Volume visualization and automatic tracking in CFP-related processing

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Summary

The Common Focal Point (CFP) technology involves the estimation of one-way travel time operators, describing the propagation effects from a selection of gridpoints at reflecting interfaces towards the surface locations. These operators can be obtained from the data without using any velocity depth model. These operators can be used in several data-driven processing steps: prestack redatuming, internal multiple removal and velocity-depth model estimation. In any of these applications, updating of many CFP gathers along one specific boundary plays a central role. To reduce user-interaction, 3D volume visualization and automatic tracking are used to get an optimum control on the process.

Introduction

Volume visualisation may improve parameter estimation in 2D (and 3D) seismic processing by optimally exploring lateral geologically based coherencies. In this paper it is demonstrated on CFP-related, data-driven processing.

Within CFP-related processing, the updating of one-way time operators (Bolte and Verschuur, 1998) plays a central role. These updated CFP operators form the basis of several seismic processing steps:

1. Model-independent wave field redatuming (Kelamis et al., 1999), where the seismic data can be redatumed in a full prestack sense towards one of the reflectors below a complex near surface or overburden.
2. Internal multiple removal (Verschuur et al. 1998; Berkhout and Verschuur 1999), where the CFP gather related to the internal multiple generating boundary are used to predict the internal multiples in the original shot records.
3. Inversion of focusing operators (Hegge et al., 1998), where the velocity-depth model is found by tomographic inversion of the estimated CFP operators.
4. Integrated operator updating and velocity-depth model estimation (Kabir, 1997), in which the velocity-depth model is simultaneously estimated during CFP operator updating. Many of these applications are layer-oriented, where CFP locations are chosen along a geological boundary.

We propose a semi-automatic picking procedure to update all DTS panels related to one reflecting boundary. This is done by updating them as one 3D volume instead of updating each 2D panel separately, thus saving a lot of user interaction time. Also the lateral coherency becomes evident between the differential time shifts of these DTS panels. They compose a 2D coherent surface in the 3D volume. Tracking this surface in a full 3D sense improves the updating procedure. As the DTS panels play a similar role as Common Reflection Point gathers in conventional migration velocity analysis this proposed method would also be valid for updating the move-out within these gathers.

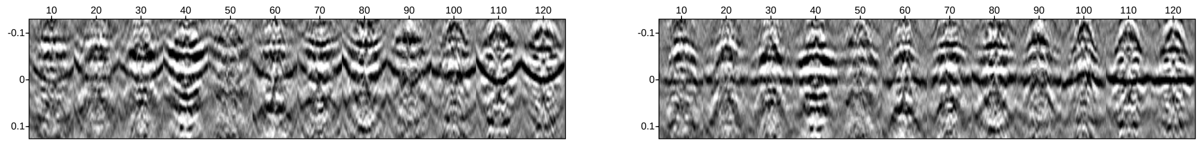
Determination of move-out in DTS panels

The CFP operator updating method can work in two modes:

- Model-driven, interactively estimating a velocity model (Kabir, 1997).
- Fully data-driven, where one-way time operators are obtained (Bolte et al., 1999).

In either mode, a layer stripping approach can be adopted, picking analysis positions along the next boundary, in depth or time respectively. From these positions, focusing operators are calculated. They describe the propagation of seismic energy from the chosen grid point to the surface locations. The CFP gathers are obtained by collecting the response of applying each focusing operator as an inverse propagation operator to the seismic data. By this synthesis step, a virtual source has been positioned in the position of analysis (grid point or CFP position), whereas the receivers are still at the surface.

The CFP gather has a very interesting property: if the grid point in the focusing step is chosen at a reflector and if the correct operator has been used for the synthesis operation, the response of the reflector appears in the CFP gather at the same travel times as the time-reversed synthesis operator. This can be easily understood, because they both describe the propagation from the chosen grid point to the surface locations. This property is called the *principle of equal travel time* and is discussed by Berkhout (1997) and Thorbecke (1997). By a correlation in time of the CFP gather and its corresponding synthesis operator, an aligned event at zero time should occur. If this is not the case, the macro model that was used to generate the synthesis operator is apparently wrong, and from the deviation with t=0 in each DTS panel a new operator need be constructed. This can be done either in the model-driven mode, via an update of the velocity-depth parameters (see Kabir, 1997) or in the data-driven mode, via a direct translation of travel time errors into a new one-way time operator (Berkhout 1997; Thorbecke 1997; Bolte and Verschuur 1998). When the velocity-depth model is correct (model-driven mode) or when the operator has been correctly updated (data-driven mode), the reflection in each DTS panel aligns horizontally.



