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Visual features of cartographic representation in map perception

Abstract. The author describes the properties and mechanisms of visual perception in the context of their significance to the principles of symbol design as used in cartography. Map perception relies on the process of visual perception. Therefore, the knowledge of its inner workings in the map environment allows cartographers to construct cartographic symbols in agreement with the properties of the visual system.

Visual perception involves neurosensory processes taking place between the eye and the short-term memory. As such, they operate independently of the beholder's consciousness and significantly influence the information received by the map user. The author discusses the mechanisms of human vision and the nature of the process of visual perception. It also shows the relationships between the image characteristic and the visual system's properties such as the optical resolution, visual adaptation, reactions of inhibition and reinforcement, reactions to the image characteristics – as well as the phenomena of contrast, grouping and spatial arrangement.

The principles of constructing map symbols that have been developed in the long course of cartography, and based mostly on the map makers' intuition, find validation in the light of properties and mechanisms of visual perception. As discussed in the paper, the fundamental properties and basic mechanisms of human vision support the view that knowledge of how the visual system works provides foundation for articulating new mapping guidelines and cartographers' calls for stricter observance of cartographic principles are fully justified.

Keywords: perception, visual system, graphic variables, visual primitives

1. Introduction

Rapid exchange of information in which maps currently participate requires a more precise than ever formulation of cartographic language to keep up with the needs of conveying information to specific audiences and for a specific purpose. The use of perception principles is particularly important in computer systems that let us generate maps quickly and easily but in hands of people unfamiliar with cartographic principles, their use facilitates making some serious errors.

Maps are images with specific graphic and conceptual properties, where reception is largely determined by the functionality of the visual system. Studies on map perception performed in the 80s and 90s of the 20th century, and experiments in cognitive psychology, shed light on the basic workings of the visual system and contribute to the deepening of our knowledge about the map perception process. From this point of view, it is important to become familiar with both the process of visual perception that serves as the basis of map perception as well as the properties of the visual system that determine how the individual features of map symbols and map as a whole are perceived.

2. Properties of the visual system

Map perception is based on the process of visual perception[1] involving the eye and part of the nervous system that transmits information

[1] We consider here only the process of perception related to the visual system. People with visual impairment use the senses of touch and hearing and in such cases, the map perception process has a completely different character and should be the subject of a separate study.

to the brain centers controlling the phenomena of attention and memory. The light rays reflected from the surface, i.e. the visible light waves of different length and amplitude, reach the photoreceptors located on the surface of the ***retina*** at variable density. These are ***rods*** and ***cones*** differing in their ability to absorb light of different wavelengths and amplitudes. Cones react to a high level of illumination. The three types of cones respond to three wavelength ranges – long, medium and short – corresponding to the three primary colors – green, red and blue. The beam reflected from the ***point of fixation***, or a small area on which sight focuses in the field of view, falls on the ***macula*** populated with tightly packed cones characterized by high resolution and good color differentiation (P.H. Lindsay, D.A. Norman 1984; M. Ostrowski et al. 1992). Moving away from the macula, the cones are replaced by rods responding to contrasts in the peripheral parts of the visual field.

Neural signals from the photoreceptors are transferred to the higher levels of the nervous system by ***ganglion cells*** that connect photoreceptors with each other and the ***optic nerve***. Impulses from cells connected to the adjacent areas of the retina can reinforce or inhibit each other, depending on the strength of stimuli in both areas (P.H. Lindsay, D.A. Norman 1984).

The eye reactions are transferred to the **receptive** ***field of the visual cortex*** where "modules" of specialized processing cells encode the presence of a certain characteristics such as size, shape, color and orientation. This information is then transmitted to the ***visual associative field*** where shapes and spatial arrangements of individual picture elements are identified. At this stage, some higher level information processing already participates in perception.

Properties of the visual system significantly affect the character of the image perceived by the map user. These include the visual resolution, visual adaptation, signal reinforcement and inhibition, recognition of the image's particular features and the phenomenon of grouping (C. Bonnet et al. 2003).

The light rays reflected from the object form an angle with the visual axis defining the ***angle of view*** or the ***field of view***. Another property of eyesight is called the ***visual acuity*** or ***sharpness of vision*** and depends on the density of receptors on the retina. The visual acuity is typically the highest at the macula and decreases rapidly with the distance from that area.

