Surrogate modelling in geophysical inverse problems

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Inverse problems in geophysics are commonly characterized by unfavourable properties such as non-existence of an exact solution, existence of multiple solutions ("non-uniqueness") or instabilities regarding small variations in the observables. Methods such as Markov chain Monte Carlo (McMC) are able to overcome these challenges, but have the drawback of being computationally expensive and even infeasible for some classes of inverse problems. We explore two approaches that aim to mitigate the negative characteristics of McMC: a) exchanging the original forward operator by one that is more efficient, but still sufficiently accurate that could be used within McMC; b) using machine learning concepts to devise new sampling strategies of the model space as an alternative to McMC.

The first approach leads to the creation of surrogate models, which have been successfully applied in engineering and some parts of Earth sciences. This can be achieved by training a neural network to generalize the characteristics of given model-data pairs, leading to a kind of interpolation task. Another idea is to incorporate the physics of the forward operator into a neural network by directly learning the underlying differential equations.

The second approach makes use of a machine learning technique known as generative adversarial networks (GANs). They consist of two neural networks which are trained in a competitive way and have proved to be powerful tools, especially in image processing. Their strength lies in the ability to produce new samples from a given distribution, without explicit knowledge of its mathematical characteristics. GANs promise to provide new ways of efficiently sampling the model space to infer the full solution of an inverse problem by reproducing the data distribution and connect it to the model space by the forward operator or its surrogate.

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