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METHODS & DESIGNS

A procedure for the computerized representation and presentation of rotated and reflected stimuli

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Psychological experiments in mental rotation and pattern recognition often require the presentation of stimuli in a variety of different orientations. Traditionally these stimuli have been presented with a tachistoscope; however, there are several advantages to using a system that presents such stimuli on a microcomputer. Unfortunately, in a typical experiment of this type, stimuli are presented after several different rotations, reflections, and translations, making the computerized representation of all the different permutations time- and memory-consuming. This paper describes a method of representation, utilizing a modified polar coordinate system, which allows for the efficient storage and transformation of such stimuli.

In studies of mental rotation, pattern recognition, and stimulus generalization, a series of stimuli are rotated, translated, and/or reflected about some point. In one version of the mental rotation paradigm, for example, alphabetic characters, in either normal or left-right mirror-reversed forms, are presented rotated about their center (Cooper & Shepard, 1973). Subjects are instructed to determine whether or not the characters are reversed, and their response times are recorded. These reaction times have been shown to be linearly related to the angle of rotation of the stimulus, with largest reaction times obtained for those stimuli oriented 180° from normal, suggesting that the rotation of the mental representations of these characters is an analogue of physical rotation. Not only is this procedure a useful tool for the study of cognitive processes, but since the effect is extremely robust, it is very suitable for inclusion in a cognitive psychology teaching laboratory.

Typically, stimuli of this type are presented tachistoscopically (Cooper & Shepard, 1973; Shepard & Metzler, 1971); however, the procedure lends itself well to microcomputer-controlled presentation. Computerized presentation is advantageous in that the equipment is more flexible, is more portable, and costs less than most alternatives. Furthermore, the computer can be programmed to keep track of the order of stimulus presentation and to automatically record reaction times. These considerations are particularly important if these types of experimental procedure are to be used in a teaching laboratory.

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One approach to the construction of a computer-generated mental rotation procedure is to predraw all of the characters, at all orientations and reversals, with some form of graphics tool (e.g., graphics tablet, light pen, or mouse). Since, in a typical experiment, three characters may be used, each presented at one of six rotations in both normal and reversed orientation (Cooper & Shepard, 1973), a total of 36 separate shapes may have to be created. This procedure has several obvious disadvantages: it is time-consuming, the shape descriptions consume large amounts of computer memory, and, once drawn, the size and orientation of the individual shapes cannot be altered. In an attempt to counter these disadvantages, a procedure has been developed whereby a shape is specified once, after which time it can be drawn at any rotation and size after both left-right or up-down mirror reversals.

The procedure utilizes a modified polar coordinate description of the stimulus outline. In the standard polar coordinate system, any point (x,y) on a two-dimensional plane can be described by specifying (1) the radius of the circle centered at (0,0) on which it lies and (2) the angle formed by moving counterclockwise from the positive x-axis along the circumference of the circle to the point (x,y) (Draper & Klingman, 1972). In the modified procedure used in this paper, angles are measured clockwise from the positive y-axis. This modification concurs to a greater extent to intuitive notions of rotation (clockwise from noon). The radius portion of the polar coordinate is unchanged from the standard notation. Using this procedure, the outline of any shape composed of a series of points joined by line segments can be described by a series of these modified polar coordinates (Figure 1). The center of rotation of the shape should be located at the origin

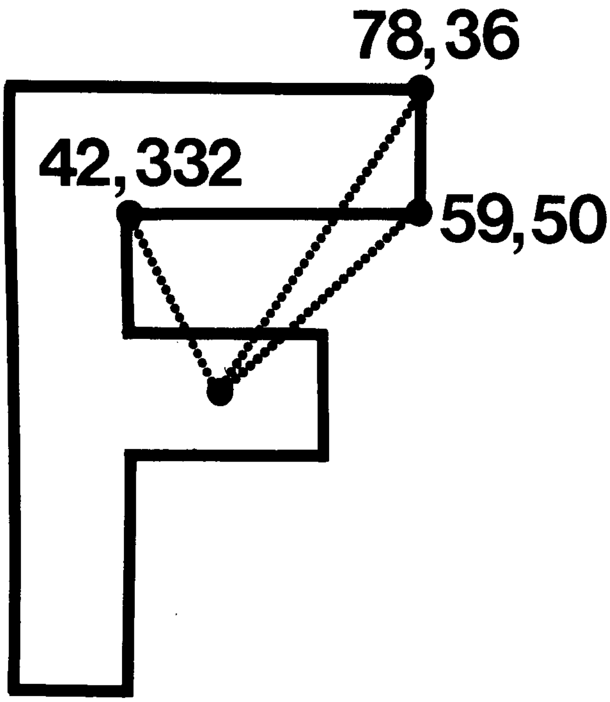

Figure 1. The modified polar coordinates of the first three points, which, when joined together, create the outline of the character F. The first number of each pair is the radius (arbitrary units from 0,0), and the second number is the angle (in degrees clockwise from the positive *y*-axis) of the point.

of the coordinate system. Where a section of the required shape is curved, the curve must be approximated by joining together a series of points with short line segments.

