Chapter 8

Conclusions

8.1 General discussion

A number of different studies have been described in this thesis. The potential of Genetic Algorithms in the inversion of geophysical data has been tested on two problems characterised by completely different physics and mathematics: seismic refraction tomography and potential field data inversion.

Before inverting the seismic data, two steps were required: picking seismic first arrivals and ray-tracing. This has been achieved by implementing two original algorithms, whose efficiency has been tested and compared with traditional methods.

The limitations imposed by the presence of inaccuracies in seismic refraction tomography have been analysed and a method to improve the results in noisy environments by jointly inverting seismic and gravity data has been proposed. Partial conclusions from each individual experiment have already been discussed. In this chapter I summarise the main conclusions that can be drawn from the overall work I presented:

- Genetic Algorithms proved to be an effective tool in the examples of inversion of seismic and potential field data discussed. This suggests the general suitability of Genetic Algorithms to geophysical problems and confirms results obtained by other researches in other geophysical applications. Their efficiency compared to traditional methods has also been demonstrated in seismic refraction tomography, in which Genetic Algorithms outperformed a number of traditional local optimisers.

- The inclusion of the pseudo subspace method proved to be crucial for the Genetic Algorithms success. By progressively increasing the dimensionality and complexitity of the problem, the method allows the Genetic Algorithm to exclude less promising areas in the solution space very early in the process. Genetic Algorithms also strongly benefit from the inclusion of this method from a computation point of view, resulting in being more that 1 order of magnitude less expensive than traditional Genetic Algorithms.

- By modifying only the selection operator, and allowing for diversity to be maintained in the population, Genetic Algorithms offered the possibility of obtaining a large number of solutions in potential field inversions. The analysis of this ensemble of solutions allowed a statistical description of the ambiguity inherent in the problem. This is a major improvement over traditional inversion methods, that usually address ambiguity by trying to limit it rather than to describe it. From this description useful information on the expected bounds on the unknown parameters, a measure of the reliability of the final solution and indications on how to conduct further geological/geophysical surveying may also be obtained.

- In all these experiments a minimum amount of 'a priori' information has been used. In particular this information is limited to the problem parameterisation. This is another major advantage in the use of Genetic Algorithms over traditional local optimisation methods whose result is strongly dependent on the selection of an appropriate starting model.

- It is also important to notice that no problem specific operator has been used. The Genetic Algorithm presented is a standard real coded Genetic Algorithms with the addition of the pseudo subspace method and a different implementation of the Creeping operator. These two additional operators proved to be crucial in achieving good performances. However, these are not problem specific operators. This shows the general potential of Genetic Algorithms in this kind of inversion problems.

- The success in the seismic refraction tomography experiments is related to the efficiency and accuracy of the ray-tracing code. As clearly stated in Chapter 7, this results would have not been possible if the forward calculation had not been accurate. Comparison with a widely used standard seismic algorithm and with physical model data proved satisfactory and consequently, the inversion procedure worked well on both model and real data sets.

- Also, global inversions would be prohibitive with the use of forward routines characterised by heavy computation. The ray-tracing routine here used belongs to a family of extremely fast algorithms, in which calculations are approximated and no wave propagation equation is explicitly solved.

- Inversion of geophysical data seems to benefit by reducing the problem dimensionality, even at the cost of reducing the amount of information used in the inversion. This has been shown in the inversion of the Nevoria seismic data set. By dividing the overall calcutation domain into a number of small subdomains the problem dimensionality is reduced as well as the number of rays available for the inversion (only the rays contained in the individual subdomains were used and the ones crossing the subdomains were discarded). In this way better results have been achieved compared to the inversion performed on the overall domain with all the information available.

- Also, the inversion process seems to benefit by its subdivision into stages in which complexity or information is progressively added. Together with their effects on the pseudo subspace method, staging procedures proved to be effective also in the jointly inversion of seismic and gravity data sets. Here good results were obtained by adding gravity information in the last stage of the seismic data inversion.

8.2 Method limitations and suggestions for further analysis

The aim of this project was to explore the potential of Genetic Algorithms in the inversion of geophysical data.

Currently the method potential can not be yet compared with traditional processing techniques neither in seismic nor in potential field applications. This is particularly true for very large problems. However, the successful results obtained with field data suggest that the method can already be considered as a useful tool to obtain a relatively fast and accurate preliminary analysis, to be used in planning successive geological or geophysical surveying.

Much of this research deserves further experiments and analysis. Here I mention the main points which I believe should be addressed in future discussions of applications of Genetic Algorithms to geophysical problems.

- Complex geophysical inverse problems are usually characterised by very large dimensionality. The possibility of any reduction in the dimensionality of these problems should be carefully considered. This idea has been extensively addressed in my research but further improvements need to be achieved. In geophysical applications reduction in dimensionality could be obtained by using a moving sparse grid able to adapt to the problem under analysis. This has been partially attempted on simple geometry in [2] and this technique has the potential to be extended to more complex cases. However, the use of a moving grid may be a very difficult task because it involves all the stages in the inversion procedure. For example, in seismic applications a more general ray-tracing code should be implemented in order to overcome the limitations imposed by regular cells. Sensible parameterisation should also be used in order to effectively compensate for the initial increase in dimensionality due to the nodes locations becoming variables to the problem. Also this implementation could result in possibly larger ambiguity problems due to the fact that the nodes are allowed to move in the calulation domain. However, to me the possibility of adapting the search resolution to the domain complexity is particularly appealing.

- Building an inversion strategy to be routinely used in real world problems means usually going from a 'black box' implementation to a problem specific one. In seismic applications this could be achieved for example by discretising the velocity range with 'problem specific' expected seismic velocity values. Also 'a priori' information could be included in the process. This would probably considerably accelerate the inversion and allow larger domains to be inverted.

- Currently the implementation for potential field inversion is limited to the presence of a single geological contact in the vertical direction. More complex implementations are possible but they would result in much larger ambiguity problems. The potential of Genetic Algorithms in these enlarged ambiguity domains should be assessed. I expect that in this case the departures from normality in the ensemble of acceptable solutions would be stronger and accordingly require more sophisticated statistics than those used in the experiments presented in Chapter 6. Also, a much larger Genetic Algorithm populations would be required.

- A crucial point in limiting the Genetic Algorithms computational cost is an effective and precise stopping criteria. This is not current available in the literature. As I showed in Chapter 5, good solutions may be found by Genetic Algorithms very early in the process and heavy computational effort can be wasted to obtain only marginal improvements. I made a number of experiments to try to determine a satisfactory stopping criteria but I have not been able to obtain a general conclusion yet.

- Improvements in geophysical analysis, as well as in Genetic Algorithms applications, come from better understanding of the underlying mathematics as well as by hardware improvements. One of the major hardware configurations Genetic Algorithms can take advantage of are parallels computers. This has been proposed often in Genetic Algorithms literature [3, 1] because Genetic Algorithms are naturally suited for parallel implementation. The advantage is not only in the reduction of computation time almost linearly dependent on the number of processor employed, but also in the possibility to implement different Genetic Algorithms configurations. In particular, the possibility to use many populations at the same time is appealing because it could be beneficial in problems characterised by many minima as well as by ambiguity.

Bibliography

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