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Antialiasing 3D prestack Kirchhoff datuming

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ABSTRACT

Irregular spatial sampling complicates antialiasing. 3D seismic surveys are designed to have even sampling in midpoints, but often have irregular sampling in offset. This presents the difficulty that prestack integral operators may have quite different bandwidth along different axes. 3D prestack Kirchoff datuming can be performed in midpoint and offset coordinates, where the data's dip range can be asssumed to be limited relative to its dip range in shot and receiver coordinates. Operator bandwidth can be preserved for a limited range of dips, even when sampling is quite sparse. A midpoint and offset formulation of Kirchoff datuming is more expensive, but may be necessary to make the operator useful for many 3D geometries.

INTRODUCTION

Sparsity of spatial sampling results in aliased seismic data, and aliased integral operators in data space. Generally the operator is treated with some variety of bandpass which antialiases the operator and largely prevents the generation of spurious events. For example, the triangle filtering applied to Kirchhoff migration in BEI (Claerbout, 1995b) is really a dip-dependent bandpass on the migration hyperbola. In a typical prestack 3D geometry, source and receiver spacings are likely to vary significantly in the inline and crossline directions (button and patch geometry seems an exception, see Chemingui (1996)). It is problematic to bandpass a 3D prestack datuming operator in the case that sampling varies significantly. Varying operator bandwidth means that reflectors with equal dip will be preferentially preserved according to strike. Energy moving across crossline offsets will frequently be bandpassed to irrelevance.

One is free to choose some particular principle time dip at which an operator is not antialiased. In general this is chosen to be zero dip, because the operator will then respect positive and negative dips in the data equally. Where one can make an assumption to limit the data's dip range, the operator can be tuned to preserve higher temporal frequencies than is possible antialiasing relative to zero dip. Performing

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prestack 3D datuming with antialiasing tuned to respect limited dips along the poorly sampled axes can help make up for the sparse sampling. This can not be done safely in shot and receiver coordinates, where any nontrivial geologic structure is likely to create conflicting dips in the recorded data. Prestack seismic data contains only non-negative dips in midpoint and offset coordinates, so the operator is less likely to lose energy. However, the operator becomes more expensive.

In this paper I demonstrate the principle on synthetic 3D data in shot and receiver coordinates, by assuming (nearly) flat reflectors. I then discuss the incomplete extension of this idea to midpoint and offset coordinates, where the flat reflector assumption is unnecessary.

ALIASING & COVERAGE

Considering the degree to which data may be aliased on the crossline offset axis, it is likely that a straightforward bandpass-type antialiasing will force unacceptable cuts in frequency content. However, antialiasing can be tuned to preserve more signal bandwidth, provided that compensating bandwidth can be traded away elsewhere. A threshold frequency for antialiasing may be calculated from:

$$\omega_{\text{threshold}} = \frac{v}{4\Delta x \sin\theta} \tag{1}$$

(Yilmaz, 1987). The θ in equation 1 is measured relative to a vertically traveling plane wave, but some other plane wave may be chosen. In poststack migration, for instance, it is reasonable to assume that data will have a wide range of positive and negative dips, so a principal dip of zero (vertical plane wave) makes sense. In the prestack datuming case, it may be that the range of time dips is limited, depending on the subset of data you are examining. A given source-receiver combination's contribution to the output space will have some optimum principle time dip, which is not necessarily zero. Considering the simple case of a flat earth, it can be seen that shot gather continuation should antialias relative to some plane wave dipping towards increasing offset. In the illustrated case, the outer offset flank of the datuming hyperbola contributes to constructing the reflection hyperbola. The inner offset flank contributes only to destructive interference with other inner offset flanks. Choosing a particular hyperbola flank is like choosing shot and receiver take-off angles. Preserving the inner offset portion of the hyperbola is like preserving energy which has divergent take offs (see Figure 1). The ray approaching the receiver from the side opposite the source makes sense in the case of a strongly dipping reflector.