Eyesight adapts to the temporal and spatial changes in the lighting levels due to the phenomenon known as the ***eye adaptation*** This property affects the perception of brightness and color as well as the size of adjacent picture elements. The average level of retina illumination is called the ***level of light adaptation***. In terms of brightness, this property is unimportant in map use under normal circumstances, i.e. when light level is sufficiently high and constant. But it plays an important role when the map is viewed under special conditions, for example while driving, navigating a plane or participating in the orientation run. In the case of polychromatic light, we are dealing with the ***color constancy*** that enables a subjective perception of an object's color to remain constant regardless of the lighting level (J. Zabrodzki, ed. 1994).

Adjacent photoreceptors augment or inhibit each other's reactions. Stimuli of similar intensity induce the effect of ***spatial aggregation***, while longer stimulatory duration causes temporal addition of reactions (C. Bonnet et al. 2000). In turn, different degrees of receptors' illumination cause the opposite reactions, called ***lateral inhibition***, resulting in the phenomenon of ***simultaneous contrast*** (P.H. Lindsay, D.A. Norman 1984; J. Zabrodzki et al. 1994; C. Bonnet et al. 2000). The phenomenon of lateral inhibition affects also the color perception, causing a perceived color change in the direction of the complementary hue. The phenomenon of ***after-image*** occurs in the event of changes in the nature of the stimulus over time.

3. Reactions of the visual system to the image features

The eye sensitivity to the light reflected from the image depends on elementary features that derive from the ***light intensity and frequency***. These characteristics include brightness, size, color, orientation, contrast and spatial frequency. Perception is also associated with the phenomena of ***grouping***, ***figure-ground*** separation, articulation of ***form*** and ***contour***, and the ***relative position*** of picture elements. The fact that some features of the image are seen as elementary dimensions[2] has important implications for the definition of ***visual (graphic) variables***. Specific features of the image become an object of perception on the condition of exceeding a certain threshold. The threshold values of stimuli are different for various dimensions and they change depending on viewing conditions, and particularly under the pull of the adaption mechanism.

3.1. Image properties depending on light

3.1.1. Brightness

The intensity of light beams reflected from the map surface evokes the impression of brightness of cartographic symbols. The brightness is not perceived equivalently to its actual value. As described by the Weber-Fechner law, its estimation undergoes a systematic distortion expressed in the formula W = log (1+ LR), where W is the brightness perceived by the eye and LR denotes the actual luminance. This means that the same increase in gray level does not produce a directly proportional increase in the perceived value (P.H. Lindsay, D.A. Norman 1982, J. Zabrodzki et al. 1994). Estimation of brightness is also subjected to the adaptation mechanism making a given level of brightness to be perceived differently depending on the brightness of its background (fig. 1).

Since the value of gray shade perceived from the map does not correspond to its physical value, gray curves showing the amount of light reflected from various gray shades are used to maintain objectivity in perceptual studies of gray scales. It has been found that perception of gray levels does not change depending on whether the tested gray scale covers the shades between the ultimate margins of black and white, or just its subset, and the curves are very similar for all types of raster patterns and colors with the exception of yellow (R.L. Williams 1958).

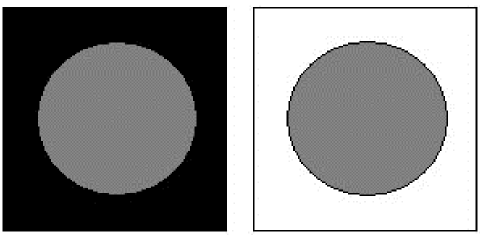

Fig. 1. The impact of sight adaptation on the perception of brightness. Gray figure on a black background appears brighter than the same figure placed against a white backdrop.

