Display of grey-scale data on a bilevel output device: addendum

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ABSTRACT

In SEP–51, we discussed ways in which grey-scale seismic data could be displayed on a bilevel output device such as a plotter. The data examples included in the paper looked fine when produced by our laser printer, but suffered noticeably when reproduced in the report. Since our object was to minimize the distracting texture created by the dithering process itself, we created the images using the highest-frequency alternation of black and white pixels the laser printer could produce. Unfortunately, reproduction devices such as photocopiers are unable to "see" such high-frequency variations. So just as we worked to correct for the characteristics of the laser printer in the last report, we must now also take into account the limitations of the reproduction process. This is done by reducing the frequency of variation between black and white that is used to produce a particular shade of grey, leaving clusters of black and clusters of white pixels. This technique is called *halftoning*. There is a tradeoff: while such halftoned pictures can be reproduced more faithfully, the originals have a coarser, more distracting, texture. For images that are not going to be reproduced by a low-resolution electrostatic printing process, the techniques described in SEP–51 remain superior.

INTRODUCTION

Continuous-tone (8 bits per pixel) images as might be seen on a graphics display terminal were converted to bilevel or 1 bit per pixel form in our paper in SEP–51 (Cole and Dellinger, 1987). This conversion allowed continuous-tone grey images to be displayed on bilevel devices such as printers. We found that the characteristics of the bilevel device being used and of the display device being simulated must be taken into account if the conversion is to be faithful. We derived corrections for various effects that allowed us to obtain images on paper that nicely matched our graphics display screens.

Unfortunately the figures that appeared in the final printed report were quite different from what we had sent off to the printer. Most images were much too dark. Isolated white regions were often lost altogether. These discrepancies were introduced by the photographic reproduction of the report. Like the graphics display or laser printer, the reproduction step has an effect on the image that must be considered. In the previous report, we discussed how to correct for the nonlinearity of display screens and the *distortions* of the laser printer. In this report we will discuss how to get around the *limited resolution* of the printing process.

The dithering methods described in the previous paper work well because the alternation of black and white pixels used to simulate grey levels is done at a high frequency. This rapid alternation causes the eye to see a diffuse grey tone rather than alternating black and white pixels. Unfortunately, photocopiers suffer even more from the same inability to "see" high-frequency dot patterns. As a result, individual dots are often lost, and the reproduced image is quite different in appearance from the original. This property of electrostatic reproduction is exploited at Stanford to cause the word "VOID" to appear magically when paychecks are mimeographed.

This pitfall of reproducing dithered images has been described by Ulichney (1987), who compares the ordered dither scheme we have used (which he calls *dispersed-dot ordered dither*), to *clustered-dot ordered dither*, where similar thresholds are intentionally grouped together in the dithering matrix. In clustered-dot ordered dither, a constant-intensity region on input yields a single black or white dot in a field of the opposite color, with the size of the dot depending on the input intensity. This method is also called *halftoning*, and is the method that newspapers use to reproduce photographs. A halftoned image has a coarser texture than a dispersed-dot ordered dither image, since it contains larger dots. However, if the dots are large enough, halftoned images survive reproduction processes where dispersed-dot images would be severely altered. Figures that are going to be included in any document that will be reproduced by standard limited-resolution methods should be halftoned. Figures that will not be subjected to such a reproduction process, however, are best constructed according to the dispersed-dot methods described in our previous paper.

HALFTONING

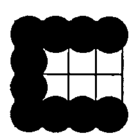
In SEP–51, we described a recursion scheme for generating dispersed-dot dithering matrices. The four by four dispersed-dot dithering matrix was found to be:

0	8	2	10
12	4	14	6
3	11	1	9
15	7	13	5

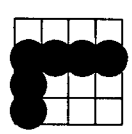
The key feature of the matrix is that similar thresholds are spaced as far apart as possible to give a diffuse pattern of dots on output rather than clusters of black and white dots. Similar operators for clustered-dot ordered dither or halftoning are easy to generate. We want a constant-intensity region to be converted to a single dot in a field of the opposite color. A good first guess at an appropriate matrix would be one where the smallest (or largest) threshold is at the center, with the remaining thresholds placed along a spiral path working out from the center. Following this prescription, a four by four halftoning matrix is:

