Why “unique fold” is a poor concept

Gijs J. O. Vermeer, 3DSymSam – Geophysical Advice

In this note I discuss the concept of unique fold and why it is not useful for guiding the choice of survey design parameters.

Introduction

Every now and then the concept of “unique fold” is popping up. Whereas fold or fold-of-coverage is defined as the number of traces in a bin, unique fold in a bin may be smaller than the actual number of traces in a bin. Unique fold is associated with absolute offset[1]. If the absolute offsets of pairs of traces differ less than a given distance from each other, unique fold is reduced by one, because those traces are deemed to contribute the same information to the final data set. A main reason to use this concept has been that traces with nearly the same absolute offset contribute similar shot-generated noise to the stack; hence such pairs of traces are likely to produce a significant acquisition footprint.

In this note I argue that all traces in a regular acquisition geometry are unique, despite any nearness of pairs of absolute offsets. Discarding traces because they are deemed to be not unique turns the geometry into an irregular geometry, which is much less desirable. I illustrate this with an analysis of a regular example geometry. Another application of unique fold is to judge the quality of infilling when some shots and/or receivers cannot be put at their nominal positions. However, the suitability of infill traces for the final migrated data can better be judged in other ways.

Unique fold in regular acquisition geometry

In a well-sampled orthogonal geometry the combination of field arrays and velocity filtering of the cross-spreads will take care of most direct-arrival ground roll. For such a geometry it is no longer necessary to rely on stacking for noise suppression and the acquisition footprint will be negligible (although S/N always depends on fold as well). Prestack noise suppression is the way to get rid of the noise; therefore, after noise removal, traces in the same bin with nearly the same absolute offset will never have significant noise residuals. Discarding traces to reduce the acquisition footprint is no longer necessary (if it has ever been). On the other hand, each trace in a regular geometry has its own unique purpose and should not be discarded as the following arguments show.

The example orthogonal geometry has shot and receiver sampling intervals of 40 m, shot and receiver line intervals of 400 m, and maximum inline and crossline offsets of 4000 m. Figure 1 shows total fold as it varies across the geometry. In the full-fold area of the geometry total fold equals 100 and it tapers to zero along the edges of the survey area. In the full-fold area of the geometry the unit cell (area between two adjacent shot lines and two adjacent receiver lines) corresponds to the periodicity of the geometry. Therefore, it is sufficient to investigate the behavior of one unit cell only. Figure 2 shows unique fold for all 20 x 20 = 400 bins inside the unit cell. Here traces with their difference in absolute offset < 10 m have been deemed to be redundant. Most “redundancy” occurs along the diagonals of the unit cell with unique fold as low as 52. Elsewhere unique fold varies from 82 to 97.

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[1] A broader definition of unique fold is given in Gedco (2012).

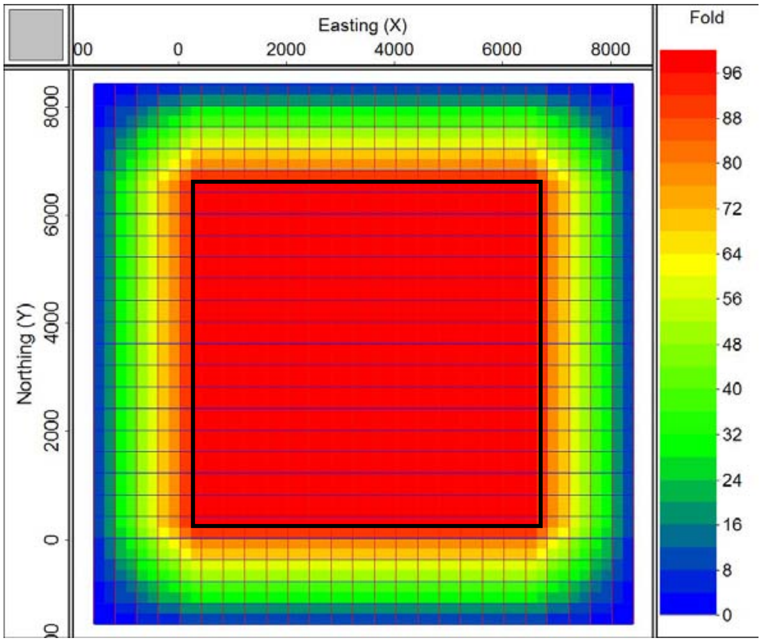

Fig. 1. Fold of example orthogonal geometry with 400-m line intervals. The black square outlines the full-fold area of the geometry.

