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Operator design for three-dimensional data extrapolation

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ABSTRACT

In this paper, extrapolation of data in three dimensions is done in two steps. First, a three-dimensional annihilation filter is calculated from the available data. Next, the result of filtering an extended volume with the calculated annihilation filter from the first step is then minimized by computing the missing data in the extended volume. This technique suffers from a limited extrapolation range and from edge effects. By making predictions with purely lateral prediction filters, the distance the data is extrapolated in the spatial directions is extended. Also, although not well understood, the use of multiple directional prediction filters appears to improve the extrapolation quality, especially near the edges of the volume where very poor predictions are made. These three-dimensional directional filters are lateral filters with the output on one corner of the three-dimensional filter. While these results are preliminary, the techniques presented here look promising.

INTRODUCTION

Elsewhere in this report, Claerbout(Claerbout, 1993) introduces a technique for extrapolating three-dimensional data based on his one-dimensional extrapolation given in (Claerbout, 1992). This extrapolation is done by calculating three-dimensional annihilation filters from the available data and then minimizing the residuals after filtering a larger data volume that includes the data to be extrapolated.

The most immediate application of this method appears to be the extrapolation of data past the boundaries of seismic lines to reduce migration end-effects. Another application is to predict areas of missing data within a line to complete a partially filled grid so techniques that operate on regular grids may be used. This application is not limited to the finite-difference and f-k techniques that require regular grids, since even integral methods that can operate on irregular grids involve assumptions

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about the regularity of the input and may benefit from filling in the missing parts of a grid.

In this paper, I show that a purely three-dimensional operator makes a significant improvement over a prediction operator that is not purely lateral. A purely lateral filter is one in which the samples in a given output trace are not affected by the input samples at that same trace position.

I also show that the prediction is improved by using a combination of several prediction filters. Several prediction filters are used to reduce bad predictions at the edges of the volume and to produce good predictions throughout the volume for dips of all directions. There are several methods of incorporating the results of the multiple prediction filters. An unexpected difference was found in predicting the residual by simultaneously minimizing the four separate results of applying four filters and predicting the residual by minimizing the sum of the four results. Minimizing the sum of the four results produced a reasonable result; simultaneously minimizing the four separate results produced a very poor extrapolation.

Comparisons between a purely lateral operator result and the result of using an operator containing vertical components are shown to demonstrate how lateral operators improve predictions. Then the application of a single operator is compared to that of multiple operators to demonstrate how multiple operators can remove poor edge predictions and how the summed filter results improve predictions over the simultaneous minimization with all the prediction operators.

The results presented in this paper are preliminary. Most of this work has been done only recently and requires further analysis.

THE CASE FOR PURELY LATERAL OPERATORS

There is a fundamental difference between the vertical and horizontal directions in seismic data. In the vertical direction, whether in time or depth, the data are expected to be unpredictable. Predictability implies either a multiple sequence or an uncollapsed source wavelet. In the horizontal directions data are expected to be predictable, and signal in seismic data is recognized by its lateral continuity. This lack of symmetry between the horizontal and vertical directions is caused by the leveling effect of gravity on sedimentary sequences.

Because of this difference, when extrapolating seismic data we expect to be able to predict laterally well and to predict vertically poorly, if at all. This directional dependence of predictability places limits on the configurations of the windows in which predictions are made. It also suggests that filters allowing vertical predictions should not be used.

In practice, a filter allowing vertical predictions does make some vertical predictions because of the band-limited nature of the data. Adjacent samples generally have comparable amplitudes, producing a significant prediction. This prediction is not especially useful for data extrapolation since it covers such a short time span. These short-term vertical predictions weaken the desired lateral predictions. A two-dimensional example of an operator allowing vertical predictions is shown in Figure 2, and an example of a purely lateral two-dimensional operator is shown in Figure 3. The original data is shown in Figure 1. The process with a purely lateral filter extrapolates the data farther than the same process with a filter that allows vertical predictions. I postulate that this difference in lateral extent is caused by the short-term vertical predictions weakening the lateral predictions.