(a) DTS panels resulting from initial hyperbolic traveltime operators

(b) DTS panels resulting from updated traveltime operators/model

Fig. 1: *Example of 2D Differential Time Shift (DTS) panels along a boundary in the North Sea data set, that shows the misfit between the modeled operator in the updated model and the Common Focal Point (CFP) gather over the offset along the seismic line. If the modeled operator and the CFP gather coincide, the event of interest is aligned at t=0.*

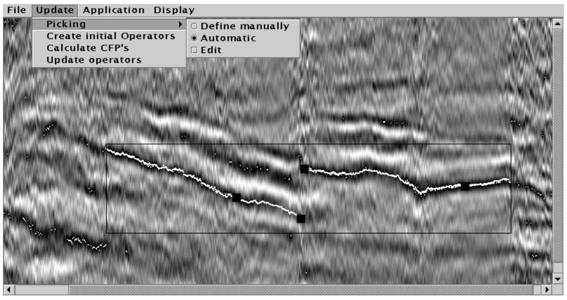


Fig. 2: *Zoom of the stacked section from the North Sea data with the boundary indicated by a track overlay (white), and the user determined picks denoted by the black squares.*

Depending on the DTS interval, the offset range with respect to the lateral coordinate of the focal point that is sampled in a DTS panel partially overlaps the range of the next panel.

3D Volumizer visualization

A software module has been built being able to read seismic data and to display a 3D volume. To display the 3D volume the OpenGL Volumizer API SGI (1998) has been used. The Volumizer API is a library of C++ classes that facilitates the display and manipulation of volumetric data and is a layer of functionality that sits on top of OpenGL. By using Volumizer we can concentrate our efforts on adding useful tools and don't have to worry about low-level graphics programming languages, such as OpenGL. Besides being a handy library, Volumizer is implemented in an optimized way for different platforms and also introduces a new way of displaying volumes. In Volumizer the geometry (e.g. a cube) of a volumetric shape is decoupled from is appearance (voxels representing the data). The basic geometrical primitive introduced in Volumizer is a tetrahedron. Like a triangle is used to construct surfaces, a tetrahedron is the simplest and most efficient primitive you can use to represent volumetric geometry.

Among the tools we added to our 3D visualization module are: an opacity editor by which the transparency can be regulated and the amplitude interval that is displayed; a tool for picking points in a 3D volume; integration of surfaces with the volume.