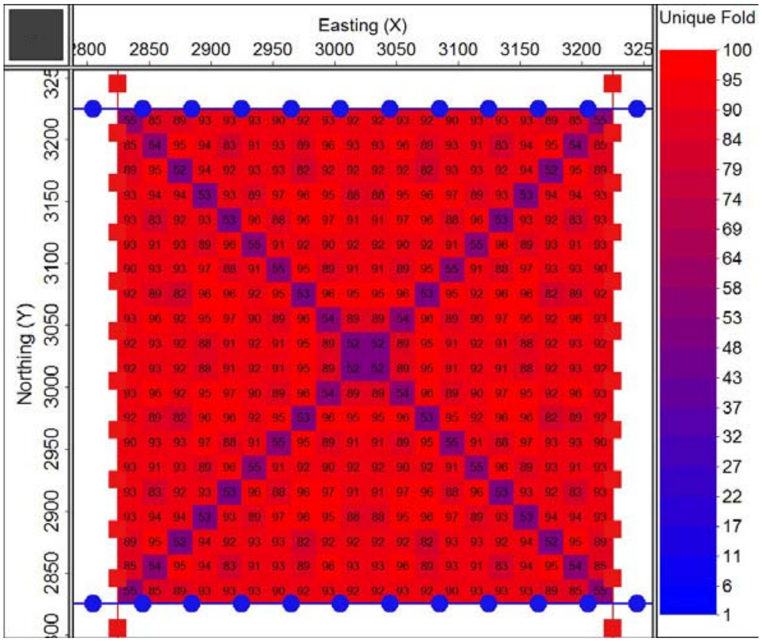

Fig. 2. Unit cell of example geometry with unique fold specified in each bin. Note low unique fold along diagonals of unit cell. Total fold in each bin is 100.

Figure 3 highlights the offset distribution in two neighboring bins. Figure 3a for a bin along the diagonal of the unit cell, and Figure 3b for a bin adjacent to the other one. The big number in the displays represents unique fold. The small colored circles in a 10 x 10 pattern describe the offsets of the 100 traces in each bin, with inline offset and crossline offset along the horizontal and vertical axis, respectively. Constant absolute offset in this display is represented by a circle with center at the zero-offset position. This means that the small circles of a pair of traces with absolute offset difference < 10 m will be within 5 m of the same absolute offset circle. Some of those pairs will lie in opposite quadrants of the offset-vector domain, these traces are nearly reciprocal with respect to each other (but they never are exactly reciprocal in a regular geometry). Other pairs will lie in adjacent quadrants; these pairs of traces have different azimuths; hence may have illuminated quite a different point in the subsurface, depending on the dip of the geology. Yet other pairs of traces may lie in the same quadrant, these pairs of traces may have similar but also very different azimuth. Yet, for all pairs of traces with absolute offset difference < 10 m, the recorded coherent noise may be almost the same. Gedco's Omni has ways of refining the unique fold calculation by also looking at azimuth. However, forget about it, it's all regrettable rejection of valuable traces as discussed below.

Imaging of regular acquisition geometry

In poststack migration, the main criteria for successful migration of a stacked data set are that

1. There should be one trace in each bin (is almost the case per definition), and
2. There should be no sudden trace-to-trace variations in the data set (i.e., no spatial discontinuities; otherwise migration smiles will be generated from those spatial discontinuities).

