# DO MAP READERS REALLY NOTICE AND USE GENERALIZATION?: THE PERCEPTUAL CONSEQUENCES OF LINE SIMPLIFICATION IN A TASK-ORIENTED THEMATIC MAP ANALYSIS EXPERIMENT

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## Abstract

One of the variables investigated in a larger map analysis study of some cartographic design elements was the perceptual response to line simplification during the performance of three different map analysis tasks. This particular part of the experiment was to investigate whether reducing the quantity of map detail through linear simplification would concomitantly reduce the amount of visual information processing necessary to accurately complete an assigned task. The experiment, a fractionalized factorial design, was carried out to examine the eye movement parameters (fixations, durations of fixations, and durations per fixation) of 16 subjects while they scanned 96 test maps in which four different levels of line simplification were used. The results indicated that in two of the three tasks, varying the level of linear simplification contributed neither major, nor interaction effects in explaining variation in the number of fixations, their durations, nor their durations per fixation. Unexpectedly, the data showed that progressively eliminating more map detail through line simplification did not alter significantly the amount of visual processing required to complete two of the tasks successfully.

## 1 Introduction

Maps usually are designed to meet a specific purpose. In order to achieve that purpose, designers need to consider a number of factors, all of which must be coordinated if the result is positive. Since line simplification affects shape, and shape impacts recognition, map designers should understand how it can influence the readability of maps. For example, would increasing the simplification of linear elements result in reducing the amount of visual processing necessary to perform a map analysis task? Do subjects performing map analysis tasks actually notice differences among maps that incorporate different levels of line simplification? Are the research efforts developing algorithms for line simplification of small-scale thematic maps warranted? To answer these questions, an experiment was designed to investigate how four different degrees of line simplification would affect visual scanning behavior of subjects performing typical map analysis tasks, i.e., counting, estimation, and comparison.

## 2 Experimental Design

The experiment was designed around a blocked, two-level, half-fractionalized, 4 x 4 x 4 factorial consisting of 32 runs. Fractionalizing the design reduced the required number of test maps, and it reduced the experimental effort without affecting the interactions among variables. Although three independent variables, namely visual angles, brightness differences, and line simplification tolerances, were used in the full experiment [1, 2, 3], only line simplification is discussed here.

Since the typical objective of line simplification is to preserve the character of the line while removing the non-essential spatial and attribute detail, the test maps were produced using the Douglas-Peucker [4] algorithm. Retention of points of maximum angular deviation is thought to produce a line that is more easily recognizable[5, 6] and the Douglas-Peucker algorithm accomplishes that quite well [7, 8]. In addition to line recognition, the Douglas-Peucker simplification algorithm is a global routine rather than a sequential one. This attribute was important because a global routine focuses on a careful selection of critical points, or the salient geometric characteristics of the line [9], a desirable quality according to Marino [10].

The four different line simplification tolerances were selected arbitrarily, but on the basis that they would produce noticeably different maps. The presence of noticeable differences was based on the work of Jenks [11]. In selecting the tolerances , consideration of any specific geometric criteria was not carried out for the test stimuli since the maps depicted either fictitious, or severely modified geographic regions that likely would have been unrecognizable to the subjects [9]. Also not taken into account in selecting the tolerance values were any resultant modifications to feature geometry that may have contributed to accuracy, or recognizability of some graphic details, as suggested by Buttenfield [12]. It is recognized, therefore, that some of the simplification tolerances produce test maps that may be cartographically undesirable. It was important, however, to produce a set of test maps that would exhibit distinctively different linear characteristics. From a set of ten pilot test maps, the following four offset tolerances were selected: 1) .000, 2) .025 inches, 3) .050 inches, and 4) .100 inches.

The experimental design also included a fourth independent variable - the three map analysis tasks, counting, estimation, and comparison. The counting task required subjects to determine the number of specific targets, which ranged from seven to nine, found on the test maps. The estimation task required an estimation of the percentage of the test stimuli covered by water. The areas ranged from a low of 11.9% to a high of 28.0%. The third task, comparison, asked subjects to compare two areas on the test maps and determine which one was larger.