Automatic 3D tracking

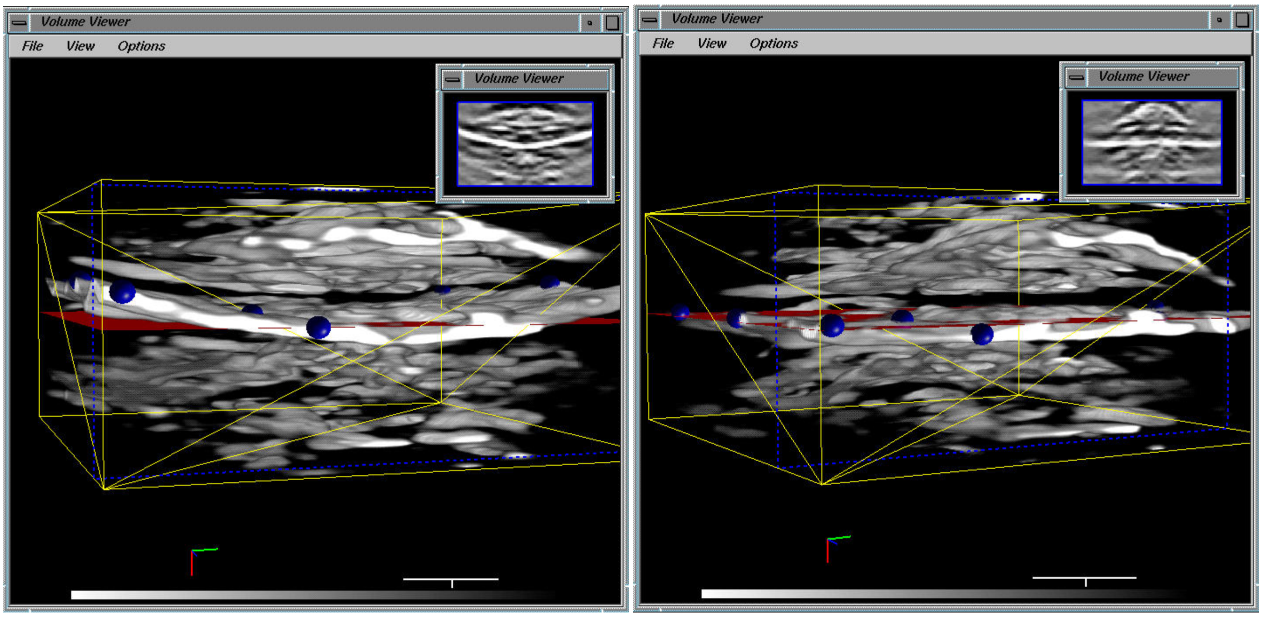
The automatic 3D tracking scheme is based on the single-interface detection/tracking algorithm described in Spagnolini and Rampa (1999). This 2-D horizon picking scheme is based on a statistical model. It describes small variations of the horizon for neighbouring traces. Since this algorithm is based on a trace to trace basis, the method can be extended to three dimensions with little effort. Bienati et al. (1999) already proposed a multidimensional tracking scheme for automatic tracking of horizons in 3 dimensional migrated data volumes. It is a region growing method, which has proved to be successful even over a faulty area. Therefore we have used this scheme to develop a tracking algorithm which can be used both in two and in three dimensional data volumes.

Procedure

Starting from calculated DTS panels based on initial (hyperbolic) operators (showing a certain move-out) that are regularly sampled along the seismic line, the data is read into the visualization package. Then, several points at the move-out volume are picked, as shown in Figure 3. Next, the 3 dimensional auto tracker is activated. Subsequently, the move-out surface over the entire seismic line is determined. From this move-out a new velocity-depth model until the reflector that is considered is derived. Then, again DTS panels along the line are calculated and the residual move-out is calculated. This is the processing flow that is applied until the move-out is at zero differential time and the optimal operators to the considered layer are determined. This can be done for all reflectors that are needed.

Application to the marine Norway data set

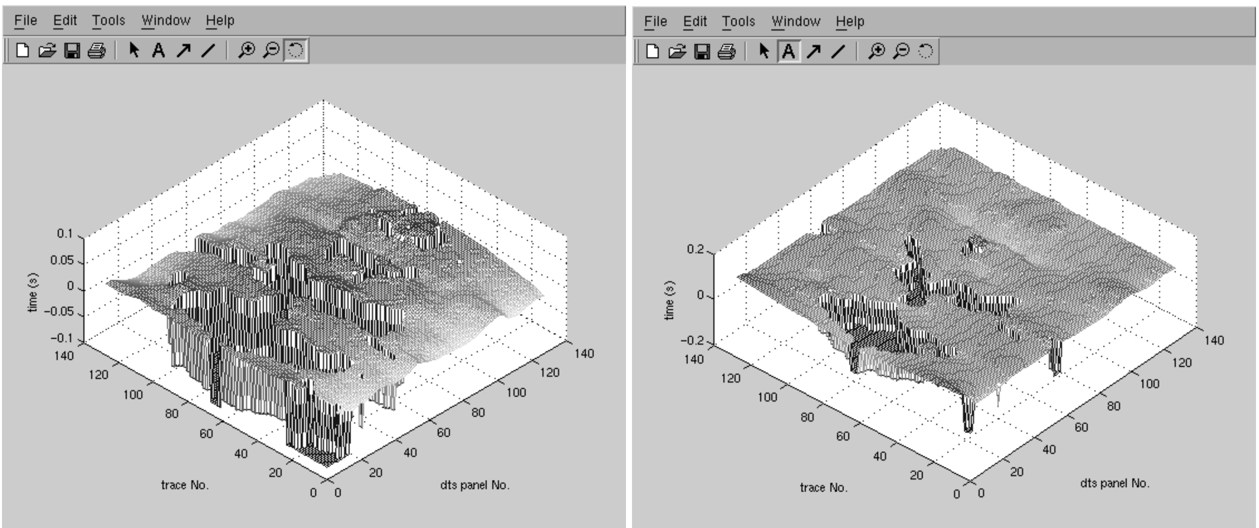
The procedure of estimating CFP operators along one boundary is illustrated on a marine dataset from offshore Norway (Haltenbanken terrace, courtesy Saga Petroleum). The purpose for this application was to obtain a table of one-way operators along this boundary, with which a volume of CFP gathers can be constructed. These CFP gathers, after muting all events related to reflections above and including this chosen boundary, are used to predict the internal multiples related to the boundary, after which they are subtracted from the input shot records (see also Verschuur et al., 1998). First, points at the boundary of interest



