Coherence and measures of coherence: An advanced 3D interpretive processing application

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In 1994, an annual report to shareholders by an international oil company highlighted a new method of detecting, imaging, and autotracking faults and stratigraphic features that has immediate and significant impact as reflected by reserves. Subsequently, the company filed patent requests for a method of processing seismic data for the purposes of imaging seismic discontinuities including faults and stratigraphic features. On October 8th, 1996, the U.S. Patent Office issued a patent, the Coherence Cube™ to Amoco Corporation for this method of seismic signal processing and exploration. This non-interpretive process results in a 3D data volume, or 'cube', of coherence coefficients, within which faults are revealed as numerical separated surfaces. In essence, the method takes a 3D data volume, divides it into 3D cells, computes the coherence/similarity of seismic traces with the cells, assigns the computed coefficient in the prescribed location, and, display the numerical coefficients in a map form. In the case of a time-amplitude data volume, breaks in the continuity of reflectors that have been interpreted as faults, are now replaced by numerically defined surfaces of low coherence. 3D numerical data mapping, constrained by a region of influence is not new, and have found wide uses in other industrial applications. The novelty of this approach here instead is the display of the computed coefficients using a reverse scale. Fault patterns and other stratigraphic features thus derived can now be compared alongside time-amplitude data for a clearer geological synthesis.

This study examines some properties of coherence and measures of coherence. The purpose of this review is to lay a basis for subsequent discussion of coherence applications in the papers to follow. This is deemed useful as a cursory look at the geophysical literature suggests that terms used with equivalent meaning as coherence are sample coherence, cross-correlation spectrum, coefficient of coherency, coherency and coherence spectrum.

In the physical sciences coherence is often described as the condition necessary to produce interference; interference being explained as an interaction of waves that are 'coherent'. Two waves can travel in space along the same path but at slightly different times or at the same time but at some distance from one another. Introduced by Norbert Wiener in 1930, the coefficient of coherence is defined in terms of power and cross-power spectra. It is related to the signal-to-noise ratio, to the minimum prediction error, and has important invariance properties. Let $x(t)$ and $y(t)$ be the input and output of a constant parameter linear system. The coherence function assumes a value of one for complete identity and zero if $x(t)$ and $y(t)$ are completely unrelated. In the intermediate range, one or more of the following conditions may exists; (i) extraneous noise is present, (ii) the system is not linear, and (iii) $y(t)$ is an output due to an input (x) as well as to other inputs. For q defined inputs and a single output, the multiple coherence function measures the fraction of power accounted for in the output from a simultaneous linear filter relationship with the input.

The coefficient of coherence introduced by Wiener is closely related to the statistical concepts of correlation and regression; the cross-spectral density function is a decomposition of covariance and the power spectral density function, a decomposition of variance. Alternative measures of coherence can now be formulated in terms of the cross-correlation functions. Complexity of these attributes range from the simple stacked amplitude to the normalized output-to-input energy ratio or semblance. Covariance and correlation structures can also be analysed by fitting planes using orthogonal least squares based on the Hotelling (Karhunen-Loeve) Transform. The technique for finding this transformation is called principal component analysis. Coherence is expressed as a function of the eigenvalues and eigenvectors of the covariance or correlation matrix. By transforming correlated variables into uncorrelated ones, the method effectively looks for linear combinations with relatively large or relatively small variability i.e. if some of the original variables are highly correlated, they are effectively 'saying the same thing' or we can effectively reduced its dimensionality.

Coherence and measures of coherence is an advanced 3D interpretive technology and provides an alternative paradigm to conventional seismic interpretation. Derived from raw seismic data it is also subjected to all compromises made in seismic acquisition and processing. A choice of measures of coherence are available for generating a 'coherence data volume', viz cross-correlation, semblance, eigendecomposition. This exercise in trying to understand better the science of coherence allow us to be a better informed consumer.