The brightness of symbols finds its application in cartography as a graphic variable used to portray the intensity of the phenomena. Among other ways, the effect of brightness differences is achieved by varying the density of raster screens. The grayscales can be constructed using various rules. The equal-value scale has gray shades increasing in equal increments and a gray tone that looks two times brighter than another is assigned twice the numerical value. The second type of grayscale based on equal intervals is formed by the division of the gray spectrum into equal steps that are not perceived in accordance with their physical values. This means that obtaining steps of equal value requires increasing the size of gray intervals. Research on the construction of equal value gray scales was conducted by R.L. Williams (1958), A.J. Kimerling (1975) and M.P. Peterson (1979). R.L. Williams observed that gray curves for point and linear raster screens are identical. Therefore, it can be assumed that similar results can also be obtained for the grain-based scales.

3.1.2. Size

Differences between the angles of view that correspond to the areas of varying brightness provide information about the areal extent or size of the viewed objects. The size of surface area occupied by a graphic object (symbol) affects the number of stimulated photoreceptors. The larger is the viewed object, the greater is the angle comprising the activated part of retina and the number of photoreceptors that get fired. The perception threshold for size is determined to be the 1'–2' of the viewing angle. Below this limit, signs cannot be seen and subsequently identified. W. Ostrowski (2008) distinguished the principle of sufficient visibility of map symbols as one of the most important principles of cartography and provided the minimum sizes

[2] J. Zabrodzki et al. (1994) and C. Bonnet et al. (2000) call therm “visual primitives”.

of point symbols, line thickness and spacing between the lines of different width.

Visual system has no mechanisms for assessing the absolute size of objects because the perceived size changes with the distance between the eye and the object. Moreover, eyesight adaptation also plays role in size estimation. Therefore, the process can only take place by comparing objects in the visual field based on the viewing angles corresponding to individual objects (fig. 2).

(1973, 1976) demonstrated that due to the phenomenon of the ***adaptation-level*** and so called ***anchor effect***, both overestimation and underestimation take place in the course of evaluating symbol sizes on the map and this makes it difficult to establish clear rules for scaling the size of map symbols.

The adaptation level is variable in symbol size estimation because the process depends on both the size of keys in the legend and the size of symbols on the map. This has been

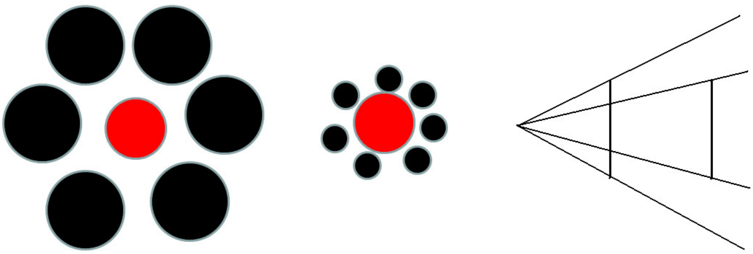

Fig. 2. The impact of sight adaptation on perception of size of symbols. Red circles of the same size appear to be larger or smaller depending on the size of surrounding black circles. The same phenomenon applies to the vertical lines surrounded by lines of different spacing.

The eye response (R) to the map symbol size (S) follows an exponential function $R = k S^w$ known as the ***Stevens' power law***. The constant ***k*** in the equation denotes the degree of adaptation of the receptor and decreases with the subsequent exposures to the stimulus. The exponent ***w*** is generally less than 1. Where *w* = 1, the relationship is linear (P.H. Lindsay, D.A. Norman 1982), meaning that equivalence between the actual and estimated size of the sign. The linearity occurs in the case of one-dimensional symbols such as lines or bars. Other shapes and 3D forms conform more strongly to the Stevens' law wielding its effect even when the size of circles is exaggerated according to the coefficient ***w*** – as unsuccessfully attempted by Williams (1956), J.J. Flannery (1971) and P.V. Crawford (1973).

T.L.C. Griffin (1985) observed that diagrams scaled according to the J.J. Flannery's rule are still subject to the power law. This creates an impression of disproportion because size exaggeration simultaneously lowers the exponent ***w*** so much that the scaling coefficient needs to be increased again. In addition, C.W. Cox confirmed in a series of tests that this author carried out in the nineties with participation of about fifty cartography students. The tests have revealed both the overrating and underrating of symbols' sizes judged against each other and the legend keys. This phenomenon is easy to notice when a single stimulus (just a single circle was used in those tests) is compared to other symbols. But in real map situations comparisons are made between various pairs of map symbols and it is hard to establish which estimates are overvalued and which are undervalued[3].

