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Automatic Tracking of Reflection Events in 3D ZO Volumes Using CRS Attributes

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SUMMARY

An approach for the automatic tracking of reflection events in 3D zero-offset (ZO) volumes is presented. The method makes use of a subset of the kinematic wavefield attributes that are obtained from the common-reflection-surface (CRS) stack technique to determine the spatial continuation of reflection events. Due to a navigation based on triangulated trace locations the approach is able to handle irregular geometries and gaps in the data. In this way, the input for all horizon based methods, for instance, layer-stripping velocity inversion, is obtained in a fully automated manner.

Introduction. The use of techniques that are applied to exactly defined stratigraphic sequences on stacked data, e. g., layer-based inversion methods, require the extraction of continuous reflection events and stacking parameters from the respective data volumes. If performed manually, this task is rather cumbersome and errorprone. Furthermore, in case of 3D data, an appropriate visualization of the data is difficult. Therefore, algorithms that allow an automatic tracking of events are desirable. In this abstract a technique that uses the stacking parameters (the so-called kinematic wavefield attributes) of the 3D common-reflection-surface (CRS) stack for the automatic tracking of reflection events in zero-offset (ZO) volumes is presented. The method is suited for arbitrary acquisition geometries and automatically bypasses areas with insufficient information for reliable tracking.

The 3D CRS stack. The 3D CRS stack technology (see, e.g., Bergler, 2004) is a second-order generalized stacking velocity analysis tool parameterized in terms of kinematic wavefield attributes. For a planar measurement surface its hyperbolic stacking operator is given in midpoint/half-offset coordinates $(\mathbf{m},\mathbf{h})$ by

$$t_{hyp}^2(\mathbf{m},\mathbf{h}) \quad = \quad \left[t_0+\frac{2}{v_0}\begin{pmatrix}\cos\alpha\,\sin\beta\\ \sin\alpha\,\sin\beta\end{pmatrix}\cdot\mathbf{m}\right]^2+\frac{2t_0}{v_0}\mathbf{m}^\mathbf{T}\mathbf{TNT}^\mathbf{T}\mathbf{m}+\frac{2t_0}{v_0}\mathbf{h}^\mathbf{T}\mathbf{TMT}^\mathbf{T}\mathbf{h}\,, \qquad (1)$$

where t_0 denotes the ZO traveltime and v_0 the near-surface velocity. The symmetric 2×2 matrix $\mathbf{T}(\alpha,\beta)$ describes the transformation from local ray-centered Cartesian to global Cartesian coordinates and the quantities α, β, and the symmetric 2×2 matrices $\mathbf{N}$, and $\mathbf{M}$ denote the kinematic wavefield attributes. These eight attributes can be assigned a simple geometrical description: α and β denote the emergence angles (dip and azimuth) of the ZO ray at the surface location $\mathbf{m}$, matrix $\mathbf{M}$ describes the curvature of a wavefront at the surface that stems from a point source at the normal-incidence-point (NIP), and matrix $\mathbf{N}$ is in the same way related to the wavefront of an exploding reflector experiment.
Implementations of the CRS stack automatically determine the eight unknown attributes for each sample of the desired output volume by means of a coherence analysis similar to conventional stacking velocity analysis. Therefore, as result of CRS processing one obtains a CRS stacked ZO volume, eight attribute volumes, and a coherence volume.

Event tracking in ZO volumes with the CRS operator. The CRS stacking operator (1) provides the curvature matrix $\mathbf{N}$ and the direction vector $\mathbf{w}=(\cos\alpha\sin\beta,\sin\alpha\sin\beta)^\mathrm{T}$ of the normal wave at the surface. These quantities are directly related to the local curvature and orientation of the reflection event at the respective location in the ZO stack volume. In this domain the complete CRS operator (1) for ZO (which is defined by the condition $\mathbf{h}=\mathbf{0}$) reduces to

$$t_{hyp}^2(\mathbf{m}) \quad = \quad \left(t_0+\frac{2}{v_0}\mathbf{w}\cdot\mathbf{m}\right)^2+\frac{2t_0}{v_0}\mathbf{m}^\mathbf{T}\mathbf{TNT}^\mathbf{T}\mathbf{m}\,. \qquad (2)$$