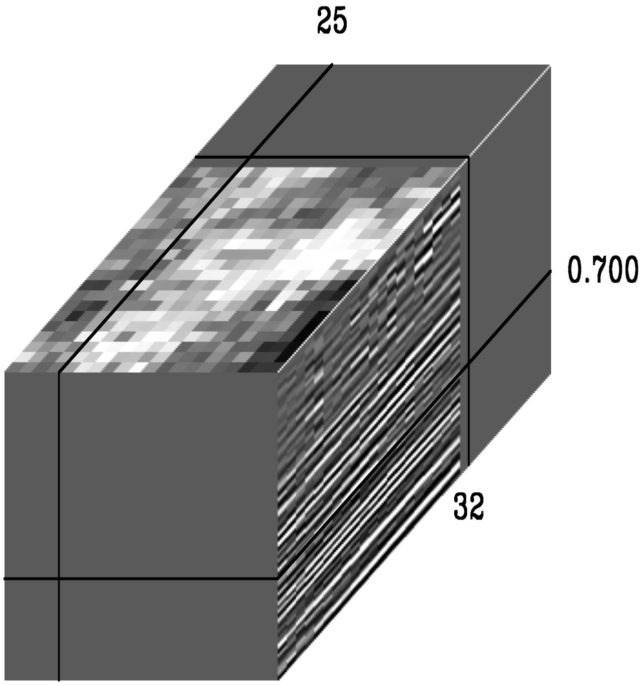

Figure 1: The original dataset. The front panel is blank because the data at the back of the cube has been zeroed. ray2-original [ER]

A troublesome failure of this technique can be seen in the front face of the cubes in Figures 2 and 3. The traces near the edge of the volume do not appear to follow the trend of the data. In other cases, these bad traces may even have polarities opposite to that of the nearby traces. While this effect is not completely understood, it appears to be confined to the areas where the traces lie between the edge of the data and the output point of the filter. The elimination of this effect is the subject of the next section.

MULTIPLE DIRECTIONAL OPERATORS

After the prediction operators are constrained to be purely lateral, additional criteria for filter design are considered to eliminate two types of prediction failures seen in this work. The most apparent failure is seen in the traces near the edge of the output

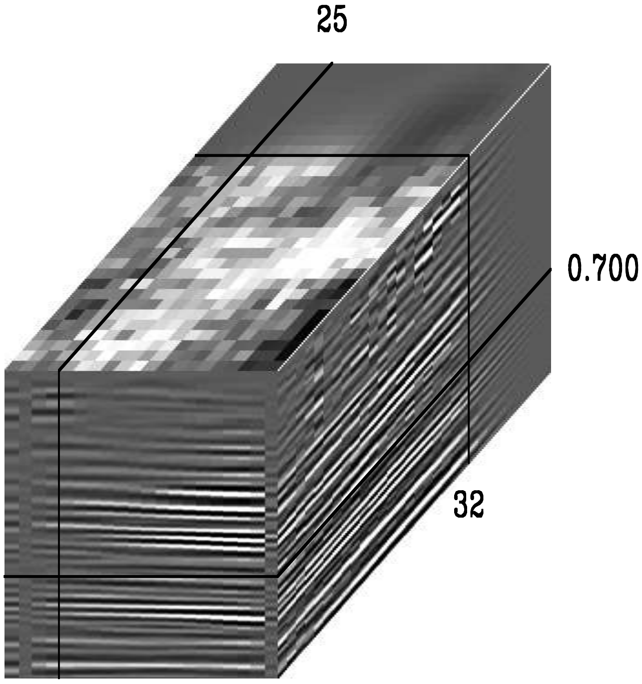

Figure 2: Extrapolation using a filter that allows vertical predictions. ray2-vertical [ER]