Two potential scenarios are possible in size perception on maps. The first one occurs when both signs are simultaneously present in the visual field. The second takes place when compared symbols are so removed from each other that comparison requires the sight to shift. This applies to symbols located in a di-

[3] The study design followed the test described by P.H. Lindsay and D.A. Norman (1984) on pp. 643–647. Experiments were conducted for the purpose of teaching and their results have not been published.

stance on the same map and especially to comparisons of map symbols against the keys in the legend. Such situations necessitate the use of long-term memory

Estimating size through symbol comparisons takes place at levels corresponding to different scales of measurement and each involves different mental operations and the varying degrees of long-term memory engagement. At a ***nominal level***, comparisons of size difference yield only the information that symbols differ and do not require detailed specifications. Comparisons at the ***ordinal level*** require the use of simple logical operators: equal, smaller, larger. The visual system is engaged here only at the sensory level associated with the iconic memory and do not access any higher cognitive structures such as knowledge of magnitude measurements.

Comparisons on the ***interval level*** include an assessment of "by how much" is one symbol larger or smaller from another and involves knowledge of measurement units (mm, cm). The difficulty in such operation is that map symbols are scaled based on various parameters: length, surface or volume. In general, however, symbol sizes are compared using one-dimensional parameters such as the bar height, the circle radius (also for circles representing spheres), the length of cube's side and so on. Size evaluation of symbols representing 2- and 3-dimensional forms entails mental operations involving the second and third power calculations. But since performance of those operations is not well understood, the operational foundation for such comparisons is missing (G.C. Dickinson 1967). This assertion was confirmed in W. Olsson (1963) and P. Grohmann (1975) studies indicating that estimates of surface area are generally more accurate than the estimates of volume.

At the ***ratio level***, assessment entails a comparison of "how many times" is one symbol larger or smaller than another, which necessitates the use of multiplication or division to calculate the ratio and raising to the second and third power in the case of two- and three dimensional parameters. These operations are performed correctly only when the threshold values of differences between the symbols are sufficient. The threshold values are not constant – they depend on both the size of symbols being compared as well as the distance between them.

The perception of symbol size as a function of the visual system causing a small circle stimulating a smaller number of photoreceptors than a large circle corresponds to the used in cartography graphic variable of size. Comparison of two differently-sized graphic symbols means increasing or decreasing the number of stimulated receptors. This provides justification for the use of this variable to represent the size of objects. But the size estimates are more accurate when an additional graphic variable, and especially color, supplement the size variable.

3.1.3. Color

As a psychophysical sensation, color is the result of various lengths of visible light reaching the eye. Modern theories of color vision are based on the Isaac Newton's discovery of colors in the visible light spectrum and the Young-Helmholtz's theory of the trichromatic nature of light perception (P.H. Lindsay, D.A. Norman 1984; S. Jabłonka 1992). The impression of color arises due to the three distinct types of photoreceptors, each sensitive to different wavelenghts. A.M. MacEachren (1995) directs attention to the essential role of the opposing relationships between cells that receive combinations of different wavelenghts from the adjacent parts of the visual field. The perception of color involves the phenomena of adaptation and simultaneous contrast, so that the color area is seen differently when surrounded by different colors (fig. 3).

Sensitivity to color is determined by the size of colored area and contrast that forms between adjacent colors. The differentiation is easier when the target object is sufficiently large – contrast is then seen more clearly. Besides physiological factors, the psychological and semantic aspects also play a big role in perception of color (A. Makowski 1967; J.C. Patton, T.A. Slocum 1985), especially the analogy between color and the on the property of the portrayed on the map objects.

As a property of images, color has a composite nature and consists of three attributes: color, also called hue, brightness and saturation[4].

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[4] Different authors use the terms "color" and "hue" interchangeably. The author uses the terminology proposed by prof. A. Makowski (1967), and used in the textbook ed. by J. Pasławski (2006).