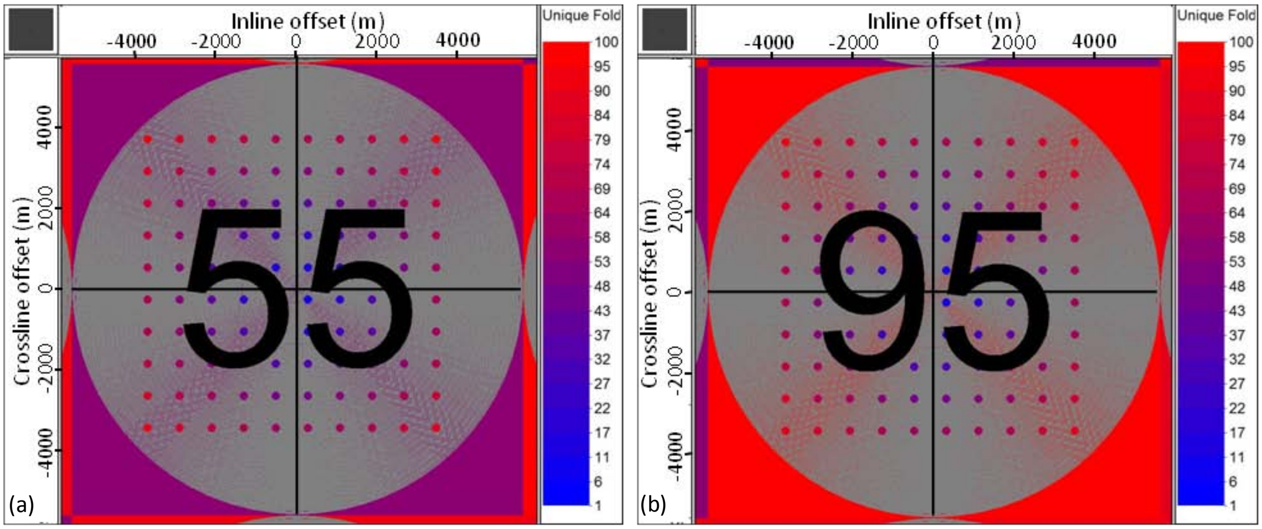

Fig. 3. Unique fold in two adjacent bins. a) bin on diagonal of unit cell, b) bin adjacent to bin in a. The small colored circles in each bin represent the offset coordinates of the 100 traces. Note that removing so-called redundant traces (45 rejected traces in a, 5 in b) would disturb the cube of data corresponding to the 100 traces. Each trace corresponding to a small colored circle belongs to one of the 100 OVT gathers (discussed below) of the regular geometry.

Ideally, the stack should be as close as possible to a zero-offset data set, but this is never achieved. More accurate migrations can be carried out by using the actual shot- and receiver coordinates that made up the data set. To acknowledge the true shot- and receiver locations, prestack migration should be carried out.

Now other criteria for optimal prestack migration may be formulated in analogy to the above criteria for poststack migration. First split the data of an *M*-fold geometry into *M* single-fold data sets. Then the criteria are that

1. Each single-fold data set should have one trace in each bin (except along the edges of the survey area), and
2. There should be no sudden trace-to-trace variations in the data set (i.e., no spatial discontinuities; otherwise migration smiles will be generated from those spatial discontinuities).

Splitting the data of an *M*-fold geometry into *M* single-fold subsets may be achieved in a huge number of different ways. However, there is only one way of splitting that gives the best solution to the above criteria. This way is splitting into data sets that look as much as possible like common offset-vector (COV) gathers. This method is called offset-vector tiling (OVT) into OVT gathers, (or pseudo-COV gathers, also known in the industry as COV gathers). For a detailed discussion of these OVT gathers and their use in imaging see Vermeer, 2012, and many other papers.

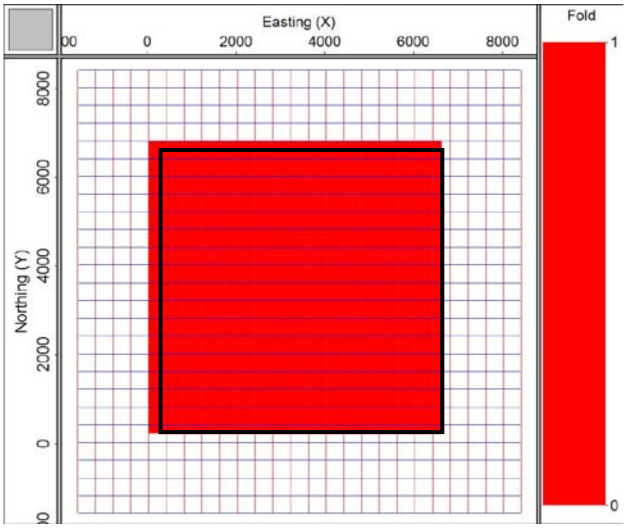

Fig. 4. OVT gather for inline and crossline offsets 3200 – 4000 m (bottom right hand corner of the cross-spreads). The black square outlines the full-fold area of the geometry.

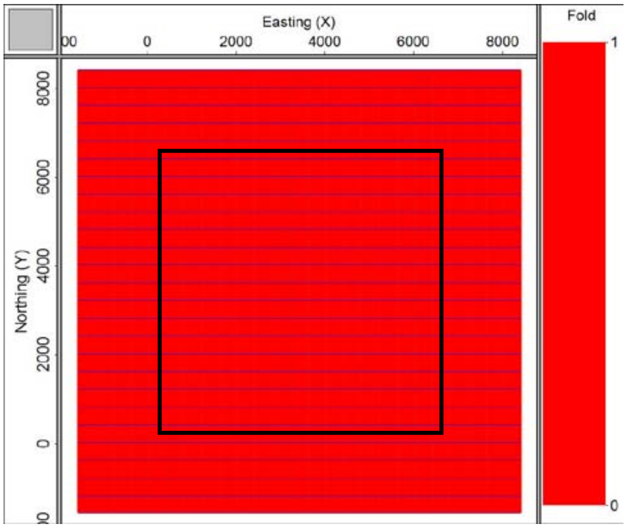

Fig. 5. OVT gather for inline and crossline offsets -400 – 400 m (central area of the cross-spreads). The black square outlines the full-fold area of the geometry.

