

Evaluation of the Selectivity of Visual Variables

Research Team

Vassiliki Filippakopoulou, *Associate Professor, NTUA, Greece*

Byron Nakos, *Associate Professor, NTUA, Greece*

Evanthia Michaelidou, *Ph.D., NTUA, Greece*

Leda Stamou, *Ph.D. Candidate, NTUA, Greece*

Introduction

Undoubtedly cartography has a long tradition to symbolization. However, before Bertin formulated Image Theory [1] and introduced systematic guidelines for symbolization, cartographers were largely based on convention and experience. Bertin proposed seven visual variables as the building blocks of the sign language and syntactic rules to match the variables to characteristics of the data to be represented. The influence of his theory has been considerable and his framework has been adapted and extended by the cartographers. But, Bertin based his theory solely on his introspection and made no attempt to provide any empirical data support, or to ground his theory on perceptual or physiological research. He placed the control and explanation for behavior in the image and overlooked the viewer. In contrast, psychology and physiology can explain perception by process within the viewer.

The target of the present study is the examination of the map user's response to the visual variables introduced by Bertin and adopted by the cartographers.

Theoretical background of the study

Bertin's image theory serves as a medium that provides a bridge between cartographic symbolization research and research in psychophysics, psychology and vision. Bertin [1] defined two classes of variables: planar variables (position in the plane - X, Y location) and retinal variables (shape, orientation, color hue, texture, color value and size). He used the term "retinal" based on an assumption that humans have automatic, preconceptual reactions to these variables at the level of retinal processing. According to Bertin shape, orientation and hue are associative visual variables. Variations within each of these variables can be ignored, allowing the symbols using that visual variable to immediately form a group. Hue, texture, value and size are selective variables. The eye can isolate all the symbols of this category, disregard the others and immediately perceive the image formed by the given category. Value and size are ordered variables that lead to preattentive appreciation of underlying order. Size is quantitative variable that gives preattentive cues to the numerical ratio of two signs, which differ along the variable. The terms "preattentive", "immediate", "preconceptual" and "automatic" emphasize the necessity of designing displays so that the viewer can effortlessly perceive the fundamental visual elements. The distinction between immediate and sign

by sign perception proposed by Bertin is analogous to the dichotomy of preattentive and attentive perception defined by psychology and vision researchers.

Researches in psychology and vision, working to explain how the human visual system analyses images, can provide explanations for many aspects of Bertin's theory. There are several theories, which attempt to explain why some searches are preattentive and others require focal attention like Triesman's Feature Integration Theory [2], Julesz's Texton Theory [3] Duncan and Humphreys's Similarity Theory [4], and Wolfe's Guided Search Theory [5]. A literature review revealed that only for a small number of attributes there is consensus that they are preattentive features or basic features [6]. There are converging data for color, orientation and size, which support that they are undoubted basic features. Shape, line termination, closure, topological status and curvature can be considered probable basic features.

Marr [7] in his Computational Theory of Vision determined attributes of shape, which are basic to form representations at different stages of processing. If Marr's assumptions about shape and mental representations are correct, they can be applying in creating map symbols.

MacEachren [8] analyzed cartographic researches focusing on the perceptual properties of visual variables and concluded that further study is needed. More recent studies [9, 10] in cartography were based on the above-mentioned theories of psychology and vision but they used very simple backgrounds or very simple maps, which did not correspond to the usual complexity of maps.

Description of tests

A series of tests have been conducted focusing on the examination of the level of perceptual organization supported by four basic visual variables applied in cartographic symbolization: shape, hue, value and size. Specifically the followings are examined:

- The selectivity of shape (not selective according to Bertin) in relation to the degree of abstractness of cartographic symbols.
- The selectivity of hue (selective according to Bertin) with cartographic symbols of different hues.
- The selectivity of value (selective according to Bertin) in relation to laws of gradation.
- The selectivity of value in relation to number of categories or length.
- The ordered and ratio levels of organization of size (ratio according to Bertin) and value (ordered according to Bertin).

“Selectivity of shape” test

The test examines:

- Whether shape can be selective and symbols can pop out from, or be grouped with, symbols of the same complexity.
- Whether the complexity of symbols affects the degree of selectivity.

Pictures with six abstract, six composite and six pictorial symbols were designed (Figure 1). Each picture was displayed for a short period of time (7 sec) and then, the participant of the test was asked to recall the shapes he/she saw.