### *2.1 Subjects*

A total of 16 paid undergraduate students, nine male and seven female, from Memorial University of Newfoundland participated in the experiment. None had participated previously in such experimentation, and all had normal, uncorrected, visual acuity.

### *2.2 Experimental Apparatus*

Data were collected using the Stoelting Wide-Angle Eye Movement Tracker and Pupillometer, Model 12861. The system, based on pupil center tracking, detects the dark pupil in the video signal and locates its center. A high-sensitivity infrared video camera monitors pupil locations and samples at 60 times per second. Data collection and storage was automated using an analog-to-parallel conversion board installed in an IBM PC. Following collection, data were then reduced to fixation-saccade type eye positions (X and Y coordinates and durations in milliseconds) using a program written by McConkie *et al.*[13].

### *2.3 Experimental procedure*

The usual steps were taken to standardize testing conditions. In order to control the effects of learning, the presentation order of the stimuli was randomized, the orientation of the test maps was varied by rotating the images in the display panel, and one half of the images were photographically reversed. Each subject was seated before the apparatus which was then adjusted for fit. Every stimulus was calibrated for X and Y coordinates using a nine-point calibration target prior to and following viewing of each test map.

### *2.4 Stimuli*

A total of 32 monochrome (black and white) maps were produced on matte finish, high-contrast photographic paper for the counting, estimation, and comparison tasks. Every map incorporated a unique combination of the three independent variables, namely visual angle[1], brightness difference[2], and generalization offset tolerance[3], according to the 4 x 4 x 4 factorial design. Figures 1, 2, and 3 are examples of the test maps used in the map analysis tasks.

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[1] Experimental stimuli subtended four different visual angles: 5, 8, 11, and 14 degrees measured at a viewing distance of 18 inches.

[2] Four brightness differences of 0, 10, 20, and 30 percent between figure and ground were created using 133 lpi tint screens.

[3] The generalization offset tolerances used were .000 (no generalization), .025, .050, and .100 inches.

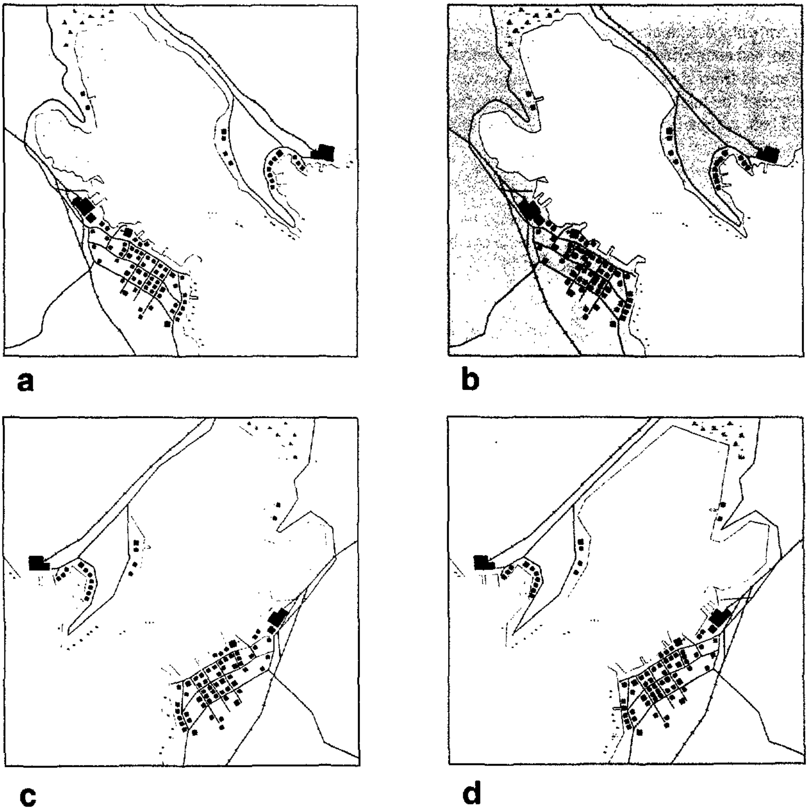

Figure 1: Examples of test maps illustrating the four generalization offset tolerances used in the counting task, reproduced at 100% of original size: a) Map 12 - .000; b) Map 23 - .025; c) Map 26 - .050; d) Map 15 - .100.

