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Keynote Presentation: Efficient and Neutral Uncertainty Quantification for Discrete-facies Reservoir Models

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SUMMARY

Introduction

Almost all methods used in geophysical data inversion and history matching are based on the least-squares method. This method is essentially an application of Gaussian statistics, and when it is used in classical voxel-based models to defeat underdetermination (through a quadratic penalty function) it adds unphysical information to our inverse problem. The result is geologically unrealistic solutions.

The most obvious non-geological property of a least-squares solution is its smoothness. This smoothness is inconsistent with distinct geological facies present in the subsurface, but in many applications this flaw is not seen as a serious problem. For example, images of the subsurface produced by geophysical least squares inversion are often used in combination with geological expert knowledge to produce facies distribution models, and for this purpose blurred images may be sufficient. However, the datafits of the final models are rarely checked (and would in most cases be poor).

The situation in history matching is radically different. Here, the hydraulic connectivity of the subsurface is of extreme importance, and it is therefore necessary to develop modeling strategies that are capable of resolving facies boundaries (while fitting data). In this case we need to replace classical least-squares with other methods.

Methods

The problem of fitting discrete-facies models to geophysical or flow observations is basically a combinatorial sampling- or optimization problem and therefore computationally intractable. Melnikova et al. (2014) overcome this difficulty by recasting the frequency matching problem (Lange et al., 2012; Cordua et al., 2014) as a smooth problem. A probabilistic formulation using a smooth, multimodal prior with maxima in models with pattern histograms close to that of a given reference model (training image), allows a deterministic search for near-maximum a posteriori models and a calculation of the posterior probabilities of each of these models.

The use of frequency matching as prior information is a dramatic improvement over arbitrary Gaussian assumptions, because it uses geostatistical information obtained from geologically consistent reference models. Still, it is a purely statistical technique, and is therefore depending on the empirical information obtained from the chosen reference model(s). For this reason there is a danger that the prior will introduce an unwanted bias in cases where the subsurface structure is not compatible with the reference model.

A new approach to data inversion introduces effectively bias-free priors through purely physical constraints. Physical constraints do not rule out any geologically possible models, but they provide rather strong restrictions on the models based on

- Global constraints: Volume conservation, energy conservation, energy minimization/isostatic balance, etc.
- Local constraints: Upper limits on local stress (breaking point), consistency with elastic equations, consistency with flow equations, consistency with mathematical laws for sedimentation, etc.

We demonstrate how a probabilistic formulation using purely physical constraints can be successfully used in data inversion. In some cases the use of sparse physical constraints has strong influence on the solutions, leading to more realistic geological structure.

Conclusions

Least squares constraints are purely statistical and create physically unrealistic solutions with artificial smoothing. Geostatistical constraints can learn from real structures through reference models/training images and give more realistic solutions, but there is a considerable risk that the subsurface we analyze is not consistent with the reference model(s). For this reason, purely physical constraints may, in the future, supplement, or in some cases replace, statistics as a way of obtaining defensible solutions to inverse problems.

References

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