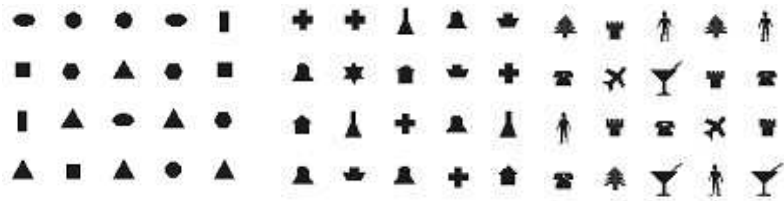


Figure 1. Segments of pictures with abstract / composite / pictorial symbols

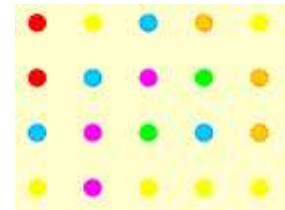


Figure 2. Segment of picture colorful symbols

The mean number of symbols recalled was: 4.20 ± 1.13 for abstract symbols, 2.87 ± 1.11 for composite symbols and 3.67 ± 1.18 for pictorial symbols. Circle and triangle were the most recalled and hexagon and rectangular the least recalled abstract symbols. Cross and star were the most recalled and ship and bell the least recalled composite symbols. Man and tree were the most recalled and tower and ship the least recalled pictorial symbols

“Selectivity of hue” test

The test examines:

- The relative selectivity of specific hues: red, yellow, green, blue, magenta and orange.
- Whether the hue of the background affects selectivity: ochre, green and grey

Three pictures with background of different hue and with six symbols of different hue were composed (Figure 2). Each picture was displayed for a short period of time (7 sec) and then, the participant of the test was asked to recall the hues he/she saw. Hues that are perceived as basic by the human visual system according to Hering theory: red, yellow, green and blue were recalled statistically significant more times than magenta and orange. The hue of the background affected the results.

“Selectivity of value-saturation in relation with laws of gradation” test

The test examines:

- How the two color dimensions, value and saturation, can be used to symbolize information in digital, choropleth maps.
- The effectiveness of the laws (linear and exponential) used for the gradual variation in value and saturation.
- The influence of hue and map complexity in map perception.

Choropleth maps were composed with three and five classes of data (Figure 3). The gradual variation in value and saturation was based on linear and exponential laws. Maps of blue, red, green and brown color were used. The participants of the test, having the map on a display, had to fill a questionnaire. The questions asked for comparison of the density of two polygons, determination of the density of a polygon, determination of a polygon with a given density. The performance in extracting information from the maps was higher when the gradual variation in value and saturation was based on the

exponential law rather than the linear law. When the exponential law was applied, the performance was higher on maps with three classes of data rather than on maps with five classes. There was no significant difference among the maps of different colour.

“Selectivity of value in relation to number of categories or length” test

The test examines:

- The number of values perceived by the human optical system for specific hues along their gradual variation from white to fully saturated color
- The impact of the background hue (white-black)
- The impact of the law (linear-nonlinear) used for the implementation of the value variation.

The test was performed on a 17 inches CRT screen, utilizing application software specially developed to support it in ARC/INFO (ARCPLOT) environment. For all the “hue-background-law of variation” combinations, independent pictures were produced (Figure 4) and the subjects were asked to allocate (using a crosshair) the estimated points of value change, along the corresponding continuous color ramp.

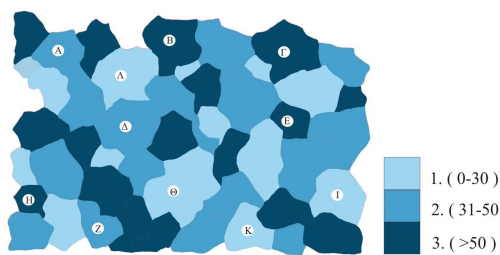


Figure 3. Choropleth map

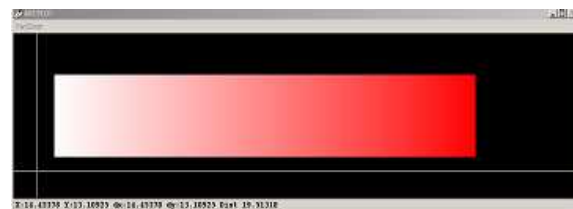


Figure 4. A picture with variation in value

The data selected reveal that the number of perceived variations of value depends on the hue, the background hue, as well as the law of variation. The bandwidth of the fully saturated color is much wider than the one of the white color. The high value (intense) hues (yellow, cyan) have the smallest number of observations

“Ordered and ratio levels of organization of size and value” tests

Two tests conducted in order to examine:

- Whether the visual variables of hue and shape can activate schemata of classification of data to map users with no systematic education on map syntactics.
- Whether the visual variables of size and value can activate schemata of ordering of data to the same map users.