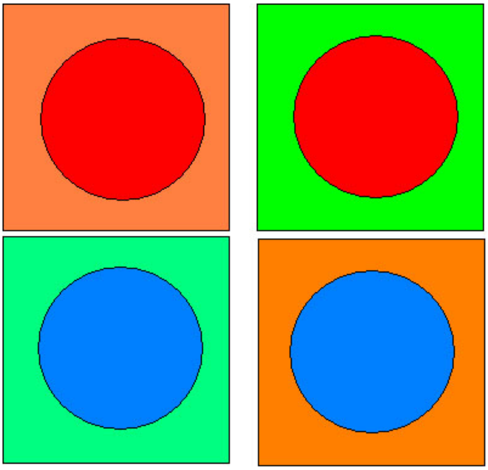

Fig. 3. The impact of simultaneous contrast on color perception. The differences between the colored spots on the background of complementary colors are more pronounced.

Color depends on the light wavelength, brightness is related to the wave amplitude and saturation determines the relative amount of monochromatic light that is mixed with white light. The hue of ink used in printing depends on the degree to which the ink absorbs all light wavelengths – with the exception of reflected light that produces a sensation of color. Blue paint absorbs the long waves, yellow absorbs the shortwaves. Waves from the middle part of the spectrum produce an impression of green.

The function of color in cartography was noticed already at times when color printing techniques were still unknown. The use of colors permitted to present a variety of information and contributed to the development of thematic and hipsometric maps. In cartography, brightness and saturation are two color components that are viewed as simple variables. The color variable conveys the message of difference between symbols and unless it is diversified in terms of brightness, it should only be used for qualitative data as a discriminating variable. Given the presence of white light component, the human eye perceives saturation as brightness. Therefore, saturation is less frequently distinguished as a separate dimension. J. Morrison (1984), A.M. MacEachren and D.R.F. Taylor (1994) describe it as the saturation of color and include it among graphic variables, next to the brightness and tone. In opinion of M.-J. Kraak and F. Ormeling (1998), saturation can be used to extend the hue scale, while according to W. Żyszkowska (2000), color in its entirety can be treated as a complex variable. It is used as an independent variable to express the intensity of phenomena and to reinforce other variables, in particular the size and form.

Application of different colors makes it easier to identify spatial arrangement but it has not been determined whether any particular wave band is more effective in the task than others (J.C. Patton, T.A. Slocum 1985. W.R. Doslak, P.V. Crawford 1977). However, A.M. MacEachren (1995) believes that the eye sensitivity to color blue is lower than that to other primary colors.

3.1.4. Orientation

The eye sensitivity to orientation of image elements is associated with the functioning of special ganglion cells and cells in the cortical centers that react when stimulus has a specific orientation and the corresponding position on the retina. Sensitivity to orientation is limited – differentiation occurs at an angle of approximately 20°. J. Bertin (1967) recommended to use only the inclination angle of 45°. Perception of orientation involves also the simultaneous contrast that creates an impression of the increasing difference between adjacent orientations (P.H. Lindsay, D.A. Norman 1984; C. Bonnet et al. 2003).

Variable orientation is used in cartography to create area patterns and distinct point symbols (e.g. crossed hammers that indicate active and closed down mines). Analogously to form, J. Bertin (1967) assigns to orientation the properties of uniformity and discrimination.

3.1.5. Contrast

Differences in brightness or color between individual picture elements create simultaneous contrast that changes the sensation of the perceived characteristics. Contrast is a prerequisite for setting symbols apart from the background and adjacent symbols. On the one hand, contrast should be large enough to avoid confusing one sign with another, but on the other, excessive contrast can disturb a visual balance. Maintaining the adequate contrast among the map symbols is one of the important problems in mapmaking because it determines the perceived harmony of the image.

The luminance differences in the field of vision form a ***brightness contrast*** that provides information on the boundary existing between two adjacent areas or between the background and the map symbol (J. Zabrodzki et al. 1994). The extent of noticeable contrast is not constant and depends on the current state of eye adaptation contrast between light and dark areas undergoes strengthening as a result of the inhibition mechanism. On the border between the areas of different brightness, it evokes an impression that the dark area looks darker on the edge than in other parts of that area and the light area appears lighter on the edge than in the rest of that area[5] (fig. 1), (P.H. Lindsay, D.A. Norman 1984; M. Ostrowski 1992; J. Zabrodzki et al. 1994).