The 100-fold example geometry must be split into 100 OVT gathers. For this purpose the 4000 x 4000 m midpoint area of the cross-spread of the geometry is split into 10 x 10 = 100 tiles. Each tile has a limited range of offsets and azimuths and has a size 400 x 400 m, the same size as the unit cell in Figure 2. The offset range in each tile is always twice the dimension of the tile; therefore across each tile both inline offset and crossline offset vary over 800 m. Figure 4 illustrates the OVT gather for (signed) inline offsets and crossline offsets varying from 3200 – 4000 m (this is the tile in the bottom-right hand corner of the cross-spread). The tile for this gather consists of long inline and long crossline offsets only; the corresponding midpoints only occur in the full-fold area of the geometry. Short-offset gathers may be constructed as well of course, an interesting one is the tile with inline and crossline offsets ranging from -400 m to +400 m. The corresponding OVT gather is shown in Figure 5. It covers the whole survey area.

It is clear that OVT gathers do not really satisfy the second criterion mentioned above. Inside each tile there is complete spatial continuity, but at the tile boundaries spatial discontinuities exist, because the smallest inline/crossline offsets in one tile are adjacent to the largest inline/crossline offsets in the next tile. There are two ways to mitigate the effect of those spatial discontinuities. First, reciprocal OVTs (OVTs mirrored between opposite quadrants) mitigate each other's spatial discontinuities and corresponding illumination irregularities (Vermeer, 2012, Ch. 10). The more expensive solution is to reduce the line intervals of the geometry; this produces smaller sized unit cells, hence smaller sized OVTs. The smaller the line intervals the better it is for the geometry.

Imaging and unique fold

If traces of a regular geometry are considered redundant because their absolute offsets are nearly the same, then discarding the redundant traces would lead to empty bins in the OVT gathers. Especially the diagonals of each tile would show many empty bins giving rise to migration artifacts. All those redundant traces are in fact traces we bargained for, and should be used for optimal imaging results. *Noise removal should not be done by removing complete traces, but by some filtering operation that leaves primary energy intact.*

This reasoning applies always. Also if prestack migration is not carried out using OVT gathers, complete and regular data sets should give the best results. The main reason for this is that if the same algorithm is used for migrating OVT gathers followed by stacking and for migrating just all data in one go, the end result is identical or close to identical. Discarding "redundant" traces leads to fold variations and such variations will cause amplitude irregularities.

Practical consequences for survey design and processing

The ideal acquisition geometry is regular with no variation of fold in the full-fold area of the geometry. In practice, this is never achievable. However, knowing what is best for the final data leads to better solutions for survey design (for instance, never use full-swath roll, unless you have designed the geometry for redundancy of data), and should translate in processing choices to generate as much as possible the regular geometry that was designed in the first place. Such regularization and interpolation may be carried out in OVT gathers.

Unique fold and infilling

One of the practical problems may be that in certain parts of the survey area shots cannot be taken and/or receivers cannot be laid out. Then it is often attempted to find alternative shot and/or receiver locations to mitigate the effect of the missing data.

Millis and Crook (2012) use unique fold to judge the quality of the final infilled data for an area where shots are not allowed/possible. On basis of their analyses, they argue that adding extra receivers inside the no-shot area is better than adding shots along the outside of that area. In fact, this result may well have general value; however, judging on basis of unique fold only has questionable merit. (If azimuth is included in the definition of unique fold, the inline/crossline offset distribution of traces in the resulting bins may be used to judge the ability to interpolate to a regular grid inside each bin, see Figure 16 in Millis and Crook, 2012.) With the analysis of unique fold, one focuses on the effect of noise in bins, but the more general requirement of spatial continuity (from bin to bin) is not given any attention.

Spatial continuity may be achieved in two different ways, either by ensuring optimal spatial continuity of the infill data taken together with the existing data, or by ensuring that the infill data taken together with the existing data allow the construction of spatially continuous data by interpolation.

Therefore, my suggestion is to analyze the effect of infilling using the OVT gathers of the geometry. How can we use the infilled data to regularize the holes in the OVT gathers? This is an area for further research.

Conclusion

This note argues that all data of a regular geometry are there to be used. There are no redundant data; hence the concept of unique fold should not be applied to regular data. Unique fold (defined for absolute offset only) is not a good criterion to judge the quality of infill data, because it does not say anything about the spatial continuity of the final data. A better way might be the use of OVT gathers in combination with a judgment on the suitability of interpolation to a regular data set. This is an area for further research.

References

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Millis, K., and A. Crook, 2012, The benefits of receiver infill stations: A technical case study: CSEG Recorder, **37**, no. 7, 48-56.

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Acknowledgment

The analysis in this note was carried out with the Omni 3D package of Gedco.