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Technical Note

Generation of fractal patterns for probing the visual memory

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SUMMARY

The effective use of computer-generated pictures as a trial-unique probe for studying the visual memory is described. The shape of the pattern is determined by means of a fractal algorithm with pseudorandom parameters. This method enables us to easily obtain thousands of moderately complex and sufficiently diversified pictures in series from a given number which serves as the seed of a pseudorandom number generator. We can thereby create a new and unique set of pictures if a new seed is given, as well as retrieve exactly the same pictures in the same sequence as when the original seed is given. These properties eliminate the demand for the massive memory space in a computer otherwise needed to store the entire set of stimulus pictures.

In testing the non-verbal form of memory or perception, various kinds of complex scenes have been utilized as a probe for event-related potentials [10], positron emission tomography [3] or single-unit recordings [4]. The scenes included geometric figures [2,3,10], complex 'junk' objects [7], faces [2,4] or TV frame images [1]. However, since the declarative memory which depends on the integrity of the medial temporal lobe [6] is best tested through a task requiring the memory of trial-unique objects [7,11] we need a considerable number of novel visual stimuli presented to a subject in the study of the non-verbal declarative memory.

To meet this requirement, we have developed a new method based on the fractal algorithm [5], with which (a) thousands of different color pictures were generated by a computer; (b) the complexity of the pattern was readily chosen through the adjustment of some fractal parameters; (c) each set of consecutively generated pictures originated from a unique number (a seed) that could reproduce exactly the same set of pictures as when given to the computer; and (d) the memory space needed in the computer for storage of the pictures was thereby reduced without losing the patterns' reproducibility. We applied this method to a delayed matching-to-sample (DMS) task; some of the results of single-unit recordings during the task have been reported previously [8,9].

A computer (VAX-11, DEC) interfaced with image-processing hardware (IP8500, Gould Inc., Image and Graphics Division) was used to generate stimulus pictures and to control the DMS task. The stimuli were displayed on a video monitor (KX-14HD1,

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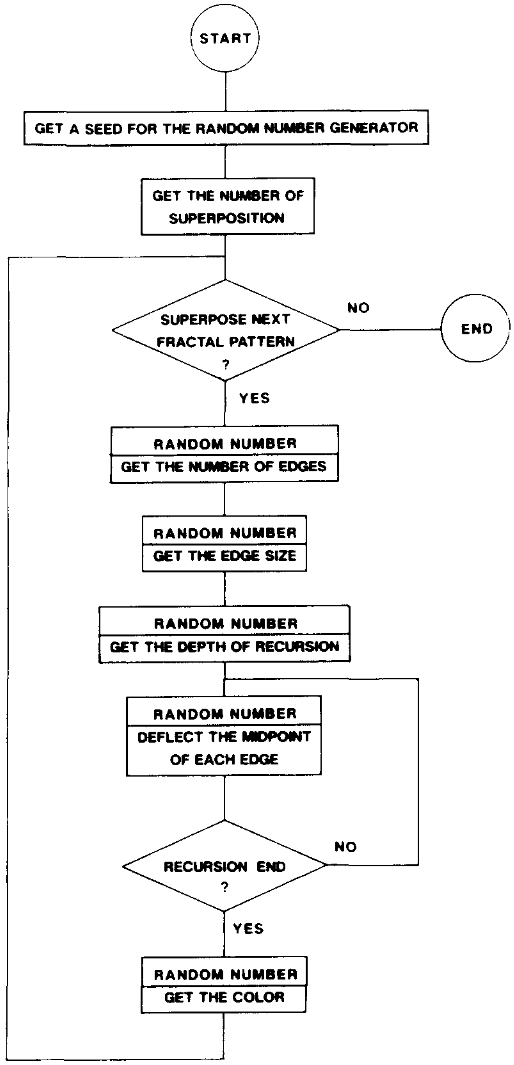

Fig. 1.

SONY) with a resolution of 512 × 512 pixels in 256 colors. The program was written in FORTRAN77 and C, and linked with the image library routines supplied by Gould IGD. Some characteristic parameters in the fractal algorithm (see below) were determined by sequential calls to a pseudorandom number-generating function ('RAND') in DEC FORTRAN77 or C.

