**Finding and exploiting correlations between 3D seismic, log, and engineering data using machine learning**

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**Abstract**

One of the key objectives of seismic interpretation is to correlate the spatially sparse, but detailed, “hard” data measured by well logs, core, and at the well head to the more densely sample, lower vertical resolution, soft data provided by 3D seismic volumes. Initially, such correlations consisted of simply tying the seismic data to the well log tops. More modern workflows consist of constructing rock physics property templates against elastic parameters measured by the electric logs and core and then applying the resulting probability density functions to the elastic volumes computed from the 3D seismic data to predict 3D property volumes.

The key to such prediction is to establish some type of correlation between a property or feature of interest and the seismic data. The correlation between a feature of interest and the seismic response can be either indirect or direct. For example, natural fractures can be indirectly predicted, or inferred, to be more likely if a candidate rock layer is more brittle, is closer to a fault, is strongly folded, or is relatively thin. In contrast, natural fractures may directly influence the seismic response, giving rise to azimuthal anisotropy, geometric scattering, decreased impedance, abnormal attenuation, or shear-wave splitting. In both cases, the correlations are established within the context of structural deformation and perhaps a specific tectonic model.

Machine learning can be used in three modes. In the simpler mode, the interpreter hypothesizes (based on geomechanical, depositional, diagenetic, and tectonic models) correlations between a property of interest (e.g. fractures), and a suite of seismic attributes (e.g. coherence, curvature, impedances, and azimuthal anisotropy). The “algorithm” then quantifies the relationship, allows it to be validated, and then applies the relationship to the 3D volume. In the second mode, the interpreter does not know the correlation between the property of interest and the seismic attributes. In this case, the interpreter conducts “exploratory data analysis” to determine which combination of attributes might predict the property. In the ideal case, the interpreter “discovers” a previously unsuspected relationship but can then explain it using a deeper understanding of the geology. One such relationship is that of high TOC and high quartz in several of the shale resource plays, where they are “correlated” through the deposition and preservation of kerogen-rich Radiolaria in anoxic deep-water environments. In my opinion, correlations where no physical or geologic basis can be established require greater statistical significance in order to make a valid prediction. The third mode which has received a great deal of attention in the general market place, involves “deep learning.” In this scenario, the interpreter doesn’t apply any attributes at all, but rather simply supplies the seismic amplitude volume and the desired output (seismic facies, geologic facies, or rock types) to be predicted. Using a technique called convolutional neural networks, deep learning implicitly generates “attributes” (relationships at deeper hidden layers) upon which it works. Deep learning requires an immense amount of training data. Unlike the vendors of *Shazam*, who can buy millions of songs for one dollar each from the Apple Store, gaining access to proprietary well logs, production data, and seismic volumes will be challenging for the oil and gas industry for both licensing and financial reasons.

My prejudice is towards the more traditional, attribute-based machine learning workflows, which is called (pejoratively by some) “shallow learning”. Shallow learning requires “deep thinking” and careful geopsychological analysis of experienced interpreters. Interpreters have been quite successful in using the “pattern” in a vector of attributes at a given voxel to predict geomechanical behavior. In contrast, computer assisted delineation of a progradational package is much more difficult, where the human interpreter examines the feature of interest within a depositional framework (or context) of what is above, below, and to the sides of the feature. In computer science, we now enter in the more difficult arena of “scene analysis”.

In this presentation, I’ll review what I think are relatively easy and some of the more difficult tasks in seismic facies analysis. I will then focus on tasks I believe will be of economic importance in the exploitation of resource plays, showing predictions using a proximal support vector machine of the rate of penetration and the number of bit trips to 3D seismic geomechanical and texture attribute volumes for a Woods County, Oklahoma Mississippi Lime survey.

**Kurt J. Marfurt** joined The University of Oklahoma in 2007 where he serves as the Frank and Henrietta Schultz Professor of Geophysics within the ConocoPhillips School of Geology and Geophysics. Marfurt’s primary research interest is in the development and calibration of new seismic attributes to aid in seismic processing, seismic interpretation, and reservoir characterization. Recent work has focused on applying coherence, spectral decomposition, structure-oriented filtering, and volumetric curvature to mapping fractures and karst with a particular focus on resource plays. Marfurt earned a Ph.D. in applied geophysics at Columbia University’s Henry Krumb School of Mines in New York in 1978 where he also taught as an Assistant Professor for four years. He worked 18 years in a wide range of research projects at Amoco’s Tulsa Research Center after which he joined the University of Houston for 8 years as a Professor of Geophysics and the Director of the Allied Geophysics Lab. He has received SEG best paper (for coherence), SEG best presentation (for seismic modeling) and as a coauthor with Satinder Chopra best SEG poster (one on curvature, one on principal component analysis), best AAPG technical presentation and with Roderick Perez-Altamar best paper in Interpretation. Marfurt also served as the EAGE/SEG Distinguished Short Course Instructor for 2006 (on seismic attributes). In addition to teaching and research duties at OU, Marfurt leads short courses on attributes for the SEG and AAPG, and currently serves as Editor in Chief of the AAPG/SEG Journal *Interpretation*.