A Short Note on:

Stochastic Inversion for Integration of Seismic Data in Geostatistical Reservoir Modeling

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The integration of seismic data into reservoir models is a longstanding problem. Most approaches are statistical in nature, that is, a statistical calibration is done between seismic attribute(s) and the petrophysical properties of interest. The idea of directly accounting for seismic data was launched in the early 1990's by workers at Elf (Bortoli, Haas, Dubrule). The basic idea is to simulate acoustic impedance and use the seismic data via the forward model; Figure 1 illustrates the forward model where the geological model of acoustic impedances is read together with the wavelet and converted to the seismic response.

All stochastic inversion techniques require information related to the correlation between acoustic impedance, porosity, and lithofacies proportions. Figure 2 illustrates the types of correlations needed. At times there is additional complexity introduced because the density and velocity are separated.

The original idea proposed by Bortoli and Haas was to generate a number of cross sectional models, say 10 to 100, and perform forward modeling on each cross section. The difference between the forward simulated seismic and the real seismic data is computed for each realization. Then, the simulated cross section with seismic traces closest to the data is retained. Multiple cross sections are simulated one after another to create a 3-D model. Each cross section is simulated conditional to all well data and previously simulated cross sections.

Dubrule and Haas extended the original approach to work on each 1-D column one at a time. This speeds the convergence of algorithm. The only practical consideration with this approach is the "string-effect" encountered when kriging with 1-D strings of data.

Some comments on the *Original Approach*: (1) problems related to artifacts due to kriging with strings of data, (2) the influence of the original histogram and variogram relative to the result after updating with the seismic data; the selection of the optimal column may cause the input statistics not to be honored, and (3) the original approach does not consider lithology/facies directly; however, the resulting acoustic impedance could be used for both lithology/facies modeling and porosity modeling.

Second Approach

Jason Geosystems implements a different version of geostatistical or stochastic inversion. The lithofacies are simulated in 3-D conditional to seismic data. The key steps in the algorithm:

1. Generate an initial 3-D lithofacies model and assign an acoustic impedance to each cell based on a stochastic drawing from the conditional distribution of impedance given the lithofacies.

2. Forward simulate the seismic response given the acoustic impedance model and the wavelet. Compute a measure of mismatch O between the seismic response of the model and the seismic data (a L2 or squared difference is considered).
3. Loop over all nodes in the entire model in a random path:
    a. Consider all (other) lithofacies at the current location $k=1,\ldots,K$; propose updates to the acoustic impedance model
    b. Update the seismic trace and calculate the mismatch for each lithofacies O_k, $k=1,\ldots,K$
    c. Choose to retain a lithofacies on the basis of a simulated annealing decision rule, that is, the probability to retain lithofacies k is given by:

    $$P_k \approx e^{\frac{-O_k}{T}}$$

    where T is a control parameter that is gradually lowered to zero. Many implementations of simulated annealing set the temperature to zero from the start; commercial software may have done this. This means that the lithofacies associated to the lowest objective function will be kept.
4. Continue to loop over all grid nodes until the mismatch is sufficiently low. A number of studies report that 10-15 iterations are required.

Some comments on the latter approach: (1) there is no explicit use of statistics related to the lithofacies proportions or indicator variograms, (2) the transform from lithofacies to impedance is required, (3) there is some question about how to define the annealing schedule and whether or not simulated annealing is even used.

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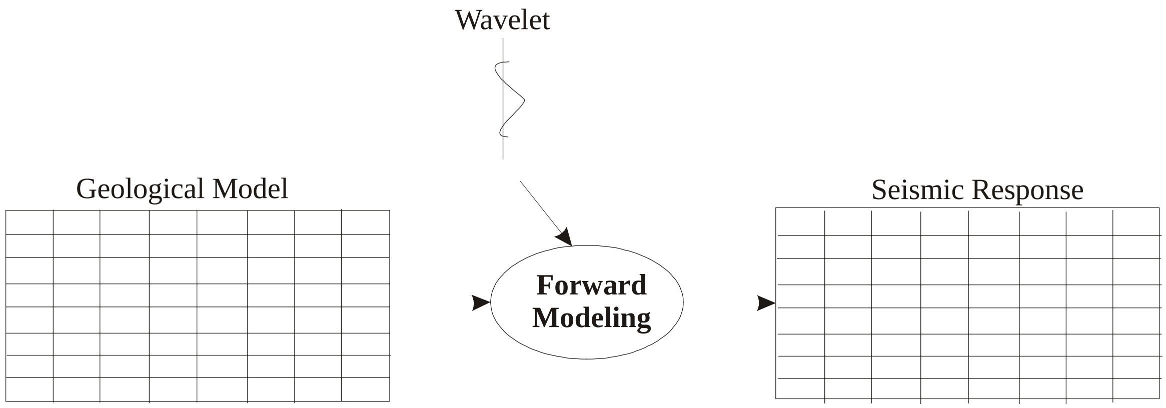

Figure 1: Illustration of forward seismic modeling: the geological model of acoustic impedances are read together with the Wavelet and converted to the seismic response.

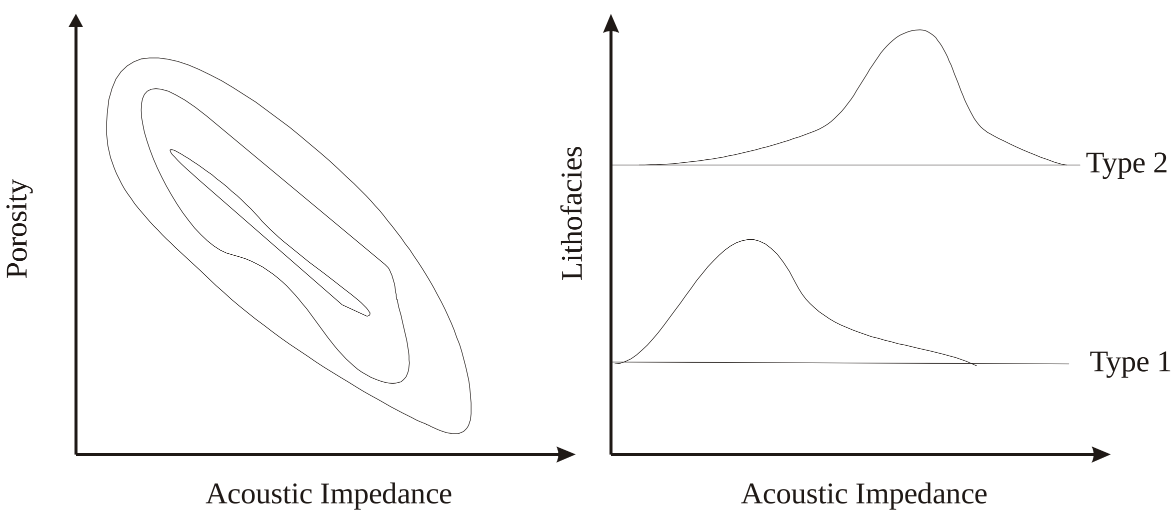

Figure 2: Illustration of how porosity is related to acoustic impedance (left) where the elliptical lines with negative correlation represent probability contours. The relationship between lithofacies and acoustic impedance is shown on the right, where we see a histogram of possible acoustic impedance for each lithofacies type.