Inverse Problems in Geosciences: Modelling the Rock Properties of an Oil Reservoir

Even the most optimistic forecasts predict that Danish oil production will decrease by 80% in the period between 2006 and 2040, and only a strong innovative technological effort can change that. Due to the geological structures of the subsurface in the Danish part of the North Sea, Denmark is currently missing out on approximately 70% of the oil, which is left behind, trapped in unreachable parts of the reservoirs.

An increase in the oil recovery rate can be achieved by better planning and optimisation of oil production. Both require an improved description of the rock properties of the subsurface of the reservoirs. Hence the focus of this work has been on acquiring models of spatial parameters describing rock properties of the subsurface using geostatistical a priori knowledge and available geophysical data. Such models are solutions to often severely under-determined, inverse problems.

The focus of the study has been on the computational aspects of inferring such models. Reservoir modelling is a large-scale problem with great computational complexity and the work should be seen as a first part of a foundation for one day, when the computational resources are available, being able to handle the large scale problems of the petroleum industry. But for now most of the study is based on simplified and idealised models.

We have proposed a method for efficient and accurate interpolation of rock properties from seismic data. It is based on a recently published paper on interpolation of rock properties that breaks with the dominating influence of spatial coordinates in traditional interpolation methods. The thesis contains work involving a test case study of the method demonstrating how the interpolation in attribute space ensures the geological structures of the computed models and how the method can be further improved by an orthogonal transformation of the attribute space.

We have formulated a closed form expression of an a priori probability density function that quantifies the statistical probability of models describing the rock properties of a reservoir. This can be used to evaluate the probability that a model adhere to prior knowledge by having specific multiple-point statistics, for instance, learned from a training image. Existing methods efficiently sample an a priori probability density function to create a set of acceptable models; but they cannot evaluate the probability of a model.

We have developed and implemented the Frequency Matching method that uses the closed form expression of the a priori probability density function to formulate an inverse problem and compute the maximum a posteriori solution to it. Other methods for computing models that simultaneously fit data observations and honour a priori knowledge are not capable of computing the maximum a posteriori solution. Instead they either sample the posterior probability density function or they sample the a priori probability density function to optimise the likelihood function.

This thesis consists of a summary report and seven research papers submitted, reviewed and/or published in the period 2010 - 2013.

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