The operator impulse response, antialiased with respect to a horizontally travelling plane wave, is shown in figure 2. Turning the plane wave horizontal is overkill, but it illustrates the principle plainly. It also illustrates an important point related to the interaction of the inline and crossline directions. Compensating for sparse sampling in the crossline direction by changing the principal dip should not interfere with the well sampled inline direction. A vertically travelling plane wave and a plane wave

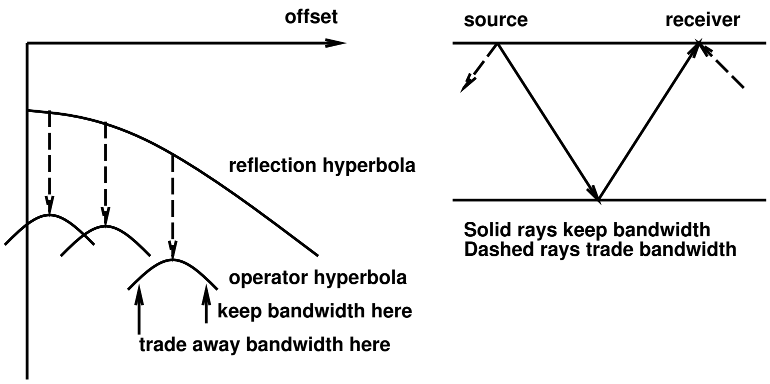

Figure 1: For simple earth models, the principal dip for antialiasing purposes can be chosen to favor the increasing offset portion of the operator hyperbola. sean1-simp-pic [NR]

travelling horizontally in the crossline direction are an equal ninety degrees from a wave travelling in the inline direction.

A simple 3D synthetic shot gather is shown in Figure 3. Here the crossline receiver spacing is four times the inline spacing. It is easy to see that the reflection event is mildly aliased in the inline direction, and severely aliased in the crossline. The gather is shown in Figure 4 after upward continuation. Note that there is a noticeable event other than the reflection; this is the upward continuation of a modeling artifact, visible in the original. Also note that the data still contain frequencies above the spatial nyquist.

Conflicting dips created by negative offset (acquisition geometry) do not create a problem, because each input trace is a separate experiment and may be antialiased with a particular principle time dip, so long as that dip corresponds to an energetic part of the wavefield. However, conflicting dips in the data due to dipping reflectors in the earth do create a problem. This energy propagates through the most strongly antialiased part of the datuming hyperbola, and so will lose a great deal of energy and bandwidth.

Changing to midpoint and offset coordinates allows one to safely favor positive dips. However, the operator is no longer separable along the two axes, so it is considerably more expensive to apply. Also, the optimum principle time dip becomes a relatively complicated function of input offset, output offset, midpoint dip, and time, as illustrated to some degree in Figure 5. Some optimum time must be chosen based on shot and receiver geometries.