Thus, if a point A on an arbitrary event is considered and the corresponding wavefield attributes are known, equation (2) can be used to approximate the spatial continuation to a point B of the event on a trace in the vicinity of A.
As the CRS stack is performed for each sample of the stacked ZO volume, the wavefield attributes and, thus, an approximation for the continuation is also known at each sample. This means that a reflection event can be tracked automatically from a single seed point on the selected event. However, an implementation solely based on the calculation of the continuation is insufficient to perform a consistent tracking as it does not account for discontinuous events which may occur, e. g., at faults or in regions of poor signal-to-noise ratio. In that case, continuations can be evaluated but they are actually meaningless as they point to positions where the reflection event does not exist. Thus, additional criteria to validate the consistency of the continuations are required. Depending on the available data arbitrary criteria can be defined. A restriction to information that is available from the CRS technique yields continuity criteria which state that along

the reflection events the wavefield attributes, coherence values, and stack amplitudes should vary smoothly. Thus, the corresponding quantities at point A should not substantially differ from the quantities on the continuation point B. Therefore, user given thresholds for the variations can be used as validation criteria.
Other criteria, which are not related to the CRS technique, are, for instance, thresholds based on instantaneous quantities (e. g., instantaneous phase or frequency). Also, additional coherence criteria may be applied to the data.
In addition to the above mentioned validation criteria the evaluated continuation has to be refined. This is due to the fact that the attributes used for the calculation of the continuation are determined from data within a search aperture, i. e., they are obtained as best fit attributes from a number of traces. Therefore, the calculated continuation B will most likely not coincide with the true continuation B_T. However, as the spatial distance to the continuation is usually significantly smaller than the search aperture, it can be expected that B is at least located within the wavelet of the reflection event. As B_T is usually defined to be associated with the absolute maximum stack energy of the wavelet the refinement consists of the determination of this energy within a user-defined window centered around B.

Navigation in ZO data volumes. For 3D data the proper selection of the traces for the calculation of the continuation is essential as it defines the movement scheme and the regions in the data that are covered by the algorithm. In the following, it is assumed that the selected reflection events appear only once on each trace. If this is not the case, e. g., along triplications, the tracking has to be performed independently for each of the branches. Using this assumption the navigation in the ZO data volumes $(t, \mathbf{m})$ can be split into two independent routines, one which controls the movement along the time axis and one for the movement in the midpoint plane $\mathbf{m}$. Actually, the former movement defines the continuation. Therefore, it is given by the evaluation of the CRS operator (2) with the proper wavefield attributes and validation criteria. In contrast, the movement in the $\mathbf{m}$ plane defines the traces along which the continuations are evaluated, i. e., it provides the input and the extrapolation direction for the tracking of the reflection events. For traces that are regularly distributed along the midpoint plane the navigation may be simply specified. However, for an irregular distribution of the traces the movement and the treatment of discontinuous reflection events needs to be more sophisticated. Therefore, the movement scheme is realized by means of a recursive function that acts on the triangulated trace locations.
In a first step, the trace locations are triangulated using a Delaunay triangulation. The triangulation yields the nearest neighboring traces to an arbitrary central trace. They are given by all the traces that share a triangle with the central trace (see Figure 1(left)). The spatial continuation of the selected reflection event is now evaluated for the neighboring traces which have not yet been successfully validated (the latter condition is necessary to prevent repeated tracking of a trace from different central traces for a given seed point A). Whenever a valid continuation to any of these neighbors is found this trace becomes successor of the central trace and the above process is repeated. If no continuation is found (this may either be the case if all remaining continuations are invalid or all neighboring traces are processed) the current central trace is discarded and its predecessor becomes active again and continues the validation of the remaining neighboring traces. The process terminates automatically if the active trace does not have a predecessor, i. e., it coincides with the initial trace that started the navigation, and if this trace has validated all of its neighbors. In the implementation this algorithm is realized by means of a recursive function. Although such a recursive function generally degrades the memory and runtime efficiency of the implementation, it provides a vivid and simple solution to the navigation problem. It automatically keeps track of the movement path, i. e., it records where and when valid continuations are found, and is, thus, able to bypass regions of unreliable data.

