Various levels of interactivity in geological inversion

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Abstract

We present some very simple tools to perform, direct and analyze inversion of geological modeling. The tools rely exclusively on visual appraisal of geological models and allow full inversion to be controlled by mere mouse clicks. Underlying such simplicity, these tools provide a way to deal with concepts as sophisticated as global search, visualization of multidimensional spaces, segmentation of parameters spaces, inclusion of a priori expert knowledge and real time adjustment of global search parameters, in a way that is as transparent as possible to the user, who is let to concentrate on the geological side of the problem.

Introduction

What is inversion? In this abstract the term 'inversion' is not intended in the geological sense, rather in the mathematical one. Inversion refers to the attempt to 'reverse' a mathematical operation. In broad sense, division 'reverses' a multiplication (), square root 'reverses' the square of a number () and so on. However, if the mathematical operation is as complicated as time dependant mechanical modeling, unique 'reverse' operations cease to exist (compare trying to reverse multiplication by zero). Inversion now becomes far more difficult and requires complicated iterative approaches. If, to make thing worse, the mathematical operations contain equations (like diffusions) whose reverse is unstable, inversion in itself becomes impossible.

Attempting to achieve what is mathematically impossible is what geophysics is often about anyway, so we do not worry too much — we take the pragmatic view that we can probably find a workable, common sense solution. In geological modeling, 'inversion' attempts to reconstruct the initial conditions (material properties, stress fields, sedimentation rates etc.) that generate a certain geological response (such as folds/faults patterns, fluid flows etc). The geological response is modeled by geomechanical codes (Flac, FastFlo. Ellipsis, etc.). Inversion attempts to guess the input parameters of the model, given the output produced by the geomechanical code.If the equations in the geo-mechanical code could simply be 'reversed', inversion would be as simple (not really, but almost) as 1) geting the output of the geo-mechanical code 2) fitting it as input to the reverse code and 3) obtaining the starting parameters as result. Since nature has not been so friendly to provide us with the 'reverse' of most geo-mechanical equations, the only way to perform the 3 operations described above is to execute a more or less clever 'trial and error' search, until we get as close as possible to the answer we want. Years of research, myriad of algorithms and thousands of books have been written on how to optimize such 'trial and error' search. We use an approach called Genetic Algorithm (Gas) (Davies, 1990). A good 80% of those myriad of algorithms (especially the ones produced in the last 20-30 years) attempt to remove the user from the inversion process, in order to give an as unbiased answer as possible. We believe (see Boschetti and Moresi 2001 for a more detailed explanation) that this 'black box' approach is not optimal for geological applications where expert knowledge, experience and intuition play a major role. We have thus implemented a system for inversion of geological models with different layers on interactivety.

Inversion of geological models

If the equations in the geomechanical code could simply be 'reversed', inversion would be as simple (almost) as taking the naturally observed phenomena, fitting it as input to the reverse code, and obtaining the starting parameters for the forward geomechanical model as result. The equations of geomechanics which nature has presented to us are, unfortunately, not time-reversible in this sense. For example they invariably contain dissipative terms (such as diffusion) which are difficult to reverse. Consequently, the only way to perform the operations described above is to execute some form of 'trial and error' search, until we get as close as possible to the answer we want. Years of research, myriad algorithms, and thousands of books have been written on how to optimize such 'trial and error' searches. We use an approach called the Genetic Algorithm (GA) (Davies, 1990). A good 80% of those myriad algorithms (especially the ones produced in the last 20-30 years) attempt to remove the user from the inversion process, in order to give an as unbiased answer as possible. We believe (see Boschetti and Moresi 2001 for a more detailed explanation) that this 'black box' approach is not optimal for geological applications where expert knowledge, experience and intuition play a major role. We have thus implemented a system for inversion of geological models with different layers of interactivity

Interactive inversion

The first level of interactivity is shown in Figure 1. A GA generates a number of (random) input parameters for a geomechanical model. The model is run and a number of output (images or animations) are generated. The user has the option of viewing the outputs and ranking them according to how well they reproduce the geological feature or process of interest. Similarity is not a simple concept in geology, it may involve more than mere pixel by pixel resemblance. This is where the expert knowledge comes into play. The ranking is then used by the GA to converge towards a desired result. Some applications of this idea are presented in this meeting (Wins et al 2001, Gressner et al. 2001). Despite 7 years of experience in inversion and use of GAs the excellent performance of this approach have surprised us and exceeded our initial expectations.

Beyond this explicit cooperation between the inverse process and the user there is a more subtle level of interactivity. In choosing the ranking of the solutions the user can also direct the GA process in a more sophisticated manner. Users with expertise in mathematical inversion and GA can realize when some solutions, despite looking geologically non-ideal, may have properties that will enhance future convergence of the algorithm. A typical case would be to favour a solution that has a 'good' feature (for example a proper layer thickness) that is not present in other solutions. Allowing such solution to survive in the GA process may allow such good feature to appear in geologically better solutions later on. Another option would be to manipulate GA parameters like cross-over and mutation according to the solution distribution.distribution.

A further level of interactively can be provided by an additional visual tool. This tool allows the plotting of multidimensional parameters (the input parameters of the geo-mechanical modeling) into pseudo 2D maps. This is achieved by Self Organized Maps (SOM), but others methods are also available and currently under analysis. An example is seen in Figure 2. Here some solutions (as 2D vertical sessions) are mapped from 128 dimensions to 2 dimensions. The location of the solutions in the plot, together with a measure of 'how good' such solutions are, helps the user to choose areas in the solution space where to concentrate further GA search. The method has also been tested with success (Boschetti and Takagi, 2001). Further, the visual appraisal of possible grouping of solutions according to similarity criteria, given by such visual tool, allows a rough partitioning of the solution space. This can facilitate domaining of mechanical or geological behaviors and a better understanding of the problem under analysis. This avenue will be tested in the coming months and result presented thereafter.