The algorithm for picture generation is shown in Figure 1. First, a polygon is constructed which is then recursively deflected at the edges to make a contour of a unit fractal pattern. The algorithm proceeds as follows. Coordinates of corner points of the polygon are represented as a list. The recursive deflection subroutine returns an output list twice as long as the input list by inserting intermediate points lying on the perpendicular bisector of the line between two adjacent input points. The essential part of this calculation is shown in the Appendix. This deflection procedure is repeated as many times as predetermined by the parameter of recursion depth; more repetitions of

Fig. 2.

this procedure produce more elaborate, complicated contours. The unit contour is filled in with color, and several colored unit patterns are then superposed one onto another to form a stimulus picture. The phase angle for the superposition is usually fixed at zero, but can be randomized if necessary. The characteristic parameters determined by RAND include the initial number of edges of the polygon, the initial size of the edges, the depth of recursion, the amplitude of deflection of the edges, and the color of each unit fractal figure, as indicated by 'RANDOM NUMBER' in Figure 1. The seed for RAND was given by the experimenter for the first picture, while the following pictures were generated automatically in succession.

Pictures generated by the algorithm shown in Figure 1 are exemplified in Figure 2. Each picture was made up of 3 superposed colored fractal figures. The initial number of the edges ranged from 2 to 6. The depth of recursion was limited to 2–5. Expansion of these parameter limitations resulted in more complicated pictures.

The pictures generated by the present method are sufficiently diversified and still highly distinguishable to the subjects. In fact, the pictures were successfully used as sample and match stimuli in the DMS task in a single-unit study of the visual memory of monkeys. Sample and match stimuli were displayed on the video monitor for 0.2 s with a delay interval of 16 s. The monkey was to memorize the sample stimulus during the delay period and to decide whether the match stimulus was the same or different. The monkeys performed the DMS task at more than a 90% correct level even when a new, unfamiliar set of pictures was used as the sample stimulus [9]. Furthermore, the neurons in the anterior ventral temporal cortex responded very selectively to only a few (sometimes just one) of the set of 100 pictures, and the optimal stimuli varied from cell to cell [8]. These experimental results confirm the distinguishability of the pictures. Obviously, the present algorithm can produce much more complex fractal patterns than those shown in Figure 2, and the degree with which the patterns can be distinguished in a given task limits the practical range of the patterns' complexity.

The trial-unique stimuli used in a memory task are usually supplied by real 'junk' objects with various shapes and colors [7]. However, the practical number of such 'junk' objects in a laboratory is less than a thousand, and thus the same object must be used repeatedly in a pseudo-trial-unique manner. The present procedure overcomes such limitations. It guarantees that different seeds generate different pictures, and that the same seeds generate exactly the same pictures, thus eliminating the demand for the massive memory space in the computer otherwise needed to store the whole set of stimulus pictures. Since the algorithm developed here can be implemented on any computer with an image frame buffer, this method will facilitate the probing of the visual memory with exact stimulus control.

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APPENDIX

The box 'DEFLECT THE MIDPOINT OF EACH EDGE' in Figure 1 is calculated as follows. The Cartesian coordinates of the ith corner point of the polygon are stored in an array, say fract-$x(i)$ and fract-$y(i)$, $i = 1$ to n, where n is the number of edges. The recursive deflection subroutine works on this array and returns an output array of length $2n$.

In the subroutine, the ith point is moved to the $2i$th point ($i = 1$ to n). Then, the coordinate of the intermediate point, fract-$x(i + 1)$ and fract-$y(i + 1)$, lying on the perpendicular bisector of the line between two adjacent points, i and $i + 2$, can be calculated as:

$$\mathrm{m}x = (\text{fract-}x(i) + \text{fract-}x(i+2))/2$$

$$\mathrm{m}y = (\text{fract-}y(i) + \text{fract-}y(i+2))/2$$

$$\mathrm{d}x = \text{fract-}x(i+2) - \text{fract-}x(i)$$

$$\mathrm{d}y = \text{fract-}y(i+2) - \text{fract-}y(i)$$

$$\text{theta} = \arctan(\mathrm{d}y/\mathrm{d}x)$$

$$\text{fract-}x(\mathrm{i}+1) = \mathrm{m}x + GA * \sin(\text{theta})$$

$$\text{fract-}y(i+1) = \mathrm{m}y - GA * \cos(\text{theta})$$

where GA is a parameter determined by RAND, and specifies the amplitude of deflection for the $i + 1$-th point on the perpendicular bisector. Note that GA can have a negative value.

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