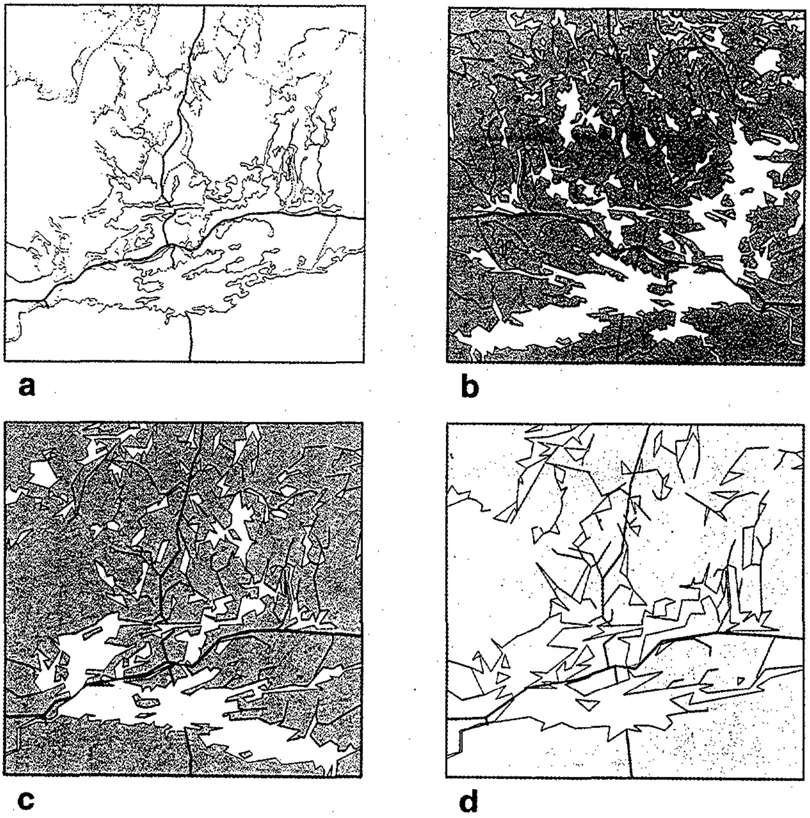

Figure 2: Examples of test maps illustrating the four generalization offset tolerances used in the estimation task, reproduced at 100% of original size: a) Map 08 - .000; b) Map 24 - .025; c) Map 25 - .050; d) Map 06 - .100.