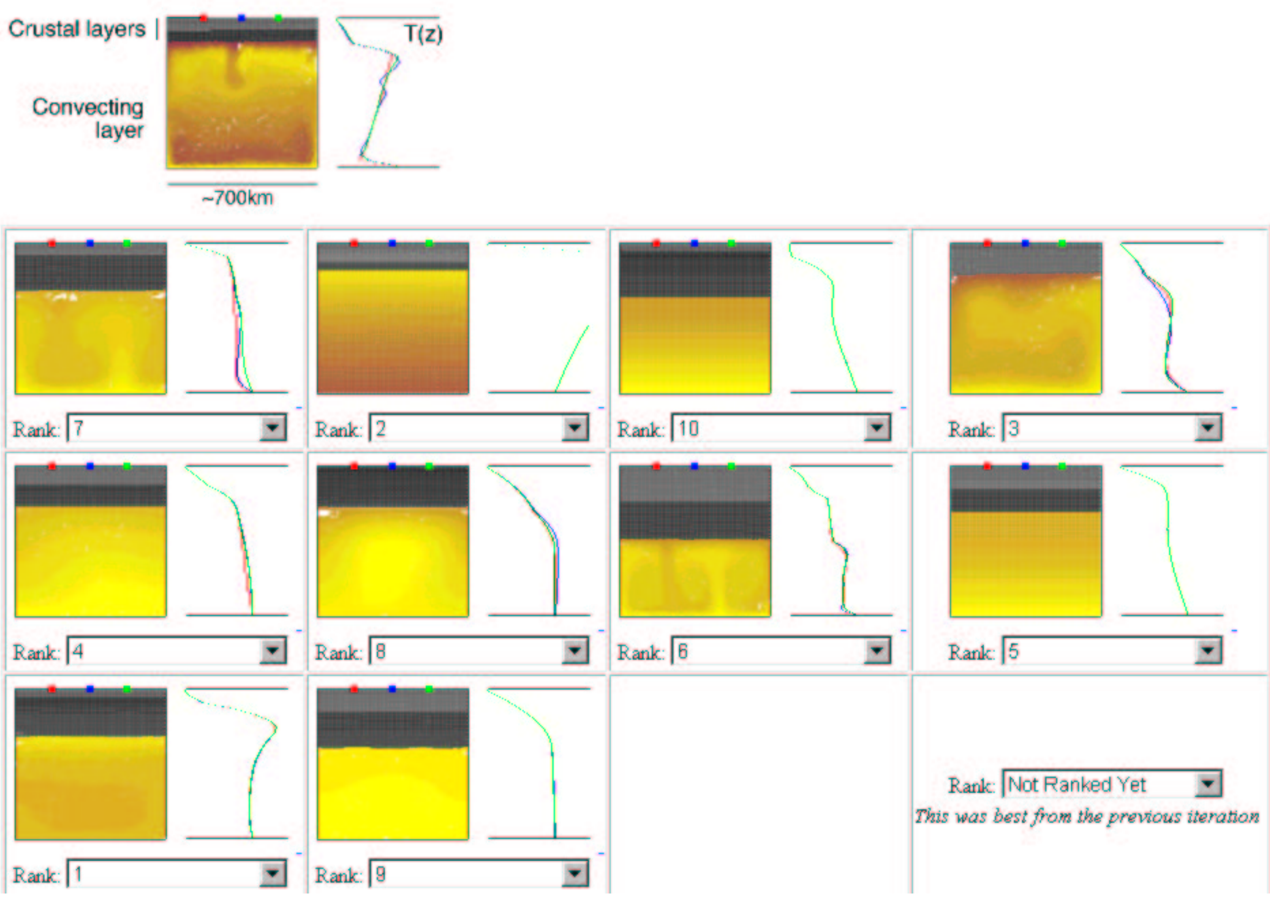

Figure 1. Basic interface for Interactive inversion. Models of the result of various runs of a geological model are displayed. The user can view them and rank them according to the similarity to the process he/she attempts to reproduce.

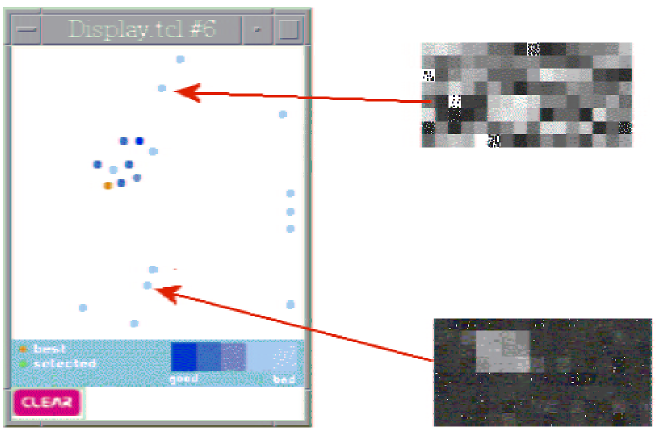

Figure 2. Mapping of multidimensional data into a pseudo 2D plot. The location of the solutions in the plot may gives suggestion about solution clustering and can help the user guiding further GA search.

Summary

An implicit advantage of these interfaces, is to allow the user to interact with the geological modeling process without dealing with the underling mathematics and computer input/output requirements. We try to allow the field geologist to run models easily and (as much as possible) quickly. We aim at the geologist providing the expertise that is necessary to make geological modeling meaningful, without worrying about the technical aspect of running a geological model. Avoiding the mathematics and repetitive computational tasks usually involved in these processes will hopefully maintain a high level of geological inspiration and also facilitate communication between modelers and geologists.

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