Plotting Seismic Data As Intensity Arrays

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Seismic data may be mapped into a white-black intensities corresponding to data amplitudes (or some other attribute). Then these intensities may be plotted as a two dimensional array on a graphics terminal or electrostatic plotter. We use paper intensity plots as hardcopy snapshots of our movie program. We also use them as an alternative to variable area wiggle plots.

Advantages of Intensity Plots

(1) Intensity plots put more information on a raster graphics terminal than variable area plots. One data sample maps into a picture element for an intensity plot while it takes 16 or so across to do variable area wiggles. The comparisons are similar when considering vector graphics terminals too*. We also believe that the number of distinguishable amplitude levels (dynamic range) are comparable for variable area and intensity plots when displaying large quantities of data (see appendix).

(2) Intensity plots are easier to write programs for than variable area and run faster. It is easier to do some interactive graphics functions, such as transposes, when the dataset is in the form of multi-dimensional picture element arrays.

(3) Intensity plots offer an aesthetically pleasing complement to variable area plots. There is more continuity and blending between adjacent data samples.

*At 10 milliseconds per line segment, a 10000 vector graphics terminal stores 1000 seconds of seismic data. A 1000 x 1000 picture element raster graphics terminal stores 4000 seconds of 4 millisecond seismic data.

Disadvantages of Intensity Plots

(1) The dynamic range of intensity plots is less than variable area plots when the amount of data to be displayed is relatively small. It is easier to distinguished two slightly different wiggle sizes than nearby gray levels when comparing individual data samples.

(2) It takes a while for newcomers to adjust to interpreting intensity plots. However, this is true whenever one sees data plotted in a new way.

A Device Independent Plot Data Representation

Before making intensity plots, we convert floating point data into the format described below. Besides being more suitable for plotting, this format decreases data file size by 75% and is graphics device independent.

The data is quantized into 256 intensity levels. The levels are biased such that level 128 is zero, level 1 is maximum negative, and level 255 is maximum positive. Only one byte of storage is needed to represent a data sample. The eye can only perceive about 40 intensity levels within ordinary noisy seismic data, but 256 levels are needed for changing contrast (discussed later in this paper).

The quantizations need not be linear. In fact they should be non-linear in order to maximize contrast control. Levels are chosen to make the amplitude distribution more uniform. This is approximately achieved by raising each data sample to some fractional power γ (Claerbout, SEP-28). This operation is similar to the contrast enhancement done for satellite image processing or turning the contrast knob on your television set.

Our heuristic for selecting the fractional power γ is to first sort the dataset by absolute amplitude. Then we force the 85th centile raised to the γ power be 50% of the 99th centile raised to the γ power, solving for γ. The fractional power γ is around .5 (square root) for divergence corrected seismic data. This heuristic does not work well for noiseless synthetic data.

A lookup table greatly increases quantization speed. The index to the table is the data value clipped against glitches. The returned value is the biased, exponentiated quantization level.

Plotting on a Graphics Terminal

Most of the computation has already been done when determining the quantization levels. Then we load the graphics terminal with the converted data. The quantization level is translated into light intensity via the graphics terminal's color lookup table. The color lookup table has a color entry (in this case white-black intensity) for each of the 256 possible quantization levels.

Plotting on an Electrostatic Plotter

Intensity levels are simulated on paper plots by varying the density of black dots in a picture element (see figure 1). Typically each picture element is a rectangle of several dozen print rasters, whose size and aspect ratio depends on the dimensions of the overall plot.

I use a random number table to decide whether to turn on a given dot. The random number table contains integers between 0 and 255. If a random number is less than the quantization level, a black dot is turned on. This is easier to program than using precomputed intensity patterns. The printed picture element boundaries are smoother too.

The Contrast Factor

The fractional power γ mentioned earlier in this paper operates as an inverse contrast factor. As γ decreases, weaker data amplitudes increase relative than stronger data amplitudes.

The contrast factor enters into plotting in four ways. First, is the intrinsic contrast of the data. This depends upon how uniformly data amplitudes are distributed. Second, is the artificial contrast factor introduced when plotting the data. This is due to the non-linear assignment of quantization levels. Third, is the intrinsic contrast factor of the display medium. Typically light has more contrast than inked paper which has more contrast than film. Last but not least, is the contrast factor of the human perception system. This last factor can vary with environmental conditions and mood, and is somewhat uncontrollable. This is why turning off the room lights sometimes changes things, or you might see something new in a movie after watching for the hundredth time.

We may change the contrast after having converting data values to quantization levels. This is done by a non-linear assignment of intensities to quantization levels by again using fractional exponentiation. This how we apply software contrast to seismic data movies almost instantaneously.

Appendix: Dynamic Range in Intensity vs. Variable Area Plots

We have studied how many bits of information (i.e., log of distinguishable intensity levels) one sees in various kinds of plots. The results help us to determine how much memory to allocate to storing plotting information and to compare the quality of various plotting styles and media.