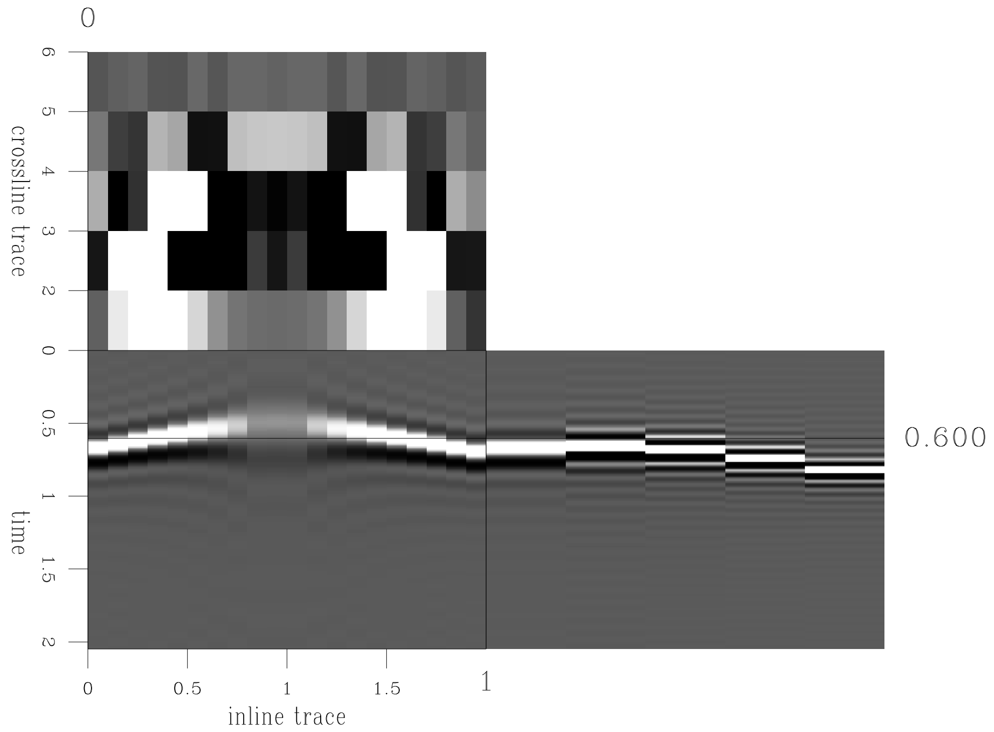

Figure 2: Antialiased operator impulse response. $\boxed{\text{sean1-imp}}$ [CR]

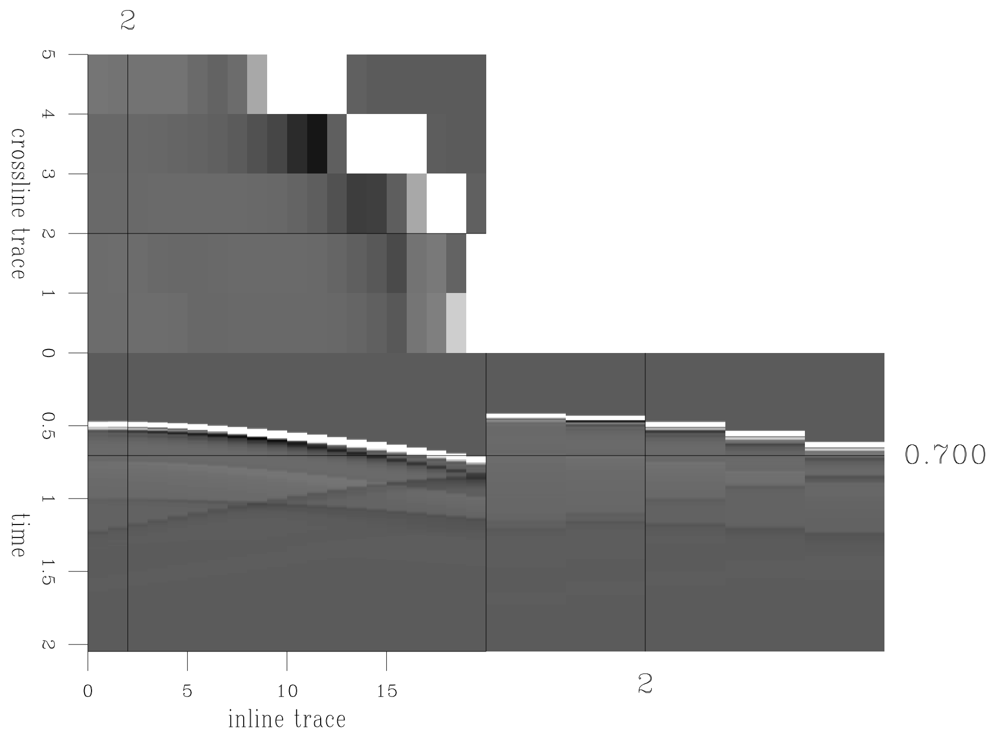

Figure 3: 3D synthetic input. The crossline direction is subsampled relative to the inline. $\boxed{\text{sean1-synth3din}}$ [CR]