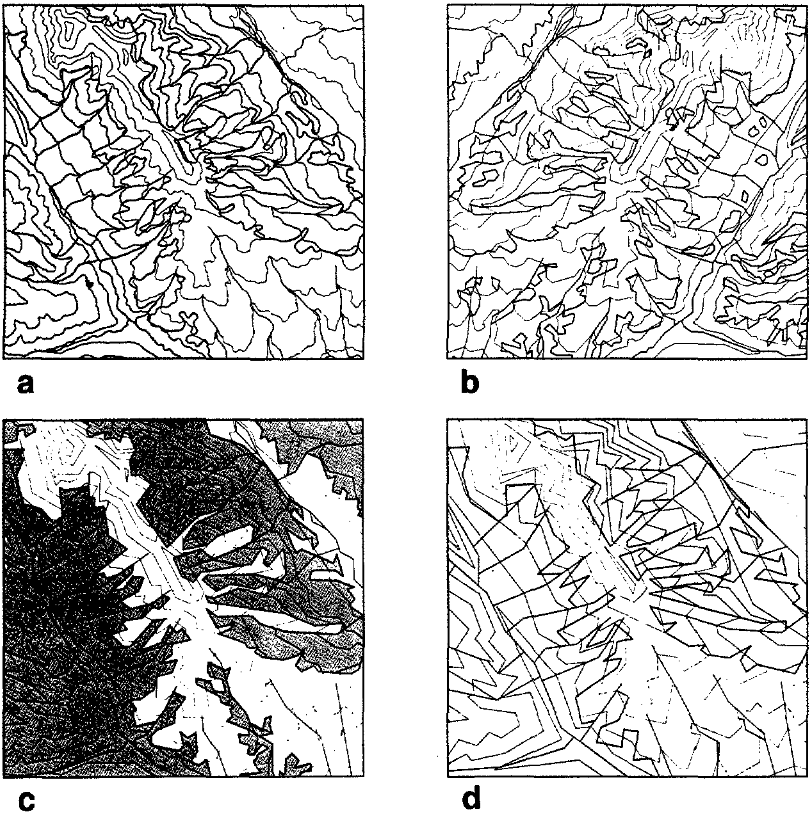

Figure 3: Examples of test maps illustrating the four generalization offset tolerances used in the comparison task, reproduced at 100% of original size: a) Map 10 - .000; b) Map 30 - .025; c) Map 21 - .050; d) Map 16 - .100.

## 3 Experimental results and analysis

Descriptive statistics were compiled for the independent variable, line simplification tolerance, in each task. Analyses of variance (ANOVA) were then calculated to determine whether differences among various simplification tolerances were significant. Since the experimental design resulted in half of the cells in the matrix being empty, however, the ANOVA only provided information on main effects. In order to determine the significance of any interaction effects, a step-wise regression analysis was run on the line simplification tolerances based on the three eye movement parameters, i.e., fixations, durations, and duration per fixation. As a final check for statistical significance of the experimental results, Tukey A multiple-comparison tests were run to determine significant differences among pairs of means of fixations, durations, and duration per fixation for each of the four line simplification tolerances.

### *3.1 Task 1 - Counting*

The first map analysis task required subjects to count the number of targets, fishing wharves, found on each map. The number of wharves varied from seven to nine. As indicated by the descriptive statistics in Table 1, as the degree of line simplification increased on the test maps, the number of fixations and the mean durations decreased. It is noteworthy that the standard deviation values also decreased as line simplification increased, suggesting that responses became more consistent with increasing simplification.

Table 1: Task 1 mean scores and standard deviations (SD) of eye movement parameters for four levels of line simplification tolerances.

| Simplification Tolerance | Number of Fixations | | Durations of Fixations, msec | | Duration per Fixation, msec | |
|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD |
| .000 | 25.63 | 4.38 | 13070.45 | 2856.69 | 542.46 | 207.00 |
| .025 | 24.38 | 3.99 | 12747.75 | 2367.62 | 551.67 | 192.29 |
| .050 | 23.82 | 3.58 | 10873.92 | 2024.35 | 477.58 | 157.38 |
| .100 | 23.25 | 4.40 | 10406.11 | 3019.25 | 486.01 | 166.06 |

When analyses of variance (ANOVA) were applied to the mean number of fixations [$F(3,22)=6.611$, $p=.002$], the mean durations of fixations [$F(3,22)=8.555$, $p=.001$], and the mean duration per fixation [$F(3,22)=3.480$, $p=.033$], line simplification tolerances proved statistically significant. All possible combinations of dependent and independent interactions were analyzed in the regression analysis. While line simplification tolerance was not found to be a major effect on mean number of fixations, it was a contributing variable in the only statistically significant interaction which involved visual angle and brightness difference [$t(1,29)=-4.976$, $p=.0000$]. A high partial ratio, $F(1,29)=92.8$, $p=.0000$, indicates that the major effect of visual angle and the interaction of visual angle x brightness difference x line simplification tolerance are highly correlated with the mean number of fixations.

In analyzing variation in the mean durations of fixations, regression analysis revealed that line simplification tolerances failed to emerge as a major effect, although visual angle was. The regression did, however, indicate two statistically significant interactions, both involving line simplification tolerances. In the first interaction, brightness differences x line simplification tolerances produced a $t$ (1,28) ratio of -4.831, $p=.0000$, and in the second interaction, visual angle x brightness difference x line simplification tolerance was also statistically significant [$t(1,28)=2.570$, $p=.0158$].