Once a character has been described in this manner and stored as a series of *n* polar coordinates of the form radius(*i*), angle(*i*), it is a relatively simple matter to obtain a left–right mirror reversal with the algorithm,

```
FOR i = 1 TO n
  angle(i) = 360 - angle(i)
NEXT i
```

Up–down mirror reversals (e.g., Corballis & McLaren, 1984) can be achieved with the algorithm,

```
FOR i = 1 TO n
  angle(i) = (180 - angle(i)) MOD 180
  IF angle(i) < 0 THEN angle(i) = 360 + angle(i)
NEXT i
```

The character can now be rotated with the algorithm,

```
FOR i = 1 TO n
  angle(i) = (angle(i) + rotation) MOD 360
NEXT i
(where rotation = degrees, clockwise about origin)
```

and scaled by some factor with the algorithm,

```
FOR i = 1 TO n
  radius(i) = radius(i) * scalefactor
NEXT i
```

Before the transformed stimuli can be displayed on the monitor screen, the polar coordinates must be converted into the Cartesian coordinates *x*(*i*), *y*(*i*) with the algorithm,

```
FOR i = 1 TO n
  x(i) = SIN(angle(i)) * radius(i)
  y(i) = COS(angle(i)) * radius(i)
NEXT i
```

It is important to note that in some programming languages (e.g., Applesoft BASIC, BBC BASIC, Microsoft BASIC), trigonometric functions are calculated from the radian of the angle, so that the above may have to be modified as follows:

```
x(i) = SIN(RAD(angle(i)))...
y(i) = COS(RAD(angle(i)))...
```

Alternatively, in languages where the RAD(ian) command is not available, the degrees-to-radians conversion can be accomplished by multiplying the angle (in degrees) by the constant 3.1416/180 before performing the trigonometric operations.

On some monitors an increment on the *y*-axis is physically smaller than an increment on the *x*-axis, which requires that *y* coordinates be multiplied by some scaling factor before they are displayed. This can be accomplished by inserting the statement *y*(*i*) = *y*(*i*) * scalefactor into the above loop.

The stimulus must now be translated along the *x*- and *y*-axes so that it appears in the center of the screen. This simply involves adding an *x* and *y* offset to the Cartesian coordinates. This procedure can be accomplished with the following algorithm:

```
FOR i = 1 TO n
  x(i) = x(i) + xoffset
  y(i) = y(i) + yoffset
NEXT i
```

Translation to other areas of the screen simply involves alteration of the offset values. This algorithm assumes that the origin of the graphics screen is at the bottom left of the screen. In many computers the origin is actually at the top left, so for these machines the *y* coordinate of each point must be transformed by using the function *y*(*i*) = max*y* − *y*(*i*) (where max*y* = the maximum addressable point on the *y*-axis of the graphics screen).

Once the shape is expressed as a series of Cartesian coordinates, it can be plotted by linking the points together using standard move and draw graphics procedures. In cases where the line describing the outline of the character must be broken (e.g., in the move from the outside to the inside of a letter o constructed from two concentric circles), a dummy coordinate must be inserted into the stimulus description to indicate to the computer that the line it has just drawn will not be joined to the next point in the stimulus description (i.e., move rather than draw).

The algorithms described above have been used to generate mental rotation stimuli for a first-year undergraduate psychology laboratory running on a local area network of BBC model B microcomputers. Although there is sometimes minor distortion of the characters on the 640×256 graphics screen, the mental rotation functions obtained after presentation of these stimuli are identical to those described in papers where tachistoscopically presented stimuli have been used.

To assist in the creation of stimuli, functions that will convert Cartesian coordinates to the modified polar form are described in the Appendix. A listing of a BBC BASIC program, which rotates, reverses, and draws the letters G, J, and R, is available on request.

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APPENDIX

The following functions may be used to convert from Cartesian (x,y) coordinates to modified polar coordinates (radius, angle):

$$\text{angle} = \text{DEG(ATN } (x\ /\ y))$$

$$\text{radius} = \text{x / SIN(RAD(angle))}$$

These functions will produce some negative angles and radii; however, these will be interpreted correctly by the main program. The DEG function can be replaced by dividing by the constant 3.1416/180.

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