Simultaneous contrast occurs also in the perception of color. The receptors activated by a given hue inhibit the sensitivity of neighboring receptors to that color, while simultaneously increasing their sensitivity to the complementary color. Thus, each color induces a complementary color in the neighboring parts of the viewed area. This phenomenon manifests itself by the impression of color difference between two fields of the same color, when each of them is surrounded by a different color. The hues appear more intense if the object is placed on the background of complementary colors (fig. 3). Two identical blue-green circles, placed respectively on the blue and green background are not seen as identical (fig. 4) (S. Jabłonka 1992; C.A. Brewer 1994). The phenomenon of simultaneous contrast decreases or disappears when a black or white line is used to mark the edges of the areas.

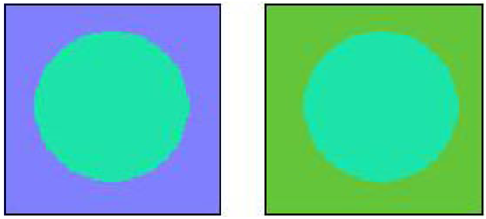

Fig. 4. The impact of color adjacency on the perception of hue. The object's color is perceived as greener (warmer) on a green (warmer) background and bluer against a blue (colder) background

The presence of ***color contrast*** has great significance for map perception because it enables the discernment among various graphical map elements and simultaneously affects the subjective sensations of brightness, hue and saturation of symbols in the immediate vicinity of each other. In the case of a large number of colors used on the map, this phenomenon may cause difficulty in color identification. It is necessary then to use additional letters annotations, as for example on the large-scale geological maps. As a property of the visual field, contrast is not classified as a graphic variable because it does not relate to the characteristics of individual objects in the field of vision. Instead, it refers to the relationships among those objects.

3.2. Image properties depending on its spatial structure

3.2.1. Spatial frequency

The discontinuity of brightness or color in the field of view creates an interweaving or mosaic-like, light and dark, differently-colored

[5] This illusion is called the Mach bands.

map areas, creating an impression of a more or less distinctive boundary. C. Bonnet et al. (2000) propose to consider the size of such areas and the distance between them in terms of ***spatial frequency***. Dense arrangements of small elements form a high frequency pattern, while large, widely scattered objects create an impression of low spatial frequency. Thus, density and size are the two characteristics of symbol arrangements on the map that contribute to spatial frequency.

The responsiveness to this property is associated with the spatial resolution of the retina, which in turn depends on the density of photoreceptive cells. What defines it is the so-called coefficient of sensitivity to contrast, with its threshold value depending on the smallest spacing between elements that makes it possible to tell them apart. At high frequencies, and hence small image elements, contrast loses its meaning, while at low frequencies, the degree of contrast must be sufficiently high to stimulate the eye. Regions with spatial frequency higher than the threshold are perceived as spatially uniform.

Like in the case of brightness, the visual system has no mechanism to assess the absolute value of spatial frequency and this characteristic is additionally a subject to the Fechner-Weber law (P.H. Lindsay, D.A. Norman 1984). Furthermore, in similarity to color, it is also susceptible to simultaneous contrast, making the region's spatial frequency to appear different than actual when viewed on the background of regions with dissimilar frequencies (C. Bonnet et al. 2000).

Spatial frequency plays a big role in cartography because it provides the basis for designing area patterns consisting of point symbols or lines and used primarily on black and white versions of maps. The two characteristics of area patterns include the size of graphic elements and their density. The size of graphic elements is reflected in defining a visual variable of "grain" as suggested J. Bertin (1967), while W. Żyszkowska (2000) utilized the pattern density to propose distinguishing the property of variable density.

3.2.2. Texture

A certain relationship exists between spatial frequency and the visual property that C. Bonnet et al. (2000) describe as ***texture***. Small graphic elements of uniform size and density can be perceived as patterns changing more or less continuously. In the case of maps, various types of patterns form texture, differing in terms of regularity, shape, spatial arrangement and density. Texture defined as a pattern is included among graphic variables by A.H. Robinson et al. (1988), while W. Żyszkowska (2000) embraced it as the complex variable.