In assessing variation in the mean durations per fixation, the step-wise regression analysis again revealed that line simplification tolerances were not a major effect, although as in the case of mean durations, visual angle was statistically significant. The regression further showed that the interaction of brightness difference x line simplification tolerance was significant [$t(1,28)=-4.556$, $p=.0001$], as well as the interaction of visual angle x brightness difference x line simplification tolerance [$t(1,28)=3.342$, $p=.0024$. No other major effects or interactions proved statistically significant at the 95% confidence interval. A further check of how well the three regression factors predicted the mean durations of fixations produced a partial $F$ ratio, $F(1,28)=83.513$, $p=.0000$. The results suggest that these three regression factors are good predictors of the response data.

The final step in the analysis was application of multiple-comparison tests to determine any significant differences among pairs of fixations, durations, and durations per fixation means for line simplification tolerances. The results indicated no significant differences at the .05 level among pairs of means of the eye movement parameters.

### *3.2 Task 2 - Estimation*

In the second map-analysis task, subjects were asked to estimate the percentage of each test map covered by water to the nearest five percent. Results are shown in Table 2.

*Table 2:* Task 2 mean scores and standard deviations (*SD*) of eye movement parameters for four levels of line simplification tolerances.

| Simplification Tolerance | Number of Fixations | | Durations of Fixations, msec | | Duration per Fixation, msec | |
|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD |
| .000 | 48.96 | 16.02 | 21514.07 | 11748.02 | 408.88 | 142.11 |
| .025 | 46.84 | 12.35 | 18391.33 | 6294.44 | 367.58 | 89.11 |
| .050 | 45.58 | 14.69 | 18188.44 | 2813.14 | 399.96 | 63.76 |
| .100 | 47.97 | 13.22 | 18593.72 | 5935.95 | 436.23 | 120.62 |

Line simplification tolerances failed to produce any statistically significant major effects at the 95 % confidence interval on the fixations, durations, or durations per fixations, as substantiated by application of the ANOVA. Step-wise regression analysis further revealed the absence of any significant interactions in which line simplification tolerances played a role. Thus, line simplification tolerance was not found to be statistically significant as a major effect, or as a contributing interaction at the 95% confidence interval. And, not too surprisingly, the Tukey A multiple-comparison tests on pairs of means of the fixations, durations, and durations per fixation produced no differences between or among them. None of the eye movement parameters produced an *F* value greater than one.

### *3.3 Task 3 - Comparison*

The third task required subjects to report which of two forested areas on a portion of a topographic map was larger. Descriptive statistics are given in Table 3.

Table 3: Task 3 mean scores and standard deviations of eye movements parameters for four levels of line simplification tolerances.

| Simplification Tolerance | Number of Fixations | | Durations of Fixations, msec | | Duration per Fixation, msec | |
|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD |
| .000 | 34.44 | 30.00 | 11302.93 | 10311.63 | 319.21 | 95.30 |
| .025 | 28.02 | 10.47 | 7985.86 | 2627.83 | 309.52 | 50.45 |
| .050 | 28.17 | 23.70 | 9148.36 | 9107.95 | 299.89 | 53.71 |
| .100 | 28.78 | 19.85 | 9274.94 | 6823.28 | 316.98 | 78.98 |

When an ANOVA was conducted on each of the three eye movement parameters, line simplification tolerances were found to have no statistical significance at the .05 level. Furthermore, results from the step-wise regression analysis revealed that line simplification tolerances were neither major effects, nor contributed to any significant interactions at the 95% confidence interval. Tukey multiple-comparison tests produced no statistical differences between any of the mean pairs of number of fixations, durations of fixations, or durations per fixations. In all cases, *F* was less than one.

## 4 Discussion

In performing map analysis tasks it was postulated that as geographic detail in a map image was progressively reduced, the number of fixations, their durations, and the durations per fixation would decrease. Thus, maps designed with rectilinear components rather than curvilinear ones would be processed visually more quickly and with fewer fixations. The interest in assessing line simplification effects is in response to the work of Attneave [5] and Zusne and Michels [14]. Both reported on the relative importance of angles or points of sharp directional change to perceiving graphic images. Attneave suggested that images composed of straight-line segments were easily recognized because of the increased informational content located at points of angular deviation. Although the researchers demonstrated their assertions using simple graphics, there remains a question of whether or not visual processing is more efficient for map when composed of linear, straight-line segments.

