An implementation of 3-D seismic binning

Mark C. Lane

ABSTRACT

The process of binning 3-D seismic data is simplified if one transforms from the survey's spatial coordinates to a binning coordinate system. For uniform rectangular bins this transform, along with an integer truncation, is all that is needed to assign bins for a survey.

INTRODUCTION

When a multi-fold 3-D seismic survey is acquired, a major step in its processing is the assignment of each seismic trace to an areal bin. Bins represent local areas on the Earth's surface which are used to collect traces for stacking, processing or analysis. Due to the two dimensional nature of 3-D seismic survey geometries, locations of interest generally do not fall on a set of surface points, but tend to scatter throughout the survey area. I will consider binning as the act of asserting that a group of traces contains a common geometrical property, usually that of being close to the same CCP, CMP, shot or receiver position. I will consider the case of a binning system defined by the boundaries of a uniform rectangular grid. All traces whose surface locations fall within the same cell of this grid will share the same bin. It is useful to work within a local bin coordinate system in lieu of the global or acquisition coordinate system. A beneficial side effect of transforming to an appropriate local bin system is that it can render the process of binning as simple as integer truncation.

THE BIN COORDINATE SYSTEM

Consider a 3-D seismic survey whose locations we desire to bin. If the survey was acquired with a geometry approximating a uniform grid, it may be advantageous to transform some or all of the survey points into a local coordinate system aligned with the acquisition grid. Assuming planar geometry, a linear transform can be used to map survey locations to a local coordinate system. For the sake of illustration, I will call the global system (E,N) to reflect Easting and Northing and the local system (B1,B2), for Bin system. Figure 1 illustrates these systems with surface locations of interest from a hypothetical survey.

The transformation of measurements from the (E,N) system to the (B1,B2) system can be performed as follows. Translate the origin of (E,N) to that of (B1,B2), then rotate this system so that E points in the same direction as B1 and N points in the same direction as B2.

Having performed these operations, it is trivial to bin the data by the simple expedient of scaling this coordinate system as follows. Lines of constant B1 and B2 define a uniform, rectangular grid suitable for binning (Figure 2). Now, if this coordinate system is scaled by the inverse of the bin sizes, in their respective directions, the spacing between bin centres, parallel to each axis, is unity. Figure 3 shows a such few bins. The bin centres fall on integer values of B1 and B2 while the bin boundaries lie halfway between integers. Note that points between the square defined by (-0.5,-0.5) and (+0.5,+0.5) fall into bin A, which I designate as bin (0,0), and in general, points in the square between (M-0.5,N-0.5) and (M+0.5,N+0.5) fall within bin (M,N), where M and N are the integer portion of B1 and B2, respectively. So B is in bin (1,0), C in (0,1) and D in (1,1). These bin centre coordinates can be used as ordered pairs of integers to define unique bin numbers for a survey of unlimited size. I will use the term 'bin number' to refer to one or both of the elements of this ordered pair. To implement this binning, for positive bin numbers, we can shift the coordinate system by (-0.5,-0.5), then truncate to integers the (B1,B2) values to get (M,N) bin numbers. For negative bin numbers, the system can be shifted by (0.5,0.5) and these values truncated. However, it is common to use only positive bin numbers in a survey, so this latter shift can be avoided.

With this system bin numbers change by one when crossing grid boundaries.

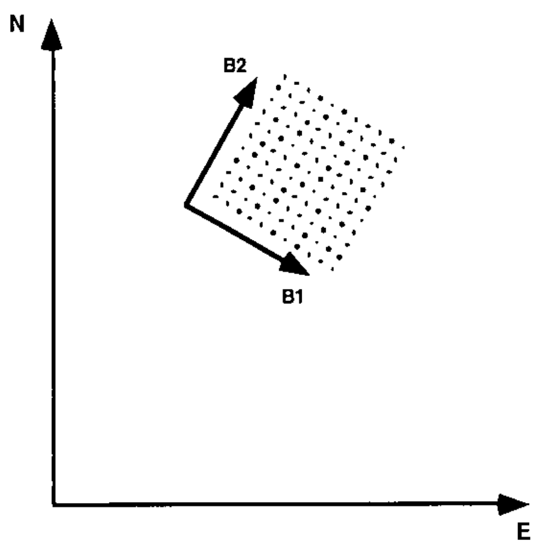

FIG. 1. Survey points of a 3-D seismic survey and the global (E,N) and local (B1,B2) coordinates systems of measure.

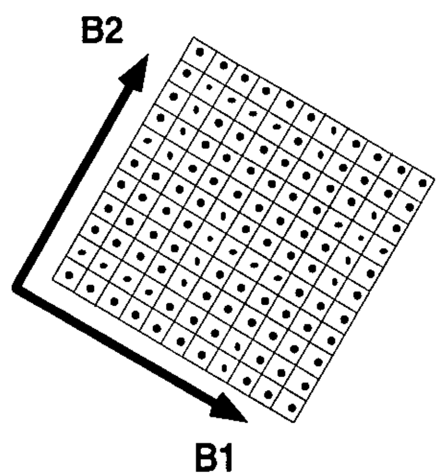

FIG. 2. Survey points of a 3-D seismic survey in the local (B1,B2) coordinate system showing a binning grid defined by lines of constant B1 and B2.

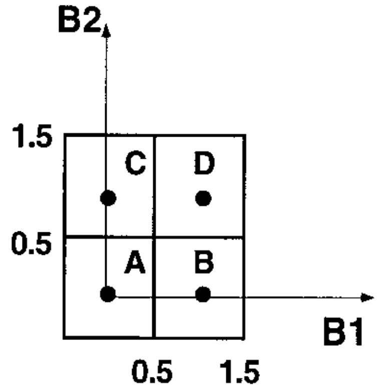

FIG. 3. Survey points of a 3-D seismic survey in the local (B1,B2) coordinate system showing details of a binning grid defined by lines of constant B1 and B2.

