2D Horizon Tracking Using Dynamic Programming

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Abstract

This paper presents a method to track horizons in a seismic section by maximizing a cost-function that measures the similarity between the seed and the tracked samples. The dynamic programming shortest-path algorithm is used to compute in linear time the optimal path between two given picks. Tests showed satisfactory results, since horizons were correctly mapped, despite the presence of faults and discontinuities.

Introduction

Seismic horizon interpretation is an important and time-consuming task. It consists in identifying, for each trace, which sample belongs to the desired horizon. For that reason, many authors have proposed methods for automated horizon tracking.

Among the seed-based approaches, the ones which extract horizons by correlating local amplitude between neighboring traces, have the problem of propagating error when a wrong sample is added to the tracked horizon. In consequence, global approaches have been proposed recently.

With the goal of avoiding the problems related to local optimization approaches and capturing geological features such as faults, we present a new method for 2D horizon tracking that uses global optimization to find the horizon with highest accumulated similarity value. The method is compared with a greedy algorithm with similar approach. A greedy algorithm is an algorithm that makes locally optimal choices with the hope of finding a global optimum.

Related Work

Zinck, Donias and Guillon (2011) present a method based on linear Poisson equation with incremental Dirichlet boundary conditions that has the objective of tracking horizons with discontinuities due to a fault throw. Their approach requires the knowledge of two points delimiting the horizon as well as the discontinuity location and jump. In the case of unknown jump and location, they present a solution that tests several candidates and is able to identify the optimal one.

Li, Ma and Du (2012) describe a method which uses the combination of horizontal derivative and mathematical morphology to track horizons. The method could effectively balance amplitudes of strong and weak horizons and ascertain the location of seismic horizons.

Brown, Morton and Whittle (2006) track salt reflections searching for the path with minimum total traveltime. The seismic image is converted into a “pseudo-velocity” section and the associated eikonal equation is used to compute the globally optimal path between two given picks.

Pauget, Lacaze and Valding (2009) presented an approach for global geological modelling 3D seismic data, that works on links between seismic points and its quality is measured by a cost function. The method finds the best model by moving some links locally until it reaches the global minimum.

Tracking algorithm

The proposed method uses dynamic programming to find in linear time the highest cost path between two given picks. The seismic section is seen as a graph and the edge costs are given by a similarity function which measures the similarity of each sample with the seed. Picking the highest cost path means selecting the samples that together, not locally, are more similar to the seed.

The dynamic programming shortest-path algorithm is a global optimization technique in which an approximation to the correct distance is gradually replaced by more accurate values until eventually reaching the optimal solution. Each node is consulted in a topological order and the approximated distance to the path’s start point is replaced by the minimum between its previous value and the length of a newly found path.

Our proposal requires the following parameters:

- A start point to guide our similarity measures.
- A final point where the tracker will stop.
- The degrees of freedom used to search the neighboring samples.
- The half window size used to compute the samples correlation.

The graph used is implicit and derived directly from the seismic image. Each pixel is interpreted as a node. The edges are placed according to the following rules:

- All edges must travel between adjacent traces.
- The edges must travel in the direction of the final picked point.
- The number of outgoing edges in a node is given by $2degree\_of\_freedom+1$.

- The set of outgoing edges must target a continuous set of nodes centered vertically with the original.

For instance, a graph with degree of freedom equal to zero would only have horizontal edges, while a graph with one degree of freedom will have edges going horizontally and diagonally one up and one down. Figure 1 illustrates the graph built with one degree of freedom. Note that the solution can only have one sample per trace.

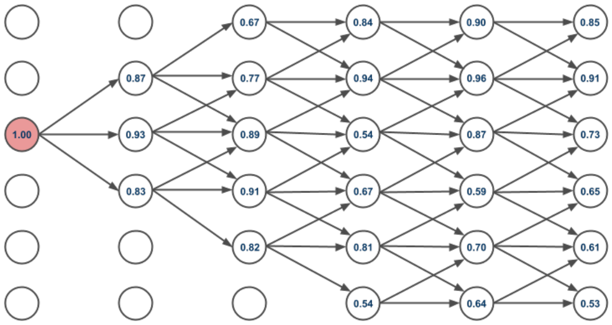

Figure 1: Seismic section seen as a graph with one degree of freedom. The value assigned to each node is the similarity coefficient between the sample and the seed.

The tracking process can be divided into 3 steps. The computation of the correlation image, the computation of the path cost to each node and the backtracking to find the best path.

The first step generates an image containing, for each pixel, the correlation coefficient between the corresponding node and the seed. In addition, the instantaneous phase gradient is used to generate an orientation vector field. These two artifacts will be used to compute the similarity between two samples.

