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Generation of random-dot stereogratings

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Stereogratings are an extension of periodic stimulation to the Cyclopean domain. A program for the generation of random-dot stereogratings is described, with discussion of the advantages and disadvantages of the program.

A method of stereoscopic presentation of stimuli in the absence of corresponding monocular information (Cyclopean stimulation) was initiated by Ames (see Ogle, 1950) by means of the "leaf room." This consisted of a rectangular room in which all walls were covered with artificial leaves of various sizes. The leaves effectively obscured monocular contour information and the stereoscopic appearance of the room could be investigated under different conditions of uniocular magnification and distortion.

The Cyclopean method was developed rigorously and with considerable imagination by Julesz (1960, 1971). He realized that the monocular input to each eye could consist of a completely random pattern, while information for a stereoscopic figure could be contained purely in the correlation between the two monocular inputs. Julesz was able to retain a considerable degree of monocular randomness with complex and even ambiguous stereoscopic figures by means of algorithms that were often expensive and time consuming.

A slight modification of the random-dot method allows complex stereograms to be developed more simply. In order to retain complete randomness, Julesz (1960) limited the disparity shifts to integral values of the dot or element size of the random matrix. It is possible, however, to make the disparity shifts only a small proportion of the element size, e.g. 10%. Such a procedure has three advantages. (1) Disparity shifts of human threshold magnitude (e.g. 10 sec of arc) may be produced without lose of visibility of the matrix elements. Such loss of visibility would occur below about 1 min of arc. (2) Monocular cues remain invisible for any rate of change of disparity in the vertical direction. In the horizontal direction slow rates of change of disparity remain invisible up to a rate of about 10 min in 1 deg which is acceptable for many purposes. For higher rates of change, the density of the monocular pattern varies perceptibly with the disparity. (3) As long as the Cyclopean figure contains only changes in the vertical direction generation of the most complex forms requires only trivial modifications of the algorithm.

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METHOD

The stereograms described in this paper were generated by a FORTRAN program on the CDC 6600 computer at Northeastern University. The output was in the form of an ink plot from a Calcomp plotter. Some problems of the inability of the pens to plot dots continuously were encountered, and it is recommended that the alternative of a microfilm output would provide a more reliable output mode.

The program was modified for many special applications, but the most general form is given in Figure 1. The program is designed to produce a one- or two-dimensional sinusoidal stereograting with the option of variable frequencies and a decay on the x axis. The sinusoidal grating has the equation

$$Z(x,y) = \left[1 + m \cos\left(\frac{10^{fx}}{f}\right)\right] \cdot \left[1 + n \cos\left(\frac{10^{gy}}{g}\right)\right] \cdot 10^{ax}$$

where Z(x,y) is the displacement required to produce a binocular disparity, and the other parameters are described below. (This could be replaced by any other desired function). The first section of the program (Lines 3-15) fixes the parameters such as those determining the size of the matrix, the dot density, the change in frequency across the stereograting (DXDF = 1/f and DYDF = 1/g), the amplitude of modulation of x (AMP X = m) and y (AMP/Y = n), and the rate of decay of amplitude in x direction (DECAY = a). The second section (Lines 16-21) sets up random values from which the modulated matrix will be derived. The computation section of the program (Lines 22-40) determines both the position of each dot in the basic matrix and the amount it is shifted by the modulation function. This is programmed so as to minimize the number of computations performed by the computer. Thus the shift must be determined for each point in the x_j loop but since the y modulation is constant along each line it needs to be calculated only once for each cycle of the y_k loop.

