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3D Geophysical Inversion for Surface-Based Model Geometry

Peter Lelièvre, Christopher Galley, and Colin Farquharson
Memorial University of Newfoundland, Department of Earth Sciences, St. John's, NL, Canada (plelievre@mun.ca)

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 is to develop a fundamentally different type of inversion that parameterizes the Earth in terms of the geometry of the contact surfaces between rock units.

In our surface geometry inversion method, the model comprises wireframe surfaces representing contacts between rock units. The inversion seeks the positions of the vertices in the wireframe surfaces. This parameterization is then fully consistent with Earth models built by geologists, which in 3D typically comprise wireframe contact surfaces of tessellated triangles. The inversion is tasked with calculating the geometry of the contact surfaces instead of some piecewise distribution of properties in a mesh. The physical properties of the units lying between the contact surfaces can be set to a priori values or allowed to vary between bounds.

This inverse problem involves high nonlinearity, discontinuous or non-obtainable derivatives, and possibly the existence of multiple minima. Hence, we must solve for the locations of the wireframe vertices using global optimization strategies, including Particle Swarm Optimization and Genetic Algorithms. This is followed with a more rigorous stochastic sampling to provide likelihood information. These optimization methods introduce high computational costs. To provide computationally feasible inversion methods, we can reduce the dimensionality of the problem by parameterizing the nodes in a coarse representation of the geological wireframe model and use surface subdivision to refine further. This also provides a simple and effective way to regularize the inverse problem. We avoid unacceptable topologies using collision detection methods.

While surface-geometry inversion is challenging, it has some major advantages. First, geophysical and geological models can use exactly the same model representation, with no need to interpret between different representations. Second, joint inversion of multiple types of geophysical data is greatly simplified because no coupling measure is required. Third, because the optimization is performed using stochastic sampling, uncertainty can be assessed and helpful information for decision makers can be calculated, such as tonnage estimates for mineral exploration. We are currently applying our 3D surface-geometry inversion method to help model seafloor massive sulphide deposits using magnetic data.