Exploring the map reading process with eye movement analysis

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Abstract. The features processed in a primary stage of vision can be of guidance to visual search. The list of preattentive features indicated by psychological research bare many similarities to the fundamental cartographic design tools (visual and dynamic variables). This paper presents the performance of two experimental studies, which examine the influence of preattentive vision in map reading process. The experimental studies involve both "top-down" and "bottom-up" procedures. The methodology of eye tracking is used in the experiments.

Keywords. Preattentive vision, visual variables, dynamic variables, eye movement analysis, cartographic experimentation

1 Introduction

The stages of visual processing have a great influence in visual perception. Studies in scientific fields as psychology, physiology, neuroscience etc, suggest the existence of two fundamental stages in vision: the "preattentive" and the "attentive" stage. In the preattentive stage introduced by Nessier [1], several features are processed rapidly over the entire field [2, 3] while in the attentive stage the so called "focus of attention" is shifted in particular locations of visual field [2]. The features that are preattentively processed (referred as "preattentive" or "basic" features) can attract attention in a "bottom-up" (or "stimulus-driven") way and can guide selective attention [4].

Cartographic symbols are design tools, used to represent a portion of the real world, which consists of phenomena, qualitative or quantitative, and of different spatial dimensions. "Visual variables” are the graphic elements essential for the design of static maps, while “dynamic variables” are the additional design tools for animations. The list of visual variables introduced by Bertin [5] includes position ("planar” variable) and size, value, texture, hue, orientation and shape ("retinal” variables). The list of dynamic variables includes duration, rate of change, order, display rate, frequency and synchronization [6]. The list of features preattentively processed (e.g.
motion, color, size etc, [7, 3, 4, 8]) bares many similarities to the list of design tools for map symbolization (static or dynamic).

Experimentation is considered essential in many scientific fields related to visual search and visual perception. Eye tracking is a valuable tool for examining visual search tasks. The analysis of eye movements can reveal crucial indications concerning the perceptual processes that occur during the observation of a visual scene, providing an objective and quantitative evidence [9, 10]. Eye tracking methodology has become a valuable tool in cartographic (e.g. [11]) and spatial (e.g. [12]) research, as it can bring about results of visual activity during the observation of cartographic representations.

The aim of the present study is to examine the influence of preattentive vision in map reading with experimentation based on eye movement analysis. Two discrete cartographic experiments conducted in the Laboratory of Cartography of National Technical University of Athens (NTUA) are presented. In experiment A, the selectivity of a topological property of the visual variable of shape is examined [13, 14, 15], while experiment B investigates optimal values in the joint function of the dynamic variables of rate of change and duration [16]. The results, concerning the impact of preattentive stage of vision in the effectiveness of map displays, are remarkable.

2 Laboratory Setup and Analysis Software

Experimental procedures are conducted using a Viewpoint Eye Tracker® by Arrington Research installed in the Laboratory of Cartography of NTUA. The eye movement recording system uses three methods for gaze detection; pupil location method, glint location method and pupil-glint vector. The sampling frequency of the system can be selected between two available choices (30Hz and 60Hz). The visual range corresponds to ±44/±20 degrees (horizontal/vertical) of visual arc while the spatial accuracy of the recording system is between 0.25–1.00 degrees of the visual arc. More information about the eye tracker equipment is cited by Krassanakis et al. [15].

In order to perform a post-experimental eye movement analysis, a specific software was developed that is a MATLAB toolbox which enables a list of functions to support the analysis of eye tracking protocol in main (fixations and saccades) and derived metrics (submitted for publication). Additionally, the toolbox supports all the well-accepted visualization techniques (e.g. heatmaps, space-time-cube) of eye tracking data. The detection of fixation events from the eye tracking protocol is performed using an introduced algorithm. The fixation identification algorithm is a dispersion-based [17] type of algorithm with spatial and temporal constraints.
3 Experimentation

3.1 Experiment A

The aim of experiment A is to examine the influence of the feature of “having a hole” of the visual variable of shape using eye tracking methodology. There are remarkable indications that the attribute of “having a hole” is processed preattentively [18, 19]. Eight subjects were asked to search for a designated point symbol characterized by the uniqueness of the topological property of hole among geometric and pictorial distractors placed on the same smooth cartographic background (Fig. 1). 16 different maps were designed in total (eight with abstract and eight with pictorial symbols). In the cases examined, the target symbols are located in the center, the middle and in the periphery of the base map. Also, the case of target absent trial was examined.

![Fig. 1. An example of the same smooth cartographic background with abstract (left) and pictorial (right) symbols, which compose two different visual scenes of the experiment A](image)

The analysis of eye tracking data in fixations, saccades and scan paths shows that in most trials visual search starts from the place where the target symbol is located in the previous stimulus. In all other trials the place where the target is located in the previous scene is included in the generated scan path. When the target is located in the periphery of the map, scan path is more complicated and covers a larger area, while when it is located in the middle or in the center it is simpler. Fixations’ areas correspond to places of the base map where point symbols are located while visual search process through target and distractors is depicted as the part of saccadic movements in the scan path. Scan path is more complicated in the trials where the target is absent from the stimulus scene. An example of a complicated scan path in comparison with a simple one is presented in Fig. 2. In target-absent trials, eye movement analysis does not reveal any special pattern of searching. The analysis shows that the verification of the target's detection is independent of the location that it is indicated.
3.2 Experiment B

The aim of experiment B is to examine the joint function of the dynamic variables of duration and rate of change. The optimal range values of rate of change while the magnitude of changes is held constant and the variable of duration changes are investigated. Eye movements of 32 subjects are recorded while observing a moving point symbol on a simple (blank background) and a topographic map (Fig. 3). The location of the point symbol changes in successive visual scenes while the background remains constant.

Different durations of point symbol placement in the visual scene are tested, specifically ranging from 100msec to 3sec. The minimum threshold of 100msec corresponds to the minimum theoretical value of duration fixation as it is indicated in many studies (e.g. [20, 17, 21]). 98 different visual scenes (49 for blank background and 49 for topographic map) are designed for the performance of the experiment.

The analysis of eye movements reveals the cases where the moving point symbol was detected or not. The relation between the duration and the change in distances is
examined. For both blank background and topographic map, a limit zone can be defined between the detected and non-detected combinations of durations and distances. The results indicate a positive relation between duration and distance; the subjects’ reaction is faster when the amount of change in point symbol location is smaller, which is translated in smaller distances between successive moving symbols. Subjects perform less efficient observations when the distance between successive moving points is increased in both blank background and topographic map. The different levels of abstraction discerned in the two different backgrounds seem to influence the process of moving point detection since in the case of real topographic map the zone of the limit area is slightly wider (Fig. 4).

Fig. 4. The limit zones for the detection of moving point symbols in blank background (left) and topographic map (right) of the experiment B

4 Future Research

Considering the similarities occurring between map design tools and preattentive features, further experimentation using other design variables (which are in agreement with preattentive features) may increase understanding of the map reading process. Conjunctive searches (combination of two variables from the list of visual or/and dynamic variables) may produce interesting results concerning the efficiency and the effectiveness of the graphic design tools. The use of base maps with discriminate levels of abstraction may be used in order to pinpoint the map locations where the gaze attention is most attracted and to indicate the way the additional map information influences map reading tasks. This fact is of major importance in cartographic design.

References