To set up the output plot for a stereogram, the modulation amplitudes (AMP X and AMP Y) are first set to zero, when the output will be solely the random matrix. Second, the modulation parameters may then be set to produce a modulated matrix. The random matrix may be used for one eye's view while the modulated matrix is presented to the other eye. When fused the viewer should obtain a Cyclopean image of the modulation function.

```
PROGRAM     STEREO1        CDC6200 FTN V3 . 0-P324  OPT=1 73/03/05
                PROGRAM STEREO1(INPUT,OUTPUT)
      C          THE FIRST CARDS DETERMINE THE PARAMETER VALUES
                WIDTH=
                HEIGHT=
5               AMP X=
                AMP Y=
                DXDF=
10              DYDF=
                DECAY X=
                DECAY Y=
                BFREQ=
                DENSE=
15    C          THE NEXT CARDS DETERMINE A RANDOM MATRIX
                CALL ENTRY(30.)
                SEED=1973.
                CALL RANSET(SEED)
                N=WIDTH/DELTA X
20              M=HEIGHT/DELTA Y
                PRINT 900,M,N
                VAL1=DELTA Y/DECAY Y
                VAL2=2.*3.14159*BFREQ*DXDF/ALOG(10.)
                VAL3=DELTA X/DECAY X
25              VAL4=VAL2*DYDF/DXDF
                VAL5=2.*3.14159*BFREQ*DYDF/ALOG(10.)
                Y=0
      C          THE NEXT CARD ADJUSTS DENSE FOR CONSTANT DENSITY
                DENSE=DENSE*DELTA X*DELTA Y*500000
      C
10              DO 800 K=1,M
                IWAY=(K-(K/2)*2)
      C
                DO 700 J=1,N
      C          X IS PLOTTED BACK AND FORTH
35              X=((J-1)*IWAY+(N-J)*(1-IWAY))*DELTA X
      C          THE FOLLOWING CARDS SPECIFY THE MODULATION FUNCTIONS
                ZY=AMP Y*COS(VAL5*(10.**(Y/DYDF)-1.))*10.**(((1-J)*IWAY+(J-N)
                1*(1-IWAY))*VAL3)+1.)
                 Z=ZY*(1+AMP X*COS(VAL2*(10.**(X/DXDF)-1.))*1))*10.**((1.-K)
40              1*VAL1))
      C           THE NEXT SECTION PRINTS OUT SELECTED VALUES OF Z
                 IF(K*DELTA Y-1/BFREQ)300,300,400
          300   PRINT 950,ZY
          400   IF(K-1)410,410,440
45        410   IF(J*DELTA X-1/BFREQ)420,420,440
          420   PRINT 920,Z
      C
          440   ID=D
                R=RANF(SEED)
50              IR=R*10000
                IF(IR-DENSE)500,500,700
          500   CALL PLOT(Y,X,3)
                CALL PLOT(Y,X,2)
          700   CONTINUE
55              Y=Y+DELTA Y
          800   CONTINUE
      C
                CALL ENDPLOT
          900   FORMAT(1H ,2I6)
60        920   FORMAT(1H ,F10.3)
          950   FORMAT(1H ,F10.3)
                STOP
                END
```

Figure 1. Program to produce a one- or two-dimensional sinusoidal stereograting. Lines 3-15 fix the parameters. Lines 16-21 set up random values from which modulated matrix will be derived. Lines 22-40 represent the computation section determining the position of each dot in the matrix and the amount it is shifted by modulation. (Please note the space in AMP X and AMP Y.)

RESULTS

The first example of a stereogram generated by the program is given in Figure 2, which represents a simple stereograting with a sinusoidal variation in disparity in the vertical direction, producing the perception of horizontal bars or troughs over the entire stereogram. In order to achieve this, the amplitude of modulation in the x direction (AMP X) is set to zero and the space–constant of decay in the x direction (DECAY X) is set to a very large value, so that there is negligible decay in the y modulation across the x axis. Similarly the spatial frequency of modulation on the y axis is also essentially constant, which was produced by setting the space–constant of frequency change in the y direction (DYDF) to a very large value. Thus the parameter values to produce a stereograting such as that in Figure 2 are

WIDTH	=	8
HEIGHT	=	10
AMP X	=	0
AMP Y	=	.1
DELTA X	=	.005
DELTA Y	=	.01
DXDF	=	10000
DYDF	=	10000
DECAY X	=	10000
DECAY Y	=	10000
BFREQ	=	1
DENSE	=	50

The second example of a stereograting (Figure 3) also consists of horizontal bars, but in this case they increase in frequency from 1 cy/in. the bottom to 10 cy/in. at the top. The amplitude of modulation decreases exponentially from .2 in. peak-to-peak on the right hand side. The parameter values required for a figure such as Figure 3 are

WIDTH	=	8
HEIGHT	=	10
AMP X	=	0
AMP Y	=	.2
DELTA X	=	.005
DELTA Y	=	.01
DXDF	=	10000
DYDF	=	10
DECAY X	=	10
DECAY Y	=	10000
BFREQ	=	1
DENSE	=	25

It can be observed in this figure that the upper limit for detection of spatial frequency modulation occurs about three fifths of the way up the y axis when the figure is viewed dichoptically at a distance of one meter. This corresponds to a spatial frequency of approximately 5 cy/deg, which has been shown to be the upper limit of spatial resolution of the stereoscopic system for line stereograms (Tyler, 1973). Initial experiments with stereograting have in general confirmed the results obtained with line stereograms (Tyler, 1974).

