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Lithological and Surface Geometry Joint Inversions Using Multi-Objective Global Optimization Methods

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Geologists' interpretations about the Earth typically involve distinct rock units with contacts (interfaces) between them. In contrast, standard minimum-structure geophysical inversions are performed on meshes of space-filling cells (typically prisms or tetrahedra) and recover smoothly varying physical property distributions that are inconsistent with typical geological interpretations. There are several approaches through which mesh-based minimum-structure geophysical inversion can help recover models with some of the desired characteristics. However, a more effective strategy may be to consider two fundamentally different types of inversions: lithological and surface geometry inversions. A major advantage of these two inversion approaches is that joint inversion of multiple types of geophysical data is greatly simplified.

In a lithological inversion, the subsurface is discretized into a mesh and each cell contains a particular rock type. A lithological model must be translated to a physical property model before geophysical data simulation. Each lithology may map to discrete property values or there may be some a priori probability density function associated with the mapping. Through this mapping, lithological inverse problems limit the parameter domain and consequently reduce the non-uniqueness from that presented by standard mesh-based inversions that allow physical property values on continuous ranges. Furthermore, joint inversion is greatly simplified because no additional mathematical coupling measure is required in the objective function to link multiple physical property models.

In a surface geometry inversion, the model comprises wireframe surfaces representing contacts between rock units. This parameterization is then fully consistent with Earth models built by geologists, which in 3D typically comprise wireframe contact surfaces of tessellated triangles. As for the lithological case, the physical properties of the units lying between the contact surfaces are set to a priori values. The inversion is tasked with calculating the geometry of the contact surfaces instead of some piecewise distribution of properties in a mesh. Again, no coupling measure is required and joint inversion is simplified.

Both of these inverse problems involve high nonlinearity and discontinuous or non-obtainable derivatives. They can also involve the existence of multiple minima. Hence, one can not apply the standard descent-based local minimization methods used to solve typical minimum-structure inversions. Instead, we are applying Pareto multi-objective global optimization (PMOGO) methods, which generate a suite of solutions that minimize multiple objectives (e.g. data misfits and regularization terms) in a Pareto-optimal sense. Providing a suite of models, as opposed to a single model that minimizes a weighted sum of objectives, allows a more complete assessment of the possibilities and avoids the often difficult choice of how to weight each objective. While there are definite advantages to PMOGO joint inversion approaches, the methods come with significantly increased computational requirements. We are researching various strategies to ameliorate these computational issues including parallelization and problem dimension reduction.