(a) Initial DTS panels based on the NMO velocity.

(b) DTS panels after operator updating.

Fig. 3: *3D display of a set of 2D Differential Time Shift panels all related to focal points positioned at the same reflecting boundary at a regular lateral interval. In this 3D volume the events of interest are automatically tracked by a 3D tracker after a human picker denoted about 5 points, blue (dark) spheres, that characterizes the 2D-DTS surface. The red surface (grey) is the t=0 plane. The inlay shows 2D DTS gather that is picked from the 3D volume at the location of the dashed blue window frame, that can be shifted along all principle axes in 3D. By the opacity shift bar at the bottom only reflections of an amplitude above a threshold magnitude are shown.*



(a) 2D surface tracked from DTS panels resulting from initial hyperbolic traveltime operators

(b) 2D surface tracked from DTS panels resulting from updated traveltime operators/model

Fig. 4: *The 2D surface that was automatically tracked from the 3D data volume built up from all the 2D DTS panels along the same boundary.*

are chosen by the user as indicated in Figure 2, with the aid of a tracking algorithm. The resulting initial CFP points are chosen regularly along this track. Next, using the available NMO velocities, these zero offset time picks are converted in a one-way CFP operator table, one traveltime curve for each point along the track. With these operators a volume of CFP gathers and - after move-out correction of each CFP gather with its operator times - a DTS volume is obtained. Figure 1(a) shows a few of these DTS panels. Note that because only the NMO velocity was used, the DTS panels do not show an exact flat event at zero time. The residual time differences are automatically tracked within the full DTS volume, as displayed in Figure 3(a), resulting in a traveltime error surface, as shown in Figure 4(a). With this traveltime surface, the operator table can be updated and new DTS panels are constructed. As shown in Figures 1(b), 3(b) and 4(b), the events in the selected DTS panels have now been flattened. No further iterations are necessary. The CFP gathers, obtained with these new operators, properly describe the situation of sources at the interface and receivers still at the surface, as required in a prestack internal multiple removal process. Note that, to achieve this goal, no information on the subsurface model (other than initial NMO velocities and time picks in the stack) was used. For the internal multiple removal process depth-velocity information is not required. However, in a separate procedure, the velocity depth model can be estimated by a one-way traveltime inversion of all operators (for many boundaries), as described by Hegge et al. (1999).

Conclusions

Volume visualization and 3D tracking have proven to be a useful tools for parameter estimation in CFP related processing. By means of plotting all 2D DTS panels along one boundary in a 3D volume, they can all be tracked as a 2D geologically coherent surface in one sweep using a 3D tracker. Since the tracker already performs well on 5 interactively positioned picks made in the 3D Volumizer plot, the amount of user interactive time is cut down severely.

The application to real data, a North Sea data set, shows that the DTS panels are very well tracked using the above procedure, automatically avoiding bad-data areas, already from the first initial stage on.

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