CONCLUSION

The technique described may be used to generate a complete range of random-dot stereogratings. These should make it possible to extend the techniques of frequency analysis of the visual system (Campbell & Robson, 1968; Blakemore & Campbell, 1969) to the Cyclopean domain. In thus probing into

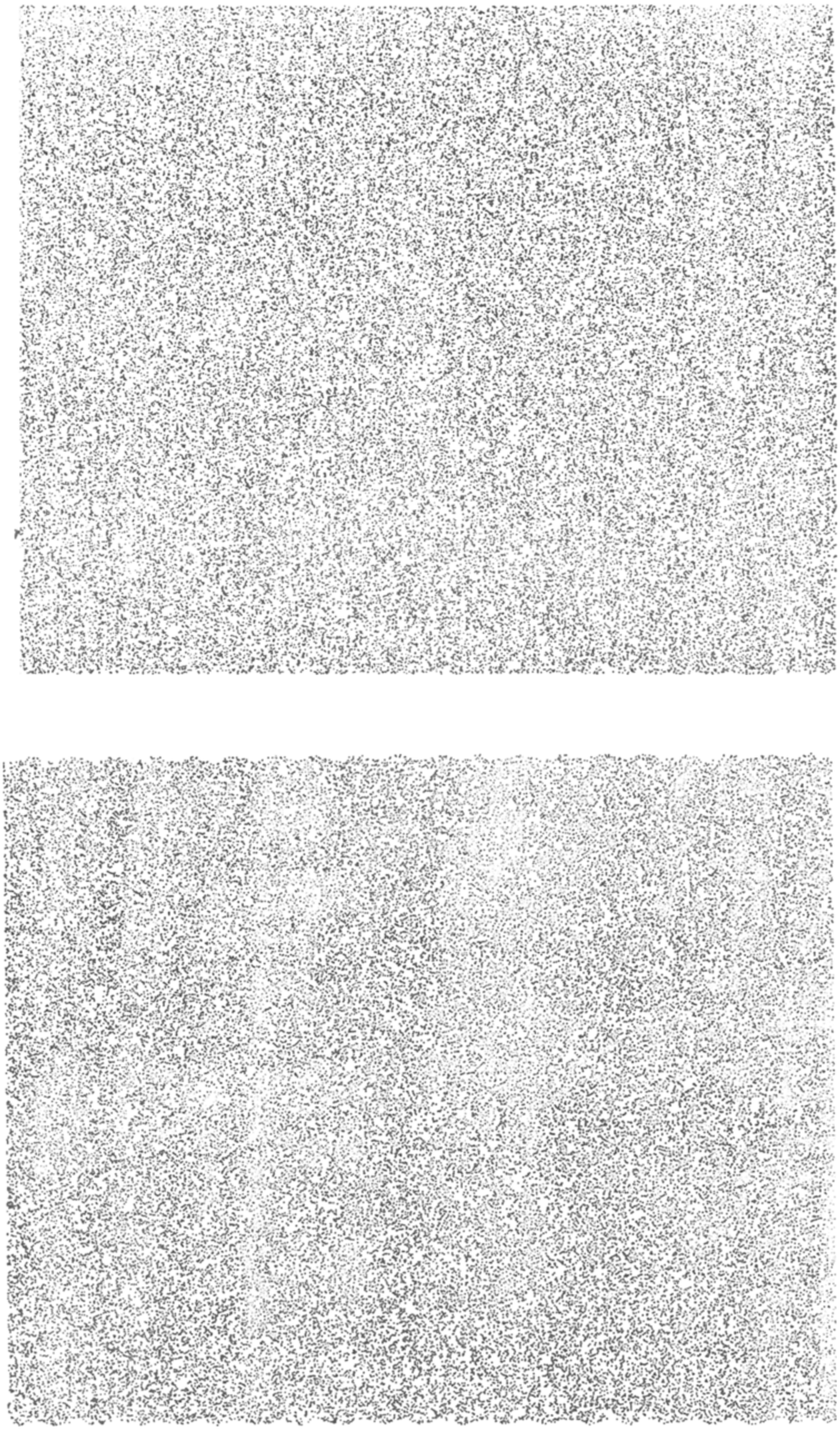

Figure 2. Example of a stereograting that produces the perception of horizontal bars or troughs. Figure 2a is for the left eye, and Figure 2b for the right.

