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Optimising uncertain 3-D geological models using topological likelihood functions in a model-based machine learning framework

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3-D modeling of geological structures is elemental for geoscientists to visualize, understand and quantify significant geological elements in the subsurface. The increasing maturity of implicit modeling algorithms enables us to interpolate meaningful geological models from input data without further human input. This enables us to effectively conduct uncertainty quantifications by regarding the input data for our geomodels as probability distributions, rather than exactly known. While basic Monte Carlo error propagation can be applied to explore the input parameter space, possible mathematical instabilities in the interpolation step, derived from the stochastic sampling of input data, can often lead to the construction of geologically unsound models.

We present here a method that uses topology information (in the form of adjacency graphs) as likelihood functions in a model-based machine learning framework to constrain stochastic implicit modeling results. This approach allows us to intuitively construct probabilistic models that can be readily implemented using a diverse set of probabilistic programming packages and makes use of newly developed open-source implicit geomodeling software.

Likelihood functions encapsulate information in a mathematical form—which can simply be numeric data (e.g. the range of likely layer thicknesses of a certain depositional environment). However, expert knowledge of experienced geoscientists can contain much more information crucial to the modeling step, for example information about the kinematic evolution of the geological system to be modeled. Although kinematic modeling software exists, it is often limited to modeling with software-specific kinematic events and deformations (often only using a few abstract parameters) and, most importantly, does not allow for the implicit integration of geological data obtained from mapping, seismic interpretation or wells into the modeling step. We can instead capture certain aspects of kinematic information in topology relationships—for example the across-fault connectivity of layers, which fundamentally differ between extensional and compressional evolution.

We first show in a synthetic case study that our approach can lead to a meaningful reduction in geomodel uncertainty, training the implicit modeling input data on the given topology information. We then go on to apply this method to a subset of the Perth Basin in Western Australia to demonstrate its applicability to complex, real-world scenarios. Specifically, we show that both the derived model ensemble realizations of implicit models and the input data itself now indirectly incorporate the topology information applied, representing a vital step forward to further integrate geological information into automated construction and uncertainty quantification of structural geomodels.