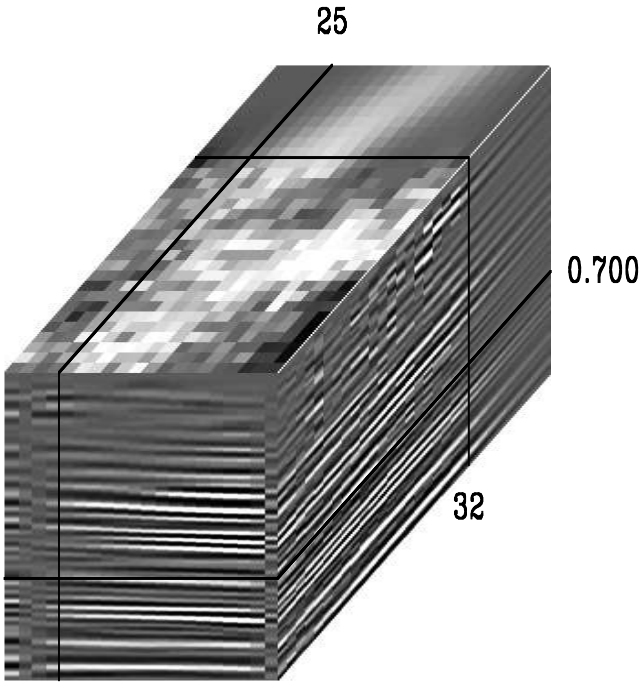

Figure 3: Extrapolation using a purely lateral filter. ray2-lateral [ER]

volume. These traces often have polarities opposite to the extrapolated data in the interior and may be stronger than the adjacent traces. The other failure is that of blank areas in output volume. This seems to be the result of events dipping in a direction where a filter cannot make predictions.

Since bad predictions are produced between the output of the filter and the edge of the data, the bad predictions along any one boundary can be eliminated by using a prediction filter with its output along that boundary. While a bad output along the opposite boundary is expected, I show later that this can be eliminated with multiple filters. This same set of multiple filters can be used to avoid the blank areas in the output volume by providing predictions in all directions.

The use of four directional filters

The use of four three-dimensional filters, one for each side of the box where the prediction is being made, can eliminate the bad predictions at the boundaries. Only four filters are needed, since reversing the order of the coefficients along all the filter axes produces a similar prediction. Thus, a separate filter is needed for each side of the box, but the front and back faces use the same set of filters.

In a three-dimensional volume, the use of four filters might also be justified through classifying dipping events by the direction of the dip. An examination of the comparative amplitudes of the filter coefficients for the four filters calculated from a single dipping plane within a volume generally shows that only one filter makes a significant prediction, with the other filters being comparatively weak. Since each filter predicts one direction well, the filters are referred to here as directional filters. Thus four filters are used to completely predict the input volume.

The extrapolation of data with four directional filters

Each of the four directional filters is calculated separately on the same input data to produce the best prediction possible with its direction. Incorporating these four filters to create a single predicted result may be done in several ways.

One obvious approach would be to merge the four results by windowing out the bad results at the edges and averaging the results in the center. The problem with this approach is that the poor predictions extend well into the data when a filter cannot predict a particular dip. Averaging the four results simply weakens the best prediction.

Another approach is to minimize a concatenation of $f_1 * d$, $f_2 * d$, $f_3 * d$, and $f_4 * d$, where the fs are the filters, d is the original plus the extrapolated data, and $*$ indicates three-dimensional convolution. Oddly enough, this produced the very poor prediction seen in Figure 4. Originally, this poor prediction appeared to be a program error, but it may be the result of no single result satisfying all four prediction requirements.