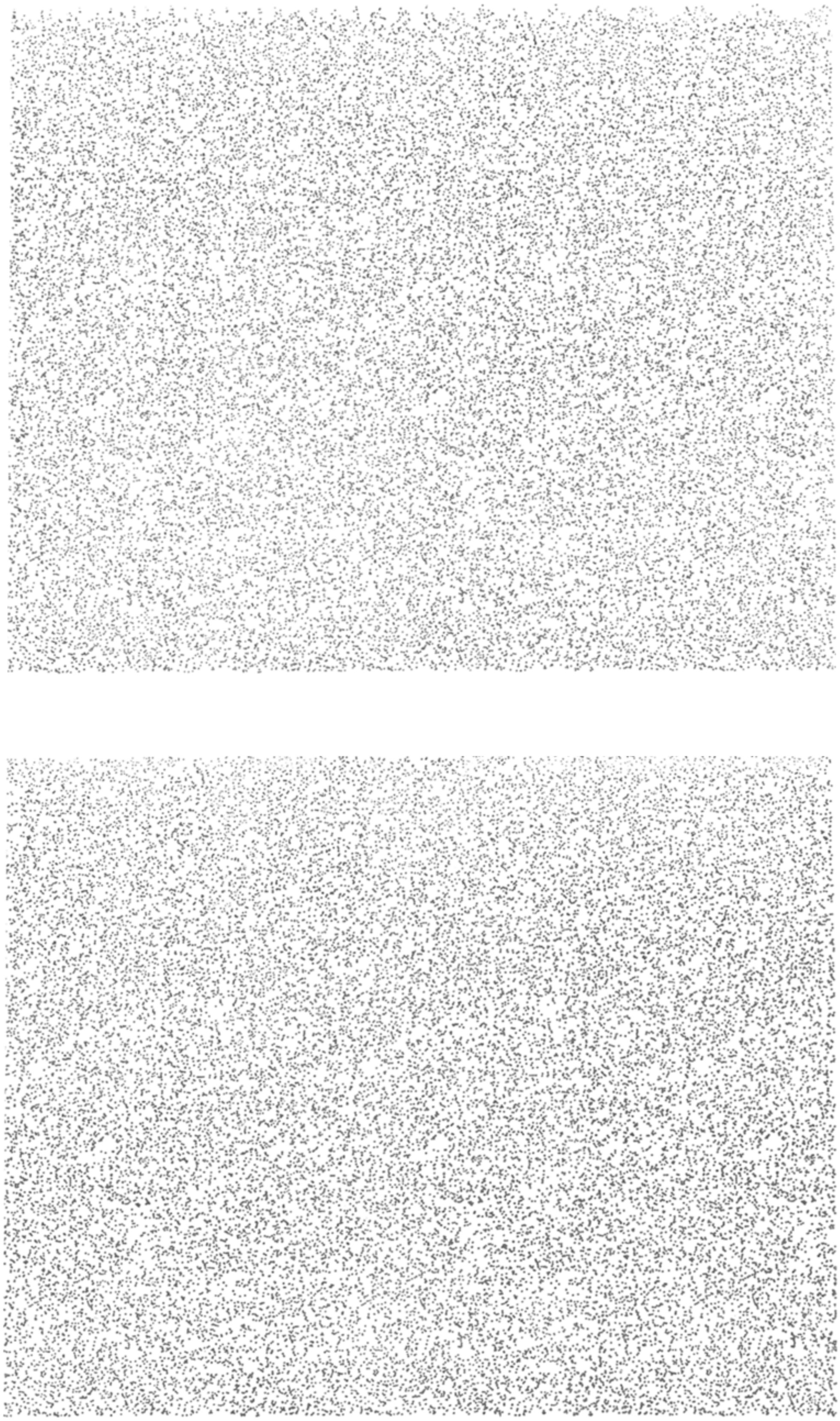

Figure 3. A second stereograting consisting of horizontal bars. In this case, they increase in frequency from 1 cy/in. at the bottom to 10 cy/in. at the top. Amplitude of modulation decreases exponentially from .2 in. peak-to-peak on the right-hand side. Figure 3a is for the left eye and 3b for the right.

higher levels of neural functioning, the technique has the advantage of making a strong dissociation of retinal and cortical effects.

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