3.2.3. Grouping

The image organization is determined through the differentiation of general image characteristics among which C. Bonnet et al. (2003) include grouping and relative position. The amount of information flooding the visual system exceeds its absorption and processing capability. To remedy this problem, the system uses the means that trim down the amount of information (C. Bonnet et al. 2003). These include primarily the grouping of information into sets comprising the same or similar types of characteristics. Grouping manifests itself in an effort to reduce the image to possibly the simplest structure that can be stored in short-term memory. Groups can encompass sets of components, as well as collections of these groups, sets of sets, and so on.

The process of grouping is inseparable from the process of perception. It plays an important role not only in image absorption, but also in the organization of memory material. By reducing the number of components, it enables remembering the more complex structures. The principles of grouping elements in image perception have been established within the framework of the theory of form or shape (Gestalt). Its supporters have identified several factors in clustering that among others include proximity, similarity, continuation and closure, or the ability to complete shapes with incomplete contours (R. Arnheim 1976; A.M. MacEachren 1995; E. Nęcka et al. 2013).

Grouping by proximity derives from the fact that the elements located closer to each other give rise to the impression of uniformity. Proximate distances decide whether a given set of elements is perceived as a group. The smaller is the spacing between elements, the more visible is the arrangement. The proximity grouping depends also on the viewing distance. We see the separate elements in a close-up view, and the farther away, the larger are the groups viewed as a whole (C. Bonnet et al. 2003). Another factor that plays role in grouping is similarity, which is for the most part based on shape and orientation, but may also include color. J. Bertin (1967) attributed the property of information uniformization to similarity, while contrasting it with discrimination. For this reason, this aspect of grouping is used in defining so-called guiding elements of symbols.

Grouping of spatial patterns constitutes the essence of organizing space presented on the map. The sense of disorientation experienced when looking at the map we cannot guess what system was used to organize the portrayed space may indicate that the process of grouping is inseparable from map perception. That is why the ways of organizing the mapped space, creating the categories of symbol and their hierarchies etc. are so important. Effective communication cartographic requires the map structure of the maps is organized in every respect. This is particularly important from the perspective of the diversity strategy that people use during the map reading. In studies of grouping strategies, J.R. Eastman (1985) observed that a variety of strategies used in map perception is based on horizontal stratification, spatial proximity, regional or linear connections, and the conformity of categories. The choice of strategy depends on the degree of symbol similarity on the map, and so largely on the nature of map graphics.

3.2.4. Figure-ground

An area with uniform properties has a nature of background when another area or line system stands out against it and creates a certain figure. The background boundaries are not clearly defined, while the figure has a contour – usually in the form of a continuous line that separates an area from its surroundings. The notions of figure and background are defined within the theory of Gestalt, whereby extraction of figures from background is the most important property of the visual system. C. Bonnet et al. (2000) point out that process of separating the image element from the background is not limited to the neurosensory level and has a close relationship with memory because figure is the element that can be assigned some meaning.

Extracting form from background has great significance in cartography especially in the case of black and white maps, so that through the use of appropriate visual hierarchy the area units or symbols on the map are clearly discernible from each other (fig. 5) (M-J. Kraak, F. Ormeling 1998).

