COMPUTER TECHNOLOGY

Generation of random-dot stereograms

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Stereograms are an extension of periodic stimulation to the Cyclopean domain. A program for the
generation of random-dot stereograms 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 unocular
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 loss 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.

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 plotter from a
Calcomp plotter. Some problems of the inability of the pen 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
stereogram with the option of variable frequencies and a decay
down the x axis. The sinusoidal grating has the equation

$$Z(x,y) = \left[ 1 + m \cos \left( \frac{x\pi}{\lambda} \right) \right] \left[ 1 + n \cos \left( \frac{y\pi}{\beta} \right) \right] \cdot 10^{kn}$$

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 stereogram (DXDF = 1/s
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 direction but since the y modulation
is constant along each line it needs to be calculated only once for
each cycle of the y 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.
RESULTS

The first example of a stereogram generated by the program is given in Figure 2, which represents a simple stereogram 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 stereogram 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 stereogram (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 stereograms 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 stereograms. 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 stereogram 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 stereogram 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.

REFERENCES

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