12	13	14	15
11	2	3	4
10	1	0	5
9	8	7	6

If we call the small thresholds the black end of the grey scale and the large thresholds the white, it is clear that an input constant-intensity region with an intensity in the black half of the scale would (as desired) produce a white "dot" in a black field, with the size of the dot a function of the input intensity. However, the same analysis shows that an input intensity in the white half of the spectrum will produce an oddly-shaped black figure in a white field. For example, an input intensity that is slightly darker than the middle of the grey scale would yield the following dot pattern on output:



while an intensity that is just on the white side of medium grey would yield:



The matrix must be ordered differently if all input intensities are to produce the desired dots. A four by four matrix that has the desired properties is:

15	11	5	13
6	1	3	8
10	2	0	4
12	7	9	14

The two input intensities described above yield on output the following dot patterns:

At our laser printer's resolution of 300 pixels per inch, a four by four halftoning matrix produces dots that are too small to reproduce reliably. Larger halftoning operators are used in the next section to display some examples.

ORIENTATION OF DITHERING OPERATORS

The operators used for dispersed and clustered dot ordered dither have been referred to as dithering "matrices", implying that only a square operator with its two axes parallel to the axes of the image can be used. In fact any shape that can "tile" a rectangular grid can be used as a dithering operator. Ulichney (1987) noted that operators such as those given in the previous section have a serious shortcoming. When such matrices are applied to the image in checkerboard fashion, the axes of symmetry of the resulting pattern are horizontal and vertical. This introduces distracting horizontal and vertical features in the resulting display, which detract from the original image. If the square operators are rotated 45°, however, the axes of symmetry are also rotated. The human eye is much poorer at detecting diagonal lines than horizontal and vertical lines, and so the resulting image will be improved if such "diamond-shaped" dithering operators are used.

A 32 element clustered-dot dithering operator that has the properties described above, as given by Ulichney (1987), is:

				18				
			9	27	28			
		1	10	26	31	30		
	6	7	14	23	25	24	17	
18	20	19	16	13	11	12	15	18
	28	29	22	4	3	2	9	
		30	21	5	0	2		
			17	8	6			
				18				

Note that some of the repeated samples resulting from "tiling" the entire image with this operator are shown to illustrate the fact that this is really just a square matrix rotated by 45°. Figure 1 shows the result of applying this operator to a linear grey scale. Note the 45° orientation of the dot patterns. In our experience, this is the smallest halftoning matrix on our laser printer that can be reliably reproduced by photocopying. The grey "bands" visible in the figure result from the fact that the dithering operator contains only 32 elements. A 32 element operator can produce only 33 distinct grey levels.

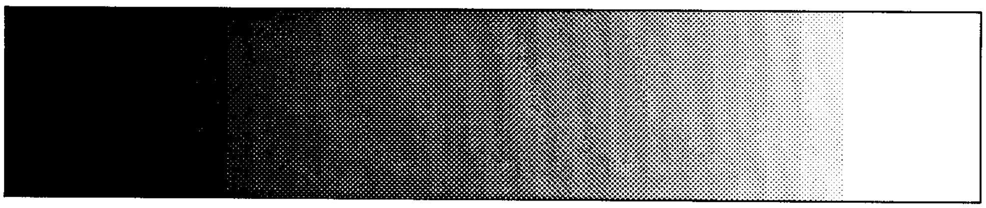


FIG. 1. A linear grey scale converted to bilevel form using the 32 element halftoning operator shown above.

Figure 2 shows a shot gather displayed using a conventional wiggle trace plot and after conversion to bilevel form using the above halftoning operator. This figure was not seriously harmed by the reproduction process in the previous report, since it contains relatively few isolated black and white pixels. Therefore it is possible to compare roughly halftoning and the dithering methods used in the previous paper. While the quality of the halftoned image is quite good, we wish to stress again that we have used the halftone method only because the image is reproduced photographically. Otherwise the dispersed-dot dithering methods described in our previous paper are superior.

CONCLUSIONS

Dispersed-dot ordered dither, as described in SEP–51, is an accurate method for displaying grey-scale seismic data on a bilevel output device. Conventional photocopiers, however, are unable to reproduce accurately the high-frequency alternating patterns of black and white dots that dispersed-dot ordered dither produces. Clustered-dot ordered dither reproduces well, because dots are grouped together instead of being isolated points. The clustering gives the original images a coarser texture, though, so clustered-dot ordered dither is a desirable alternative only for images that will be photographically reproduced.

