching food in a search space. In PSO, a number of particles cruise a multi-dimensional solution space striving to find optimal model solutions explaining the acquired data. The particles communicate their positions and success and direct their movement according to the position of the currently most successful particle of the swarm. The success of a particle, i.e. the quality of the currently found model by a particle, must be uniquely quantifiable to identify the swarm leader.
When jointly inverting disparate data sets, the optimization solution has to satisfy multiple optimization objectives, at least one for each data set. Unique determination of the most successful particle currently leading the swarm is not possible. Instead, only statements about the Pareto optimality of the found solutions can be made. Identification of the leading particle traditionally requires a costly combination of ranking and niching techniques.
In our approach, we use a decision rule under uncertainty to identify the currently leading particle of the swarm. In doing so, we consider the different objectives of our optimization problem as competing agents with partially conflicting interests. Analysis of the maximin fitness function allows for robust and cheap identification of the currently leading particle. The final optimization result comprises a set of possible models spread along the Pareto front. For convex Pareto fronts, solution density is expected to be maximal in the region ideally compromising all objectives, i.e. the region of highest curvature.