We conducted a simple experiment by plotting data in which the least significant bits were successively turned off. Then we subjectively determined whether the plot looked different from the unmasked dataset. To be a rigorous experiment we should have held better control over variable factors (such as data noise), tested more media - plot style combinations, and used a more objective metric, but the results are fairly clear.

We used the same dataset for all the plots. It is a common shot gather 48 traces by 512 eight millisecond time points. The dataset had been quantized according to the device independent format described earlier. We plotted 1 to 8 significant bits in each of three plot styles: (1) intensity plot on a graphics terminal, (2) intensity plot on an electrostatic plotter, and (3) variable area plot on an electrostatic plotter. The size of each plot display was held the same- 2.5 by 5.1 inches.

Paper plot results are shown in figures 1 and 2. Terminal plot results are on the 3rd SEP videotape. A summary of the results is:

Plot	*Significant Bits*
terminal intensity	4-5
paper intensity	3-4
paper variable area	4-5

The results mean that 16 intensity levels per data sample is probably adequate for a graphics terminal. Paper variable area wiggle plots are probably more informative than paper intensity plots. The dynamic range of a terminal intensity plot is at least as good as a paper variable area plot.

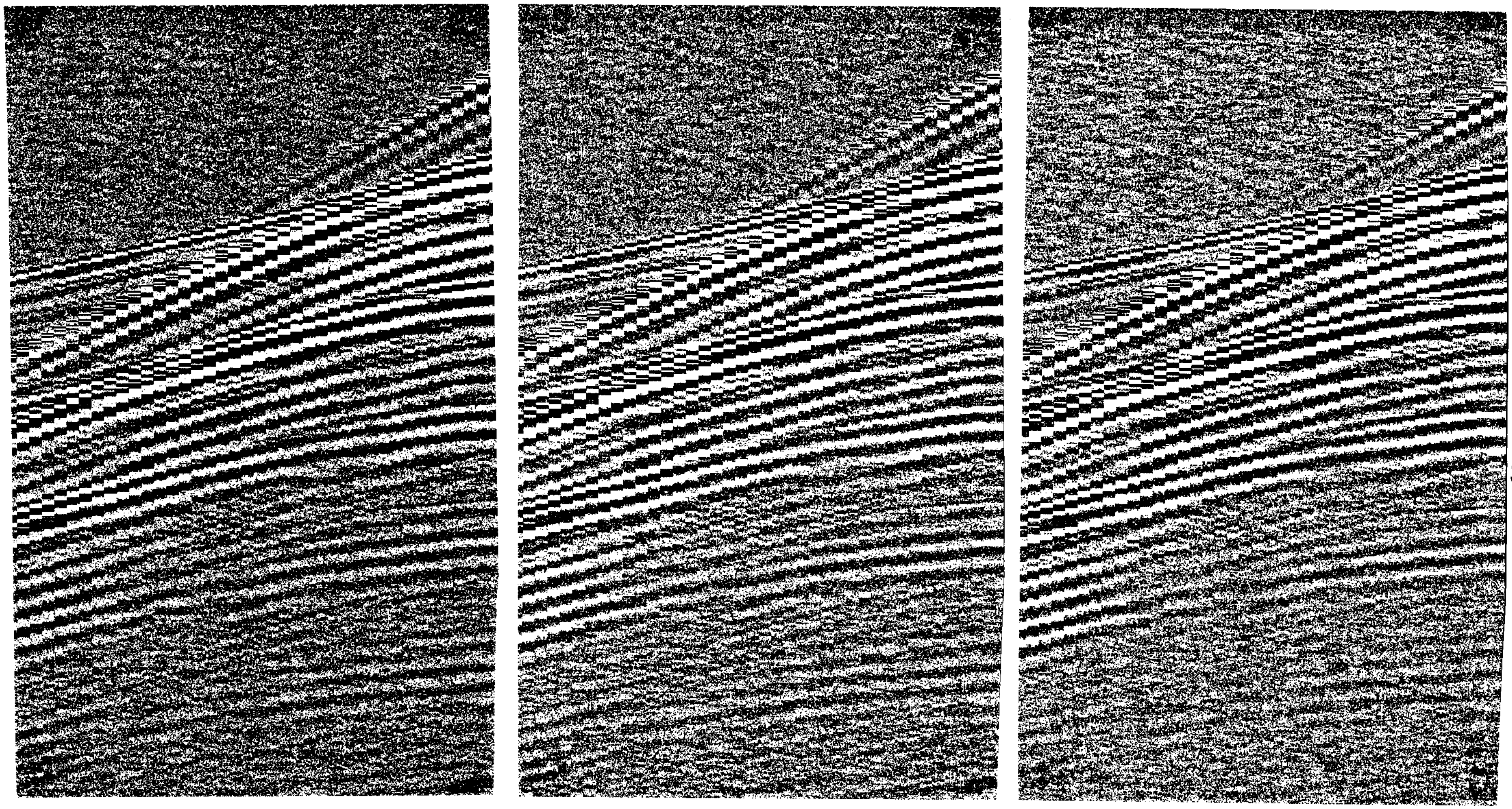

FIG. 1. Intensity plot of common shot gather: (left) 8 significant bits, (middle) 4 significant bits, (right) 3 significant bits. There is little if any detectable differences between the middle and left plot. The right plot differs from the other two.