In order to implement a numbering scheme where bin numbers increase by an amount other than unity when crossing bin boundaries, or if it is desired to start numbering from another origin, a simple scaling or translation, respectively, of the coordinate system would suffice.

Some may prefer to have a single natural number to represent each bin. If all the required points are located in the first quadrant of the binning system this can be done, as is conventional, by restricting the grid's dimension in at least one dimension. Numbers are then assigned sequentially along that restricted axis until that dimension's limit is reached, then moving by one bin parallel to the other axis and continuing the numbering. For example, if the survey is restricted in the B1 direction, the new bin numbers would be (N-1)*(MaxM) + M, where MaxM is the maximum M in the grid along B1. However, it is not necessary to put this restriction on the grid. The (M,N) system retains more information and can be used for all processing. As well, all pairs of natural numbers can be easily and uniquely mapped into natural numbers (Lewis and Papadimitriou, 1981, p23). Thus restricting the grid size is not required by the binning process, and if an (M,N) binning system is used, new traces may be added at any time after the grid is defined, without requiring any changes to the grid.

There are at least two ways to implement this binning technique. The first is to calculate the points of interest in the global system, then to transform them via translation, rotation, scaling, translating again, and integer truncation. This yields bin numbers directly. For example, this could be used for CCP or CMP locations, which are calculated during the data processing stage. Alternatively the whole input survey, including shot and receiver locations, could be transformed into the binning system and then CMP or CCP locations computed using these transformed positions. Simply truncating these computed values to integers would yield unique bin numbers.

I have implicitly assumed here that assigning a bin number to each trace defines the binning process. For the non-overlapping, uniform, rectangular binning grid discussed here, this, in conjunction with the binning system specification, contains all the information required to bin the data for further processing. However, it should be obvious that even if overlapping, or non-rectangular bins are used, the bin coordinate system is a natural one in which to work. It is left as an exercise to the reader to think of other transforms, for example including shearing, which would map more complex survey coordinates onto a uniform grid.

COORDINATE TRANSFORMATION IMPLEMENTATION

In the field of computer graphics, procedures for transforming objects through translation, rotation and scaling are used regularly and are well understood (Foley et. al., 1990). Coordinate system translations, rotations and scalings can all be implemented by matrix multiplication, provided that they are expressed in homogeneous coordinates. For our purposes this means using a special 3x3 matrix instead of a 2x2 matrix to represent the transformations. This matrix has a bottom row consisting of [0 0 1]. Using this, translations can be represented as the matrix-vector multiplication

$$\mathbf{B} = \mathbf{T} \bullet \mathbf{G},$$

where the coordinates in the local system are

$$\mathbf{B} = \begin{bmatrix} Bx \\ By \\ 1 \end{bmatrix},$$

the coordinates in the global system are

$$\mathbf{G} = \begin{bmatrix} Ex \\ Ny \\ 1 \end{bmatrix},$$

the translation matrix is

$$\mathbf{T} = \begin{bmatrix} 1 & 0 & Tx \\ 0 & 1 & Ty \\ 0 & 0 & 1 \end{bmatrix},$$

and Tx and Ty are the translation values.

Similarly, rotations can be represented by

$$\mathbf{B} = \mathbf{R} \bullet \mathbf{G},$$

where

$$\mathbf{R} = \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

and θ is the angle of rotation, and scaling by

$$\mathbf{B} = \mathbf{S} \bullet \mathbf{G}$$

where

$$\mathbf{S} = \begin{bmatrix} Sx & 0 & 0 \\ 0 & Sy & 0 \\ 0 & 0 & 1 \end{bmatrix},$$

and Sx and Sy are the scaling factors.

These transformations may be concatenated by simple matrix multiplication to form a new matrix. This new matrix contains the total coordinate transform. Multiplying a vector from the global system, say representing a CCP location, by this matrix performs the whole binning operation, yielding a bin number for the trace which produced that CMP location. For example, in order to bin a CCP location, first a total transformation matrix would be calculated as $\mathbf{F} = \mathbf{T}_3 \bullet \mathbf{T}_2 \bullet \mathbf{S} \bullet \mathbf{R} \bullet \mathbf{T}_1$. Here, reading from right to left, $\mathbf{T}_1$ translates the origin of the global system to coincide with the origin of the local system, **R** rotates this system to bring its axes in coincidence with the local system, **S** scales the system so that bin boundaries are spaced by unity along the axes, $\mathbf{T}_2$ translates so the centre of the bin (0,0) is on the origin and $\mathbf{T}_3$ translates so that the bin numbers start at non-zero values. Then, each CCP is computed in the global system, multiplied by **F**, and the new value's non-integer portion is discarded, yielding the proper bin numbers.

It is important to realise that the transformation is only calculated once for a given binning grid, then applied to each location to be binned. Thus, overall, computation time to derive **F** is essentially insignificant. An important property of concatenating these transforms in homogeneous coordinates is that the bottom row is always [0 0 1]. Thus, in order to transform each location, only four multiplications and two additions are required to perform matrix-vector multiplication.

CONCLUSIONS

A linear coordinate transformation, as is used in computer graphics, can be used to implement fast binning of 3-D seismic surveys. Due to the use of homogeneous coordinates, this transformation is computationally efficient.

REFERENCES

Lewis, H.R., and Papadimitriou, C.H., 1981, Elements of the theory of computation: Prentice-Hall, Inc, N.J.

Foley, J.D., van Dam, A, Feiner, S.K., Hughes, J.F., 1990, Computer graphics: principles and practice 2ed.: Addison-Wesley Pub. Co., U.S.A