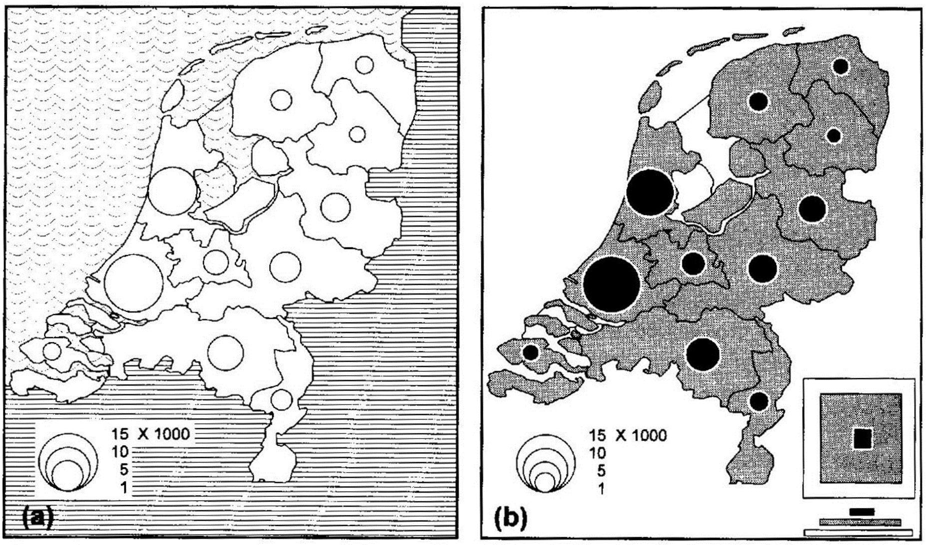

Fig. 5. The use of symbols that stand out against the background improves the map's visual hierarchy (source: M.-J. Kraak, F. Ormeling 1998)

3.2.5. Shape and contour

Each figure has a shape which results from the difference in characteristics between the figure itself and its surroundings. The shape can be emphasized by the contour. The form of cartographic signs is expressed through a graphic variable of shape that provides information on the nominal level. J. Bertin (1967) assigns to that variable a property of differentiation, as well as uniformization of information, because the similarity in one respect highlights the difference in others (R. Arnheim 1976). L. Ratajski (1989) used his principle when formulating the concept of guiding elements of symbols.

The perception of form occurs automatically, at first glance at the picture. But its identification requires differentiation and shape recognition, and those depend on two properties of form: its size and symbol complexity. Larger and simpler symbols are easier to distinguish, thus the size of point symbols with complex shape should be sufficiently large. The ability to recognize shapes is contingent on prior knowledge (for example about figure shapes and their names). P. Grohmann (1975) showed that the capacity to recall the map content is most strongly affected by semantic relationships contained in point symbols, and this applies to both geometric and pictorial symbols. Geometric symbols that exhibited any connection with the represented content (inverted semicircle as the shipbuilding industry) were recognized more easily than those that did not show such connection. An important feature of the sign is its optical weight that derives from both the size and the degree to which the contour is filled in because this affects the strength of the symbol's contrast. According to E. Vanecek (1980), shape and color also play a certain role, as well as the clustering and ordering of symbols in legend.

3.2.6. Relative position of objects

Assessment of relative positions of objects requires an estimation of angles and distances between symbols on the map and this operation requires reaching into the long-term memory and knowledge storage. Grouping also plays an important role in the evaluation of spatial relations between the map elements. J.R. Eastman (1985) and D.J. Bartram (1978) showed that the relationships between elements that belong to two different groups are memorized indirectly by remembering the relationships among groups. Specific parts of content can be absorbed in more complex ways from the perspective of location and characteristics that fall within the range of measurable properties – such as distance, size, color, brightness, density, and so on. What happens then is the automatic reduction of properties to the simplest arrangements.

The property reduction is based on two opposite but complementary activities. On the one hand, elimination of the differences between symbols takes place. On the other, differentiation occurs of everything that does not succumb to uniformization. Both similarity and difference are then the foundation for image organization. They may take into account any aspect of the image, wherein the similarity in one respect highlights the differences in other (R. Arnheim, 1976). This principle is used in mapping to define the guiding elements of symbols (L. Ratajski 1989).

4. Conclusions

Map perception relies on the process of visual perception. Therefore, the knowledge of its inner workings in the map environment enables cartographers to construct cartographic symbols in agreement with the properties of the visual system. The properties operate independently from the consciousness of the beholder and significantly affect the nature of images perceived by the map user. They include optical resolution, visual adaptation, reactions of inhibition and strengthening, the reaction to the image characteristics as well as the phenomena of contrast, grouping and spatial arrangement. As presented in the article, the relationships between image features and properties of the visual system indicate that the use of appropriate graphic variables aiming to express a variety of characteristics of the mapped phenomena is fully justified.

The principles of constructing map symbols that have been developed in the long course of cartography, and based mostly on the map makers' intuition, find validation in the light of properties and mechanisms of visual perception. As discussed in the paper, the fundamental properties and basic mechanisms of human vision support the view that knowledge of how the visual system works provides a foundation for articulating new mapping guidelines and cartographer's calls for stricter observance of cartographic principles are fully justified.

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