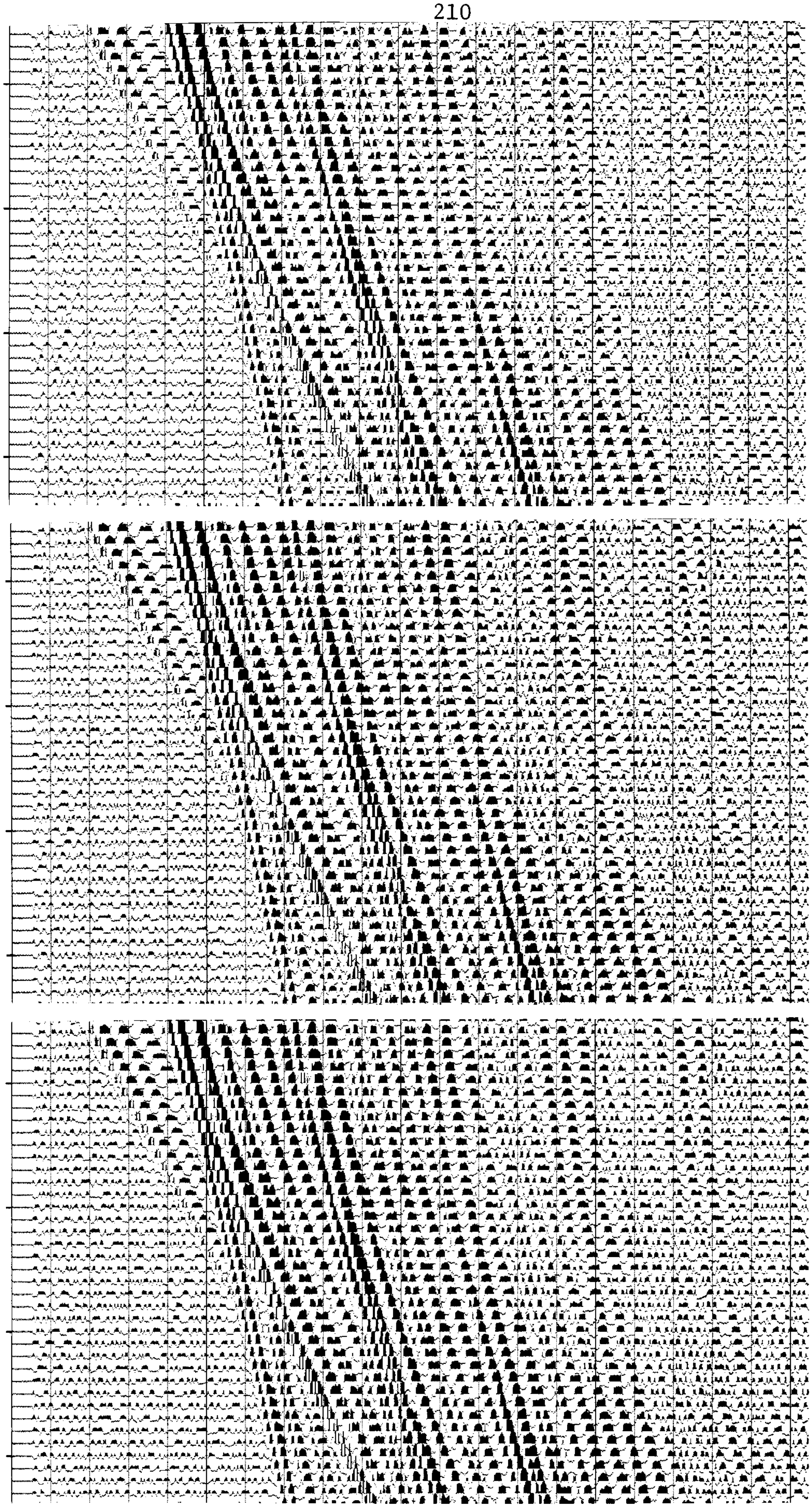

FIG. 2. Variable area wiggle plot of common shot gather: (left) 8 significant bits, (middle) 5 significant bits, (right) 4 significant bits. There is little if any detectable differences between the middle and left plot. The right plot differs from the other two.