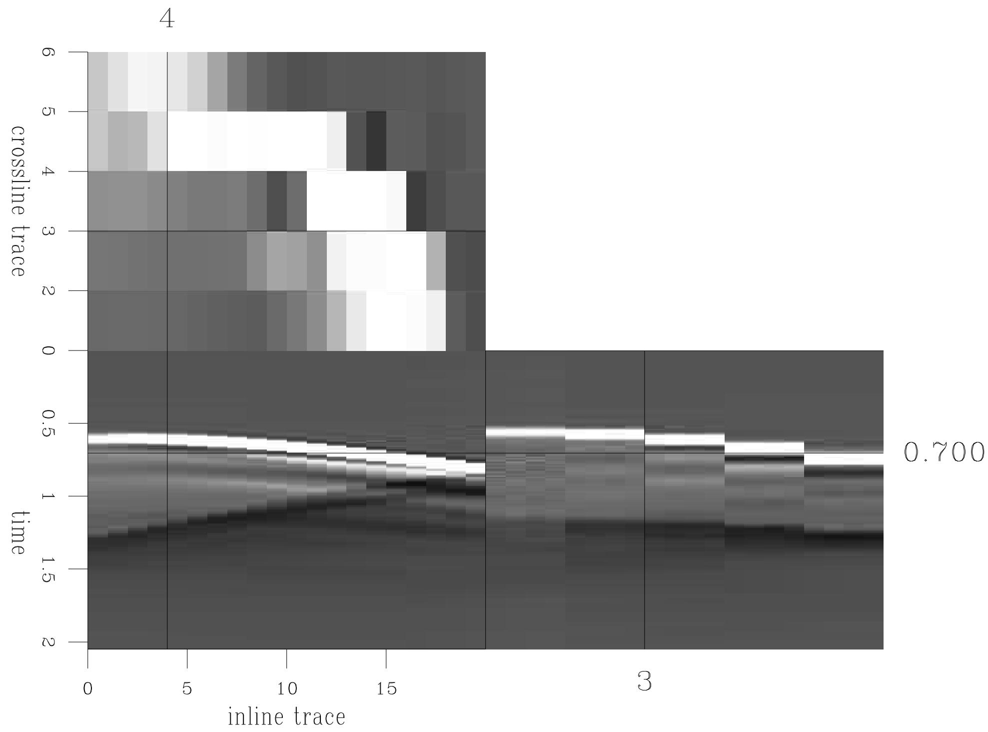

Figure 4: The 3D synthetic after upward continuation. Some crossline bandwidth is preserved, without generation of artifacts (though a modeling artifact -the black event dipping to the left- has been exacerbated). sean1-synth3dout [CR]

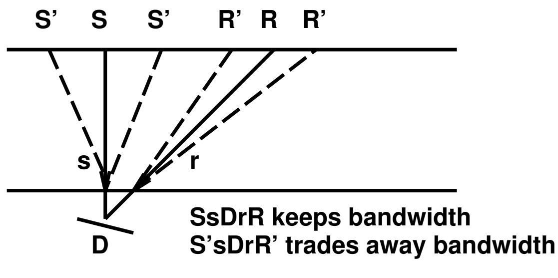

Figure 5: In midpoint and offset, the optimum principle time dip is a function of midpoint dip and offsets. sean1-comp-pic [NR]

CONCLUSION

Prestack Kirchhoff datuming is difficult in 3D, because recording geometries are such that it is likely not obvious how to antialias the operator. Because shot and receiver spacings are often significantly different along different spatial axes, bandpassing the operator will effectively suppress all energy moving in the poorly sampled directions. Operator bandwidth can be safely increased, and frequencies preserved above the spatial nyquist, for a limited range of time dips. Diffractors and dipping reflectors create conflicting time dips in shot and receiver profiles, but not in common midpoint gathers, so we should be able to preserve some reasonable bandwidth by datuming in midpoint and offset. Reformulating the datuming operator in midpoint and offset adds complexity and computational expense, but will hopefully also add considerable utility. This is an easy concept to illustrate with shots and receivers; making a more general, useful operator, in midpoints and offset, is the next challenging step.

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