Automatic picking of a reflection event in real data. The proposed technique has been applied to a real dataset with the aim to extract primary reflection events that serve as input for layer-

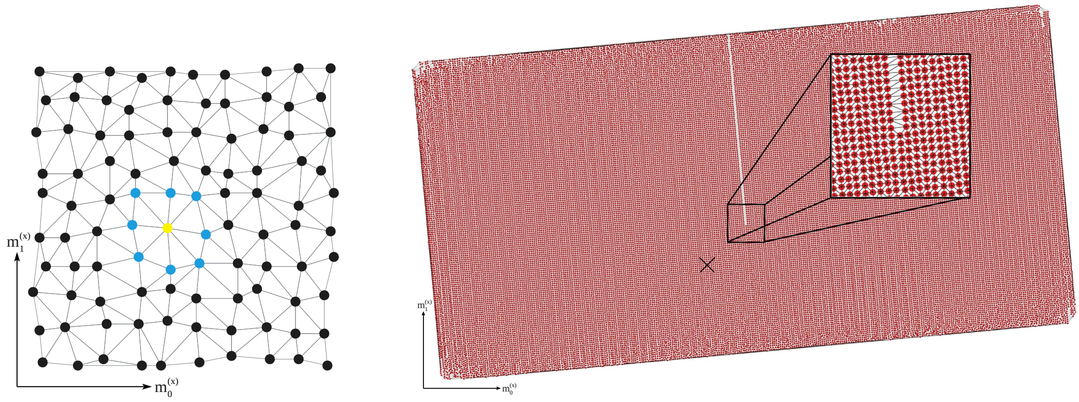

Figure 1: Left: after Delaunay triangulation the nearest neighboring traces (depicted in blue) to an arbitrary central trace (yellow) are given by all the traces that share a triangle with it. Right: Delaunay triangulation of the trace locations (red dots). As can be seen, the distribution of the traces is irregular in the midpoint plane. The cross indicates the starting trace used for the tracking.

based inversion. Due to space limitations, only a selected tracked event will be presented and discussed in this abstract.

The result of the first step, the Delaunay triangulation, is shown in Figure 1 (right). As can be seen, the trace distribution is irregular in the midpoint plane. This is especially visible at the borders of the acquisition area where a number of traces are missing. In the center of the covered area, the distribution is, to a large extent, regular but regions of irregularity can also be observed. The event tracking was started in the central part of the acquisition area as indicated by the cross in Figure 1. All the previously discussed validation criteria were applied for the validation of the continuations.

The results of the event tracking are depicted in Figure 2. Here, the tracked event is displayed together with an inline and a crossline section of the CRS stacked ZO volume. The figure shows the complete tracked event which is color-coded with the coherence values used in the respective validation criterion. As can be seen, the extracted event almost covers the full measurement area but is also subject to a number of gaps. Figure 3 shows a detailed view of one the gaps. This figure reveals that the gaps are, in fact, due to low coherence values at their borders. Also, it can be observed that the stack amplitudes of the displayed inline and crossline strongly decrease within the area of the gap. As both quantities, coherence and stack amplitude, enter into the validation criteria the algorithm is consequently not able to track the event in these areas.

Conclusions. In this abstract a technique for the automatic tracking of reflection events in CRS stacked ZO volumes has been presented and applied to a real dataset. The method uses the kinematic wavefield attributes of the CRS stack for the calculation of the continuations of reflection events and the triangulated trace locations for the navigation along the traces. Due to this navigation which keeps track of the movement path and the additional validation criteria regions of invalidity are automatically bypassed by the method.

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References

Bergler, S. [2004] On the determination and use of kinematic wavefield attributes for 3D seismic imaging. Logos Verlag, Berlin.

