PROGRAM ABSTRACTS/ALGORITHMS

An algorithm for determining clusters, pairs or singletons in eye-movement scan-path records

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Progress in the development of techniques and equipment to record eye movements (Young & Sheena, 1975) has not been matched by progress or innovation in analytic techniques for assessing eye-movement data itself. By and large, studies that employ dynamic eye-movement records as a physiological measure of attention or of cognitive processing focus on fixations or saccade amplitudes as key variables. Yet the more global feature of eye-movement records, the overall distribution of fixations on the visual two-space (the actual stimulus display) has not received as much attention. An appeal to topographic, graph-theoretic, or spatial-point type of analysis can provide insights into the distributional structure of such global dimensions of eye-movement data.

A visual scene can be regarded as a two-dimensional space that is characterized by regions that differ along a number of dimensions: informative value, texture, luminosity, and so forth. We can ask whether the successive displacement of eye positions, reflecting the global scan patterns of subjects, is regular, random, or structured in patterns of clusters, pairs, or single fixations over the visual field. Given a technique for reliably answering such questions for large data sets, we can then develop a number of indexes to characterize the ocular behavior of subjects in ways that go beyond the analysis of typically static variables, such as fixation duration and saccade amplitude.

We present here a simple algorithm that has varied applications in the analysis of eye-movement scan-path records. This algorithm is based in part on techniques developed for use in ethological and taxonomic studies of behavior. The algorithm described here departs from such techniques in one important respect. Although clustering schemes in the past have not been particularly concerned with the order of arrival of elements in a cluster, this is

an important dimension in eye-movement data. The algorithm that follows preserves the fixation order in building clusters.

Program CLSTDR. Program CLSTDR is written in FORTRAN IV for execution on a Digital Equipment Corporation (DEC) PDP-11/50 computer. Data are printed on a DEC DECWRITER III, and graphic representation of the data is produced on a Tektronix 4014 cathode ray terminal interfaced to a Tektronix 4631 hard copy unit. Only the graphic output portion of the program is hardware specific, as it incorporates code from the PLOT-10/Terminal Control System subroutine package marketed by Tektronix. The cluster program itself is easily ported to other hardware.

The program has three phases: initialization, execution, and output. During initialization, arrays for clusters, pairs, and singletons are dimensioned, and each array cell is given a starting value of zero. Each array stores the total duration of fixations, and the cluster and pair arrays also hold values for mean duration and mean x,y location for each pair or cluster. Furthermore, the cluster array contains the total number of fixations forming any given cluster in the array. The user provides answers to questions that set values to two variables. These variables are the minimum number of fixations needed to establish a cluster and the maximum distance permitted between fixations to determine whether fixations are close enough to form a cluster or to be included in an ongoing cluster. User-defined values for these variables allow for flexibility in the cluster definition to fit the nature of data and the questions asked in an analysis of that data. The values of these variables depend in large measure on the nature of the visual stimulus field and the size and density of that field.

As shown in Figure 1, the execution phase begins with program CLSTDR's reading of a single fixation record from a file containing eye-movement data on a single subject recorded during an experimental task. The relevant data in that file are the following: subject identification, slide number (indexing the particular visual field under study), fixation duration, x and y coordinates of the fixation, and distance of the current fixation from the previous fixation. The program checks to see whether the end of file or a new slide was reached. Since experiments conducted at our laboratory nearly always involve the presentation of more than one stimulus slide and more than one fixation is generally produced for any given slide, the program execution described here is suited to that experimental environment. The fixation duration and location are added to their respective counters, and the distance is then compared to the distance criterion established in the in-

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Figure 1. Flowchart diagram of program CLSTDR.