The second step runs through the graph in topological order. Upon visiting each node the accumulated similarity of the best known path to the seed is saved inside it, as well as the neighboring node that leads to this path.

The third and final step starts traversing the graph from the end point. It follows the information saved on the second step, which points to the neighbour it should go next. This traversal is also known as backtracking and it saves all the nodes it has travelled through. Upon arriving at the start position, the highest similarity path is known.

Figure 2 illustrates the final state of the graph. Note that each node knows the cost of the best path from the seed to itself. Therefore it would only be necessary for the interpreter to provide the final trace and the backtracking step could start from the sample with the highest accumulated value.

Similarity Function

The cost of each graph edge is given by the function:

$$cost(i,j) = (1-\alpha)corr(j) + \alpha cos(\theta) \tag{1}$$

where $cost(i,j)$ is the cost of the directed edge from node i to node j, $corr(j)$ is the correlation coefficient between node j and the seed, θ is the angle between the edge and the local orientation of node i and α is the weight of the local orientation on the edge's cost. The cost value lies inside the interval [-1,1]. Therefore, the value of the cost function is normalized in order to avoid having negative valued edges.

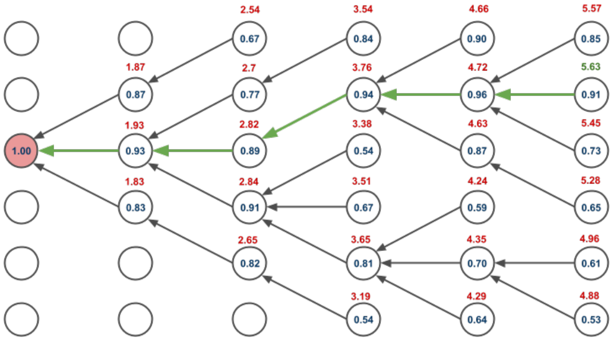

Figure 2: Final state of the graph. Each node keeps the best accumulated cost found and the neighbor sample belonging to the best found path. The green arrows show the path built to represent the horizon.

The correlation coefficient is given by Spearman's ρ, defined in Equation 2, where n is the subtrace size, $\bar{x}$ and $\bar{y}$ are the means of each subtrace and x_i and y_i are the ranks of samples X_i and Y_i. As discussed by Aurnhammer et al. (2004), the use of ordinal measures have advantages such as robustness with respect to single outliers and nonlinear intensity changes, which is typical for seismic data.

$$\rho(X,Y) = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i-\bar{y})^2}} \tag{2}$$

The orientation vector field is calculated from the instantaneous phase gradient, as described by Silva et al. (2012), and is defined by equations 3 and 4, where X is the seismic amplitude and Y its 1D Hilbert transform.

The usage of the vector field in the similarity function is intended to keep the tracker on the correct horizon. The orientation measure is however sensitive to noise in the seismic data. Thus the α coefficient is used to control the orientation weight given the seismic data quality. Although we used a fixed value for α in our tests, it can easily become a parameter for the interpreter.

$$\frac{\partial\phi}{\partial x} = \frac{\left(X\frac{\partial Y}{\partial x} - Y\frac{\partial X}{\partial x}\right)}{X^2+Y^2} \tag{3}$$

$$\frac{\partial\phi}{\partial y} = \frac{\left(X\frac{\partial Y}{\partial y} - Y\frac{\partial X}{\partial y}\right)}{X^2+Y^2} \tag{4}$$

An interesting aspect of the shortest-path approach is that the similarity function can incorporate other horizon identifier attributes, improving quality of results, without the need to modify the tracking algorithm.

Results

The proposed method was tested with several slices from the Netherlands offshore F3 block, downloaded from

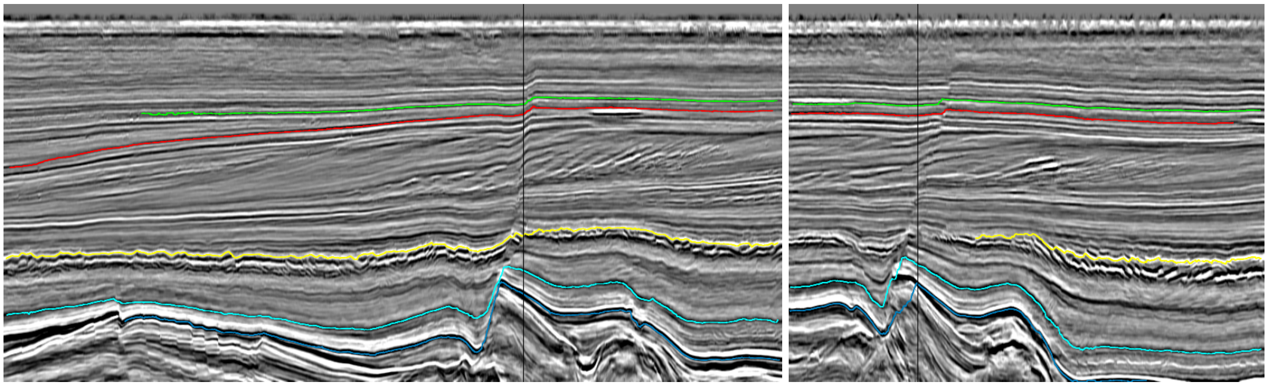

Figure 3: Horizons correctly mapped, despite the presence of a large discontinuity in inline 271 and crossline 935.