### *4.1 Task 1 - Counting*

Variations in the mean number of fixations in the counting task did prove significantly different in the ANOVA, but line simplification tolerances, by themselves, were not a major effect. Simplification tolerances were shown, however, to be contributing factors in a highly significant interaction with visual angles and brightness differences. The experimental results also showed the statistical significance of line simplification tolerances on the mean durations of fixations. As the degree of ;line simplification increased, changing the appearance of map features from curvilinear to rectilinear, the mean durations decreased. While a fixation duration difference of about 2.5 seconds between the map with the most detail (13.07 sec) and the one with the least detail (10.41 sec) seems small, the differences between the means were statistically significant. Different line simplification tolerances were also shown to influence mean durations per fixation. Regression analysis revealed the absence of a major effect attributed to line simplification tolerance, but simplification tolerance was an important element in an interaction with visual angle and brightness difference.

These results suggest that subjects did spend less time and effort in the visual processing of images that had undergone some degree of line simplification, thereby reducing the amount of detail that required visual inspection. What is bothersome is the fact that line simplification tolerances did not play a major role in explaining variation among the means. One explanation may lie in the possibility that subjects paid little attention to the changing levels of line simplification because of the nature of the task as well as the images they were scanning. In their zeal to satisfy the task, subjects may have overlooked the physical properties of the maps. The test maps also had a rather distinctive U-shaped coastline that may have obviated the need for close inspection following the first few maps. Although the location of targets varied, the basic map configuration did not. Thus, subjects may have "learned" enough about the test maps to render the line simplification tolerances less effective in influencing the eye movement parameters.

### *4.2 Task 2 - Estimation*

None of the tests for statistical significance in Task 2 revealed any major effect or interaction attributable to line simplification tolerances. The only conclusion one may draw is that, in the present experimental condition, line simplification exercises little control over fixations, durations of fixations, and durations per fixation. It is difficult to explain the absence of effects caused by simplifying the graphic images through point elimination. Use of straight-line segments in the experimental maps did not replicate the results of Attneave [5] or Zusne and Michels [14]. It is unclear whether or not their approach was of a free-scan, or a task-oriented nature. This may have some bearing on the results since Castner and Eastman [15, 16] found that physical features were more important in free-scanning, whereas cognitive ones assumed dominance in the task-related experimental environment.

### *4.3 Task 3 - Comparison*

The results of the comparison task revealed that the number of fixations was highest for the stimulus that possessed the highest quantity of detail, as had been hypothesized. The mean number of fixations for the next three line simplification tolerances (.025, .050, and .100), however, varied by less than one millisecond, indicating that removal of detail through point elimination failed to reduce the visual processing effort. Of the three independent variables, visual angle, brightness difference, and line simplification tolerance, used in the comparison task, line simplification was the only one in the ANOVA shown to have no significant effect on the number of fixations, their durations, and the durations per fixation. Regression analysis also revealed that line simplification tolerances failed to contribute to any significant interactions with the other independent variables. Despite the numerical differences among the means, they were not large enough to be statistically relevant.

## 5 Summary

It was suggested at the beginning that as an image was simplified by removing successively greater amounts of detail from a graphic image, the number of fixations, the durations of those fixations, and the duration per fixation would decrease concomitantly. The experimental data revealed that line simplification tolerances were not major effects in explaining variations among the eye movement parameters. Line simplification tolerances, as an interaction with visual angle and brightness difference, were statistically significant with respect to the number of fixations and their durations in the counting task (Task 1) only. Line simplification tolerances, either as a major effect, or an interaction, were statistically insignificant in both the estimation task (Task 2) and the comparison task (Task 3).

