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Hyperbolic dictionary learning for 3D marine seismic data reconstruction

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Introduction

Dictionary Learning (DL) is essential in seismic processing because it allows the identification and representation of complex patterns in seismic waves, optimizing geological interpretation and the detection of subsurface structures. DL, learns a set of simple structures (atoms of the dictionary) that, when combined, can represent complex seismic waves. By representing seismic waves with these atoms, it is possible to reduce the complexity of the data without losing important information, facilitating analysis. DL can highlight relevant features in seismic waves, such as reflections from geological layers. DL is used in several stages of seismic processing, such as incoherent and coherent noise removal, interpolation and regularization, among other, to the generation of high-quality images of the subsurface.

Method and Theory

The dictionary trained through standard DL is, in most cases, highly redundant and not necessarily focused on events of interest in the seismic data. For example, coherent noise would show up in the dictionary atoms, like seismic events. In order to overcome this issue, many authors include a constraint in the dictionary update step, which emphasizes only on desired seismic events. Based on paraxial traveltime description, a constraint DL approach was introduced by Turquais (2018). For the description of the desired events we employ the traveltime definition of the paraxial ray approximation (Bortfeld, 1989; Hubral, 1983; Cherveny 2001). In the paraxial ray theory, traveltimes of seismic events, for 3D seismic data, are described by 11 parameters, which may be derived from measurements and applied for data enhancement (Garabito, 2018). In the search for hyperbolic events, we design a constraint Hyperbolic DL (HDL) approach able to handle all different data configurations. By this constraint, only those elements of the dictionary vector are updated which exhibit a shape defined by the second order traveltime function. The parameters sought in the optimization process of a certain source-receiver configuration are: the slopes of the seismic event at the reference trace (the position of the central ray) of the data patch and the associated curvatures. The slopes are related to the slowness vectors of the central ray at the source and receiver positions, and the curvatures to the associated wavefront curvatures. The HDL procedure can be summarized in the following steps: In the sparse coding step, the sparse vectors are found by optimization using the dictionary derived in a previous iteration. In the dictionary update step, the calculated sparse vectors are used in an optimization with all data vectors to find the updated dictionary matrix. Running through all the traces and samples of the patch, the slopes and curvatures are determined by the least squares optimization such that the atom represents solely hyperbolic events. This step is continued for all the atoms of the dictionary and, by including data vectors and sparse coefficient vectors, the optimized dictionary matrix is finally obtained. From here new sparse vectors are calculated by sparse coding followed by the next dictionary update iteration.

Results and Conclusions

We apply the proposed HDL method to denoising, interpolation and regularization of 3D marine seismic data from the offshore Brazilian basins. The data presents very low fold and moderate noise contamination. The reconstructed data obtained by HDL show significant improvements, with the common shot gathers and error sections of the reconstructed data showing better noise removal, enhancement of coherent events, better definition and continuity of steeply dipping events.