the Opendtect website. FFA Geosciences' Structurally-Oriented Finite Median Hybrid (SO FMH) filter followed by a Tensor Diffusion (TDiff) were applied to the 3D data set to reduce noise.

The method showed satisfactory results, even in the presence of faults and discontinuities. Figures 3, 4 and 5 present different sets of horizons tracked with the proposed method. Figure 6 details the results obtained among complicated seismic features. Note that in Figure 6 (b) although the tracker does not skip the fault in the correct position on the dark blue horizon, the error is not propagated due to the fact that the method is maximizing the similarity throughout the horizon.

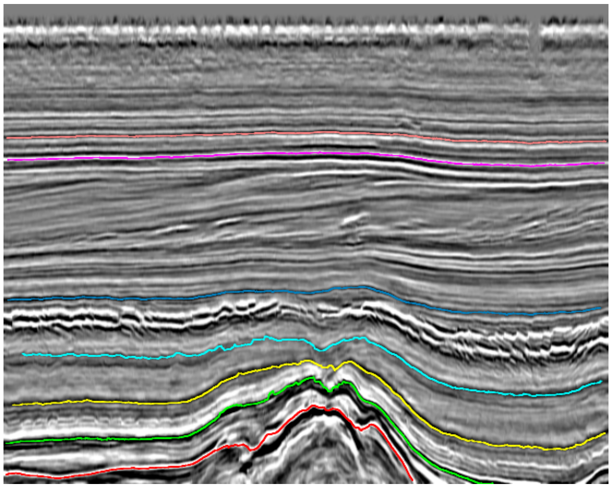

Figure 4: Mapped horizons across a salt dome in crossline number 801.

In order to test the effectiveness of the proposed method and ilustrate the problems related to local optimization approaches mentioned above, we compared the dynamic programming algorithm with a similar greedy one, that solves local optimization problems to track a horizon.

The greedy algorithm starts at the seed and searches its neighboring traces for the sample with the highest similarity value in respect to itself. The chosen sample is then considered to be the new seed and the process loops until the final trace is reached.

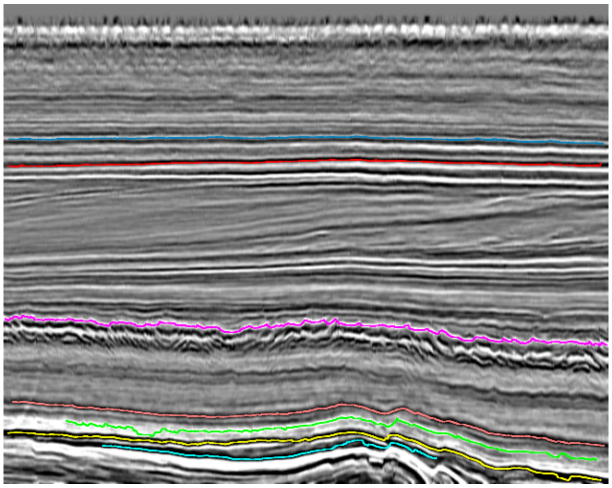

Figure 5: Horizons with small discontinuities mapped in crossline 700.

Figure 7 ilustrates the obtained results. As expected, when reaching a fault the greedy tracker looses its way, while the global approach tracker is able to ”jump” the discontinuity.

Conclusions

In this paper, we presented a method to identify horizons in a seismic section by maximizing a cost-function that measures the similarity between the seed and the tracked samples. The cost function is a combination of the correlation of each sample with the seed and the path's alignment with local orientation. We use the dynamic programming shortest-path algorithm to compute the path with highest accumulated similarity value. Since we avoid local similarity measurements, this method is able to track horizons in the presence of discontinuities without propagating error.

It is worth mentioning though, that since correlation is always computed with the seed sample, the quality of the results are extreamely related to the quality of the seed. Nevertheless, results showed the method's ability to correctly map horizons even when tracking among complicated seismic features like faults, discontinuities and at the vicinity of salt domes.