It is difficult to determine why the results for the estimation (Task 2) and comparison (Task 2) tasks were negative. In performing the estimation and comparison tasks, subjects apparently paid little or no attention to the fact that quantities of detail had been removed from some of the test maps. Had subjects recognized the more general nature of some of the maps, the results might have been more in line with the anticipated results. Or, perhaps the differences between line simplification tolerances were too small to produce noticeable differences in the test maps. On the other hand, there is a greater likelihood that subjects, under pressures associated with a performance task, were more concerned about completing the task in as short a time as possible. Unfortunately, subjects were not queried about whether or not they had noticed changes in the levels of line simplification among the test maps.

It is clear that this experiment has left many questions unanswered. First, there is the question of whether or not a free-scan, or a task-oriented experiment would produce different results. Could it be that the reported results of this experiment are artifacts of the task-driven experimental design? Secondly, there is the question of whether or not map readers actually notice and make use of a line-simplified image during visual processing of the graphic information. Until further research better defines the perceptual role of line simplification in cartography, it appears that some of the research focussed on digital line simplification algorithms may have a more pronounced mechanical bias.

## 6 References

[1] Wood, C. H., 1993. Visual search centrality and minimum map size. *Cartographica*, Vol. 30, No. 4, pp. 32-44.
[2] Wood, C. H., 1994. Effects of brightness difference on specific map-analysis tasks: an empirical analysis. *Cartography and Geographic Information Systems*, Vol. 21, No. 1, pp. 15-30.
[3] Wood, C. H., 1995? Perceptual responses to line simplification in a task-oriented map analysis experiment. *Cartography and Geographic Information Systems*, submitted.
[4] Douglas, D. and T. K. Peucker, 1973. Algorithms for the reduction of the number of points required to represent a digitized line or its caricature. *The Canadian Cartographer*, Vol. 10, No. 2, pp. 112-122.
[5] Attneave, F., 1954. Some informational aspects of visual perception. *Psychological Review*, Vol. 61, No. 3, pp. 209-222.
[6] Buttenfield, B. P., 1985. Treatment of the cartographic line. *Cartographica*, Vol. 22, No. 2, pp. 1-26.
[7] White, E. R., 1985. Assessment of line-generalization algorithms using characteristic points. *The American Cartographer*, Vol. 12, No. 1, pp. 17-27.
[8] Jenks, G. F., 1985. Linear simplification: how far can we go? Paper presented at the 10th Annual Meeting of the Canadian Cartographic Association, Fredericton, New Brunswick, June, 1985.
[9] McMaster, R. B., 1989. The integration of simplification and smoothing algorithms in line generalization. In: McMaster, R. B., editor. Monograph 40. Numerical generalization in cartography. *Cartographica*, Vol. 26, No. 1, pp. 101-121.
[10]Marino, J. S., 1979. Identification of characteristic points along naturally occurring lines: an empirical study. *The Canadian Cartographer*, Vol. 16, No. 1, pp. 70-80.

[11] Jenks, G. F., 1981. Lines, computers, and human frailties. *Annals of the Association of American Geographers*, Vol. 71, No. 1, pp. 1-10.

[12] Buttenfield, B. P., 1991. A rule for describing line feature geometry. Chapter 9 in: Buttenfield, B. P. and R. B. McMaster, editors; *Map Generalization: Making Rules for Knowledge Representation*, London: Longman, pp. 150-171.

[13] McConkie, G. W.; C. W. Scouten; P. K. Bryant; and J. Wilson, 1988. A microcomputer-based software package for eye monitoring research. *Behavior Research Methods, Instruments,& Computers*, Vol. 20, No. 2, pp. 142-149.

[14] Zusne, L. and K. M. Michels, 1964. Nonrepresentational shapes and eye movements. *Perceptual and Motor Skills*, Vol. 18, No. 1, pp. 11-20.

[15] Castner, H. W. and J. R. Eastman, 1984. Eye movement parameters and perceived map complexity - I. *The American Cartographer*, Vol. 11, No. 2, pp. 107-117.

[16] Castner, H. W. and J. R Eastman, 1985. Eye movement parameters and perceived map complexity - II *The American Cartographer*, Vol. 12, No. 1, pp. 29-40.