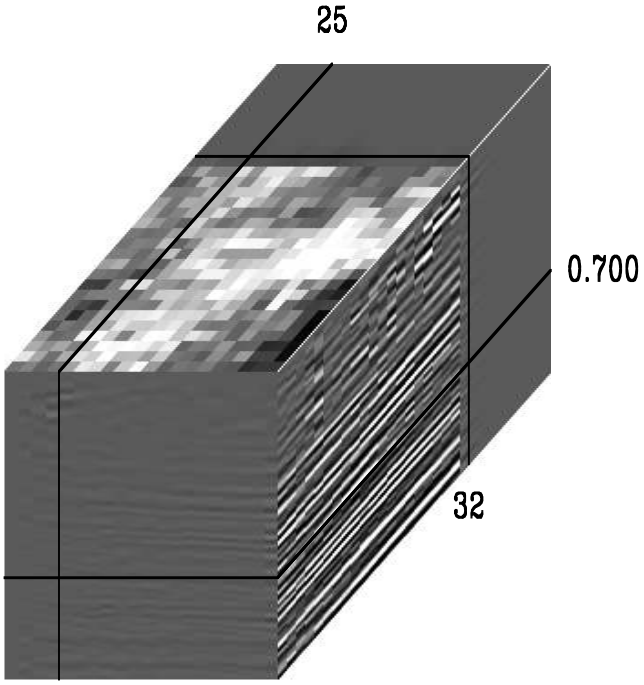

Figure 4: Extrapolation using the concatenation of the results of four directional filters. The poor extrapolation of the data is barely visible. ray2-multiple4 [ER]

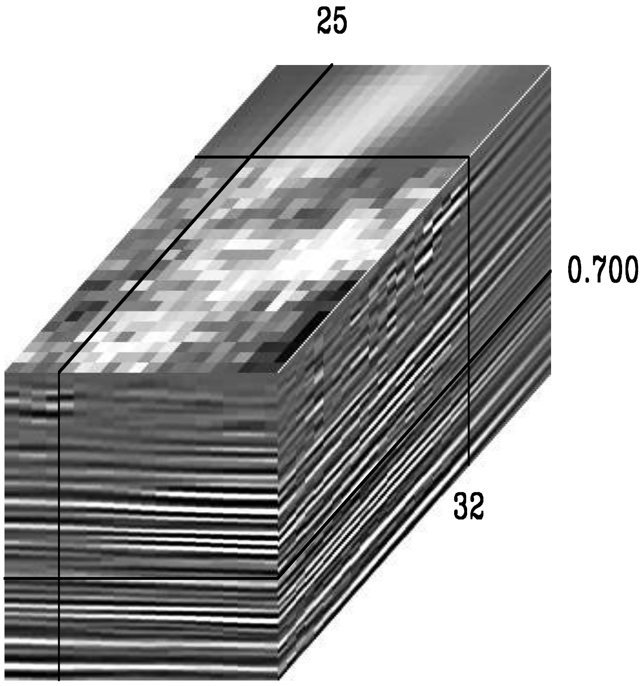

Figure 5: Extrapolation using the sum of the results of four directional filters. The edge effects have been removed and the extrapolation is acceptable. ray2-multiple [ER]

An alternative to the simultaneous minimization of all four results is the minimization of the sum of the results, that is, minimizing $f_1 * d + f_2 * d + f_3 * d + f_4 * d$. This approach appears to produce good results without significant edge effects. The results of this extrapolation are shown in Figure 5. The edge effects have been eliminated and the data have been extrapolated as far as in Figure 3. The quality of the results may be considered surprising, since it might be imagined that the sum of the predictions might work against each other to produce large errors.

While the elimination of the edge effects is still not well understood, a possible explanation is that three of the four filter actions may be ignored, while the filter with the best prediction action extrapolates the data. Bad predictions from the weaker filters are suppressed. Another way of thinking about the result is that the central part of the volume is predicted by a combination of the four filters that can be considered as a single filter with coefficients in all directions. At the edges of the volume, only one or two filters contribute to the output, but these filters do not create bad edge effects. There may be some scaling problems at the edges where changes to the number of contributing filters occur, but I have not yet had the opportunity to investigate this.

CONCLUSIONS

By making predictions with purely lateral prediction filters, the distance the data is extrapolated in space is extended. Although I do not have a firm justification for the use of multiple predictions filters in this preliminary report, they appear to improve the extrapolation quality, especially near the edges of the volume, where very poor predictions are made. These techniques should be placed on firmer foundations before more practical applications are pursued.

REFERENCES

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