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# Emulation: A fast stochastic Bayesian method to eliminate model space

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Joint inversion of large 3D datasets has been the goal of geophysicists ever since the datasets first started to be produced. There are two broad approaches to this kind of problem, traditional deterministic inversion schemes and more recently developed Bayesian search methods, such as MCMC (Markov Chain Monte Carlo). However, using both these kinds of schemes has proved prohibitively expensive, both in computing power and time cost, due to the normally very large model space which needs to be searched using forward model simulators which take considerable time to run. At the heart of strategies aimed at accomplishing this kind of inversion is the question of how to reliably and practicably reduce the size of the model space in which the inversion is to be carried out. Here we present a practical Bayesian method, known as emulation, which can address this issue.

Emulation is a Bayesian technique used with considerable success in a number of technical fields, such as in astronomy, where the evolution of the universe has been modelled using this technique, and in the petroleum industry where history matching is carried out of hydrocarbon reservoirs. The method of emulation involves building a fast-to-compute uncertainty-calibrated approximation to a forward model simulator. We do this by modelling the output data from a number of forward simulator runs by a computationally cheap function, and then fitting the coefficients defining this function to the model parameters. By calibrating the error of the emulator output with respect to the full simulator output, we can use this to screen out large areas of model space which contain only implausible models. For example, starting with what may be considered a geologically reasonable prior model space of 10000 models, using the emulator we can quickly show that only models which lie within 10% of that model space actually produce output data which is plausibly similar in character to an observed dataset. We can thus much more tightly constrain the input model space for a deterministic inversion or MCMC method.

By using this technique jointly on several datasets (specifically seismic, gravity, and magnetotelluric (MT) describing the same region), we can include in our modelling uncertainties in the data measurements, the relationships between the various physical parameters involved, as well as the model representation uncertainty, and at the same time further reduce the range of plausible models to several percent of the original model space.

Being stochastic in nature, the output posterior parameter distributions also allow our understanding of/beliefs about a geological region can be objectively updated, with full assessment of uncertainties, and so the emulator is also an inversion-type tool in it’s own right, with the advantage (as with any Bayesian method) that our uncertainties from all sources (both data and model) can be fully evaluated.