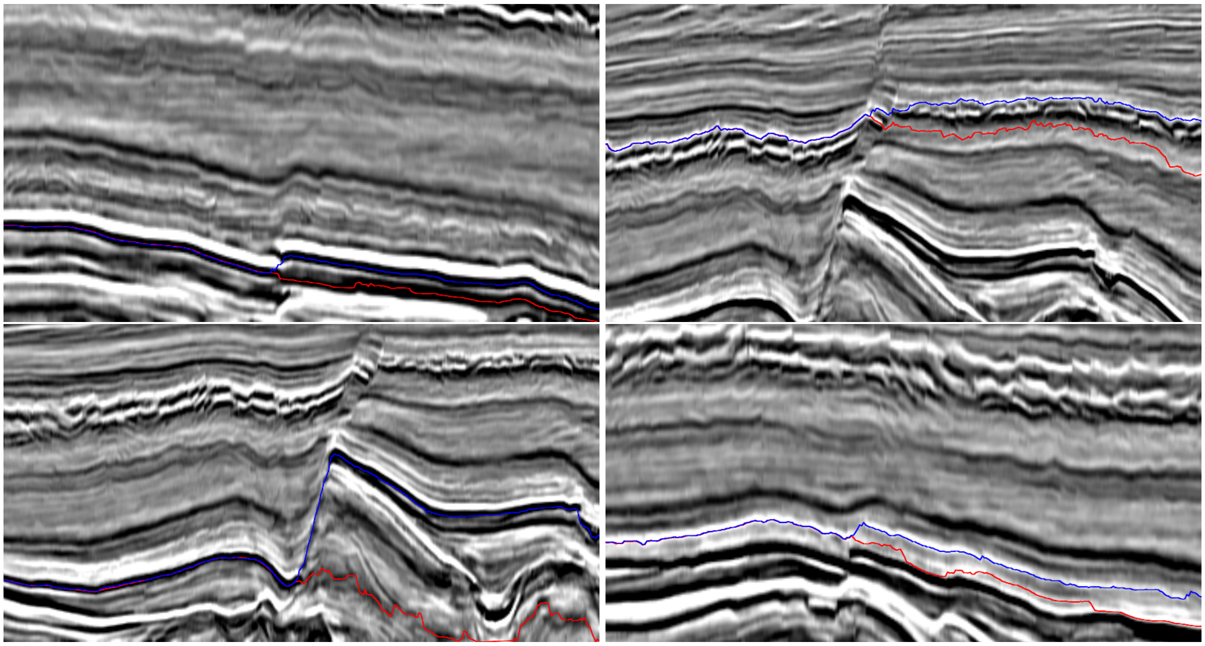

Figure 7: Global optimization (blue) versus local optimization approach (red). With the presence of discontinuities the greedy approach adds a wrong sample to the tracked horizon and propagates error until the end.

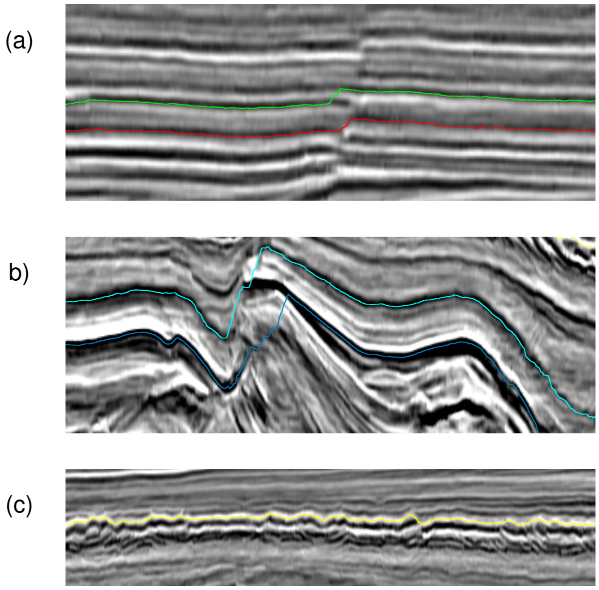

Figure 6: Detailed results among difficult tracking scenarios. (a) and (b) ilustrate the tracker's ability to "jump" across faults. Observe that the fault's exactly position is unknown, but picking the samples if highest similarity with the seed allows the tracker to skip the discontinuity at its approximate location. (c) shows a horizon correctly tracked in an extremely noisy region.

References

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Acknowledgments

The authors wish to acknowledge the help provided by the v3o2 software development team. We also would like to thank Carlos André Campos and Cristina Nader Vasconcelos for the ideas given during the develpment process and our research partners at Petrobras for the technical assistence, especially Alexandre Kolisnyk for the pre-conditioned data. Eliana Goldner would like to thank CNPq (National Research Council of Brazil) and FAPERJ (Carlos Chagas Filho Foundation for Research Aid of the state of Rio de Janeiro) for scholarship support.