For both clustered and dispersed-dot ordered dither, a significant improvement is obtained by using square dithering operators whose axes are oriented 45° away from the horizontal and vertical axes of the image, rather than the operators presented

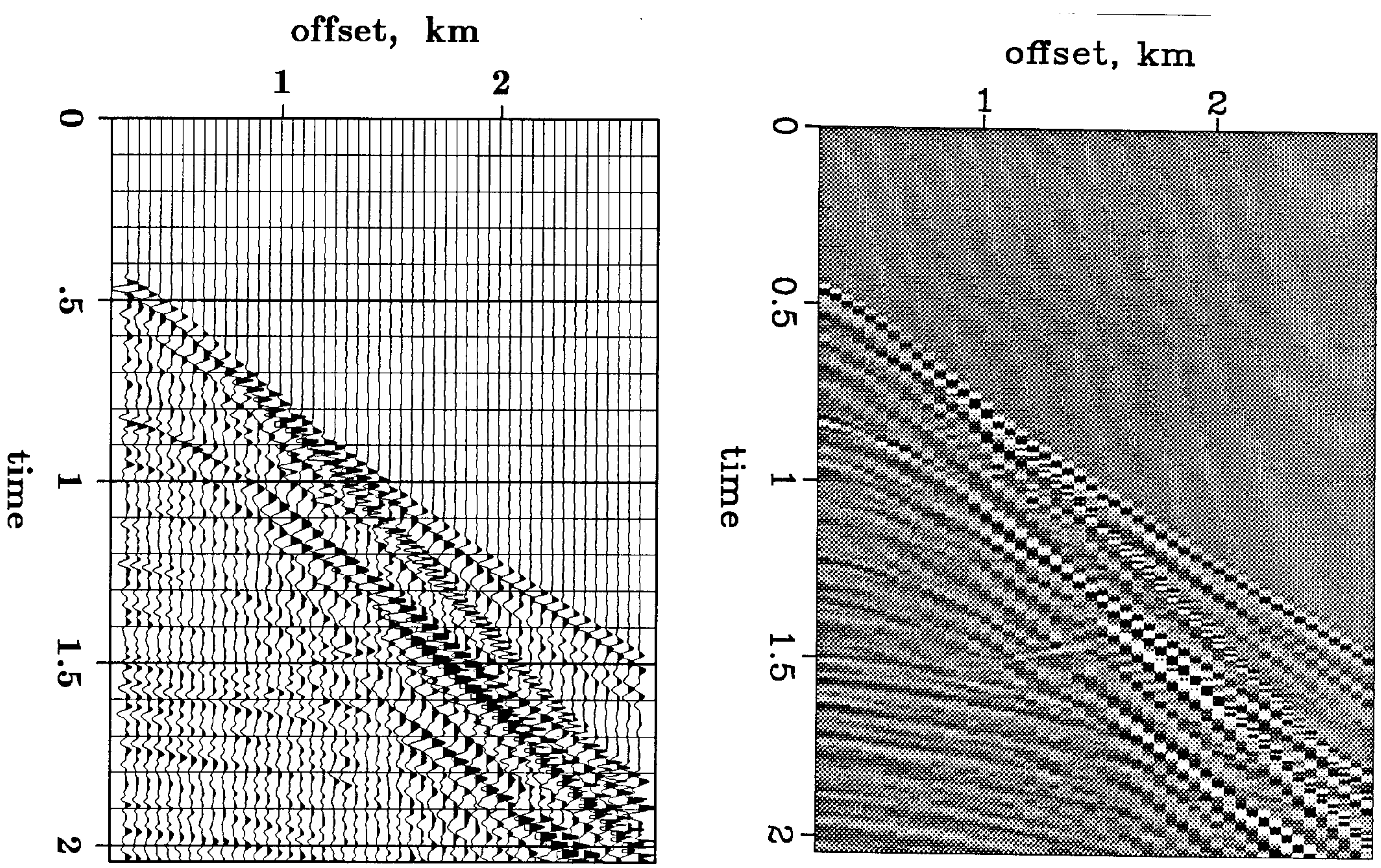


FIG. 2. A common-shot gather displayed with the conventional wiggle-trace method and converted to bilevel form using the 32 element halftoning operator given above.

in SEP–51 whose axes were parallel to the image axes. The 45 degree orientation ensures that any linear features introduced by dithering will be less discernible to the eye. Algorithms for constructing these operators are described in detail by Ulichney (1987), an excellent reference that thoroughly explores all aspects of the grey scale to bilevel conversion problem that we have dealt with in this paper and SEP–51. We recommend it highly to anyone interested in exploring the subject further.

REFERENCES

Cole, S. and Dellinger, J., 1987, Display of grey-scale data on a bilevel output device, SEP-51.

Ulichney, R., Digital Halftoning, 1987, M.I.T. Press.