At the first test, pupils (aged six to nine) of the first to third grade of elementary school, and at the second test, students (aged 14-15 and 17-18) of third grade of high school and lyceum, were asked to participate at the composition of thematic maps at the stage of symbolization. At the first test, participants had to portray themes with data of nominal and ordinal scale of measurement using point symbols, whereas at the second test, data of nominal, ordinal and ratio scale. The first test was conducted with maps on a display (Figure 5) whereas the second test, with paper maps (Figure 6).

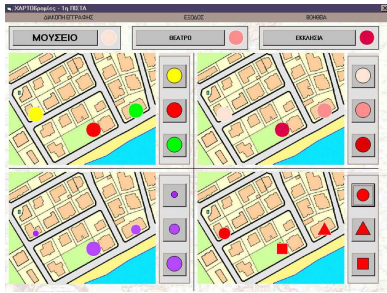


Figure 5. Maps on a display

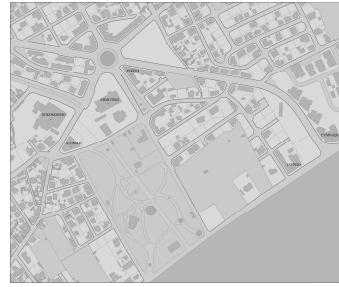


Figure 6. Paper map

The majority of the pupils of the first to third grade of elementary school could apply hue and especially pictorial shape to portray nominal data. Almost 50% of the pupils could apply size and value for ordinal data. The majority of the students (aprox. 60%) of the high school and lyceum could portray ordinal and ratio data. In both tests, size was applied more appropriate than value for quantity data.

Conclusions

- The dichotomy of the visual response to a visual variable (for example selective/not selective, ordered/not ordered) is strict. The tests reveal that between the two ends there is a continuum.
- Indications came out supporting that aspects of shape can enhance selectivity of point symbols. Such aspects are: the complexity of the outline of the symbol, the number of vertexes, the relative dimensions (high/width relation), the amorphous surface and its area and the spatial frequency which is related to the degree of abstractness of symbols.
- Recall of abstract and pictorial symbols is easier than of composite symbols.
- Indications came out supporting that different hues can be characterized by different degrees of selectivity. Red, green, yellow and blue symbols detected more times among symbols/distractors of different hues than symbols of not basic colors (come from the addition of colors). When the composite color did not have a unique component (a hue that does not exist in the other symbols), its detection was even more difficult.
- The gradation law of value-saturation affects the retrieval of information from choropleth map. The application of the exponential gradation law to differentiate the classes of data of the choropleth map enhanced the effectiveness of the retrieval of information comparing to the application of linear gradation law. Perception of the differences of value was more effective on choropleth maps with less number of data classes.
- Hue and shape can activate schemata of classification to map users with no systematic cartographic education and size and to a lesser extent value, schemata of ordering.

Suggestions for future study

- The data from the tests conducted in the framework of the present study, as well as the data from psychology and vision research support the view that the perceptual

properties of visual variables must be approached not as dichotomies, for example selective / not selective but as continuum between the two ends. This approach expands the field of research concerning the properties of visual variables for cartographers.

- Shape is the most important visual variable for cartographic symbolization. As it comes out from the analysis of psychology and vision theories and research as well as of Marr's theory of vision, the determination of the attributes of shape that are basic features, "pop out" and can be detected immediately, is very difficult. However, there are a lot of convincing data that some attributes, like terminations, topology, and size, can be basic features. The properties of these attributes could be tested and exploited with tasks on map symbols.
- More generally, from the point of view of cartography, the findings of psychology and vision research must be examined with real maps and with real cartographic tasks. The typical map is a complex display, very different from the simple displays used by psychologists.
- Bertin has determined seven visual variables but MacEachren has determined twelve by adding crispness, resolution, transparency, color saturation, and arrangement. The perceptual properties of these variables have to be examined.

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