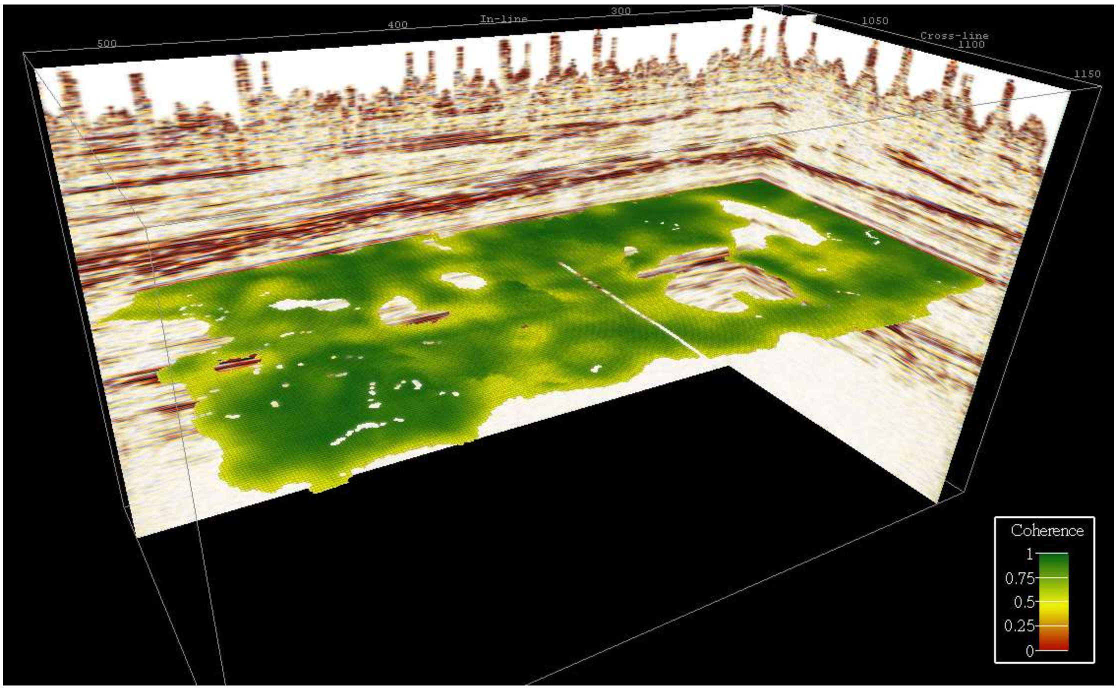

Figure 2: Automatically tracked reflection event. The colors on the surface indicate the respective coherence values. The inline and crossline sections are taken from the CRS stack volume.

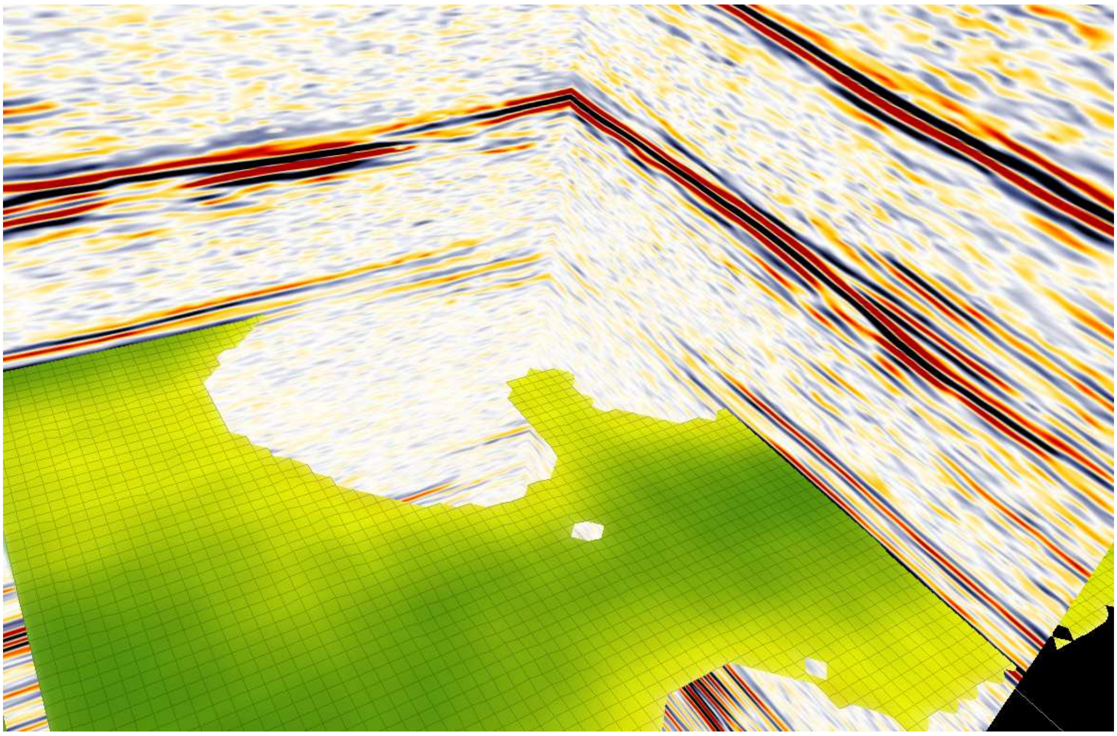

Figure 3: Detailed view of a gap in the tracked reflection event. The gaps are due to areas where no valid continuations were found. The color coding has the same meaning as in Figure 2.