Table 1
Output Generated by Program CLSTDR

Number of Fixations	Clusters				Pairs				Singles		
	X Mean	Y Mean	Total Duration	Mean Duration	X Mean	Y Mean	Total Duration	Mean Duration	X Coordinate	Y Coordinate	Duration
5	-237	-145	1.684	0.337	0	31	0.400	0.200	-174	0	0.117
9	261	-182	3.084	0.343	-277	166	0.533	0.267	-225	117	0.150
9	272	-187	3.334	0.370	455	-105	0.583	0.292	212	87	0.133
3	254	-199	1.367	0.456	373	-133	0.333	0.167	225	165	0.217
4	232	-221	1.067	0.267	-407	204	0.283	0.142	122	-163	0.167
4	115	-77	1.217	0.304	-110	115	0.550	0.275	274	-72	0.117
3	-204	223	0.517	0.172	-209	-201	0.317	0.159	-162	-44	0.183
4	-303	168	2.384	0.596	237	-179	0.483	0.242	-398	307	0.483
3	-183	100	0.717	0.239					-435	135	0.133
3	274	-219	1.150	0.383					-275	201	0.467
									-249	142	0.117
									-116	-198	0.117
									162	-215	0.250
									188	31	0.150

Note—Number of clusters = 10; number of pairs = 8; number of singles = 14. Percentage of fixations in clusters = 0.610; percentage of fixations in pairs = 0.208; percentage of single fixations = 0.182.

initialization phase. If the distance is less than or equal to that criterion, a cluster is initiated and the means of both the fixation locations and durations are calculated and assigned to the appropriate variables. Fixation records are read, updating location and duration means, until the distance criterion is exceeded and/or a record for the next slide is read, or the end of file is reached. If only the distance criterion was exceeded, any ongoing defined cluster is terminated. The program then determines whether the cluster formed a pair. If so, the means for location and duration and the total duration of the pair are assigned to their respective array locations; otherwise, these values are assigned to the cluster array. If the succeeding slide was reached and no cluster had been formed, the last fixation of the previous slide is placed in the appropriate location of the singletons array. Information from the last fixation record read (the first of the new slide) is placed in temporary storage variables until another fixation record is read, and the program determines whether there is an initiation of a cluster or whether the previous fixation was a singleton. The program then returns to the initialization phase to clear counters for processing the next slide's records. If the end-of-file mark is read, the program goes to the output module described next.

In the output module, percentages of fixations assigned to clusters, pairs, and singletons are calculated. These percentages and the information stored in the cluster, pair, and singleton arrays are printed on the DECWRITER III. An example of this output is shown in Table 1.

A graphic representation of the cluster, pair, and singleton information is produced as well. An example of this type of output is shown in Figure 2. Each circle represents a cluster, pair, or singleton determined by the number of fixations printed in the center of each circle. The center of the circle represents the mean location for that group of fixations or single fixation. The circle size indicates the total duration at that location of the cluster,

pair, or singleton. The relationship of circle diameter to time is determined in the following manner. The rectangle is dimensioned 1,000 × 600 points. A tick mark is drawn every 50 points, and every point represents $\frac{1}{60}$ th of a second. A circle with a diameter of 100 points indicates that total time spent in that cluster was 1.66 sec.

Figure 3 is an example of a stimulus slide used in a visual search study (Scinto, Pillalamarri, & Karsh, in press); superimposed on it is a subject's scan pattern while viewing this stimulus slide. The circles represent durations for single fixations determined in the same manner as described above. The lines represent nominal saccades between fixations and are included only to indicate order of occurrence between successive fixations. Figure 2 illustrates the graphic result of executing program CLSTDR with subject eye-movement data collected for the slide in Figure 3.

This algorithm presents a feasible means for characterizing a large number of scan-path records which otherwise would constitute a formidable task if undertaken by visual examination of individual scan-path records as

Figure 2. Graphic output of singletons, pairs, and clusters in scan-path record from program CLSTDR.

Figure 3. Scan-path record of subject superimposed on stimulus slide in visual search study.

shown in Figure 3. The use of the algorithm is flexible and applicable to a number of possible analyses of scan-path records. It provides a means for characterizing such scanning activity in terms of the spatial distribution of fixations and provides an alternative to methods that focus attention only on transition probabilities between different areas of the visual stimulus display.

Availability. Copies of source code for program CLSTDR may be obtained by writing the first author.

REFERENCES

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(Revision accepted for publication February 18, 1986.)