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ABSTRACT

This paper describes the physiolcgical "eye noise" effect of line contrast in maps and considers the effect of line contrast on the direct picture of terrain surface as produced by shaded relief. An attempt is made to describe map reading in its two major steps: 1) the enrichment of the brain image resulting from scanning the map sheet, and 2) the essential motion for the construction of map reading patterns. An experimental typographic map is proposed, with accompanying psychophysical scales, to study and control the eye noise effect. (Author/JLB)

# Eye Noise and Map Design

Mylon Merriam*

There is a visual effect which, in map reading, makes map lines appear under some conditions more, and in others less, contrasting with their surround as printed on white map paper. I have called this effect "eye noise" to draw attention to its source in the physiology of vision. For it cannot be detected as a physical change in illumination intensity--although, of course, meter reading and other measures can help to identify its occurrences.

In this paper I will be concerned first with the eye noise effect of line contrast, which has also been called the contrast-assimilation effect by Dr. Harry Helson, who has made a most thorough study of it suitable for scaling. Next I take up the effect of line contrast on the direct picture of terrain surface as produced by shaded relief. Then I attempt to describe map reading in its two major steps, first the enrichment of the brain image (physiological image) resulting from scanning the map sheet, and then the essential motion for the construction of map reading patterns. Finally I propose an experimental topographic map with accompanying psychophysical scales, to study and control the eye noise effect.

## Contrast and Assimilation

The patterning of lines is one of the fundamental features of any map. Conventionally, the more important the route the heavier the line that will be used. However, there is a point at which an increase

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in line weight (thickness) results in an eye noise effect that is the opposite of what is desired.

At map reading distance, map lines of 0.02" line weight and above tend to inhibit the seeing of other symbols. 1/ This effect is increased by groups of lines, until we reach a condition at about 0.03" line weight (0.03" intervening space) for black on white, where the dazzle is so great that it becomes almost impossible to fixate (foveally) a point and impossible to fixate another and then return to the first. In other words, map reading is brought to a halt.

The basis of this effect is the way in which the white paper glows more intensely around each black line while the black looks blacker. The heightened contrast is an eye phenomenon, not detectable as a change in illumination by our light measuring instruments. It is light intensity noise added by the visual system itself.

The importance of paying attention to this phenomenon in map design is underlined by the fact that most maps are based on line weights and line and dot screens that are less than a 10 times factor smaller than 0.02".

Now let us turn to the other end of the range. When the map line has narrowed to 0.002" the black line becomes grayer and the white paper also becomes gray, so that they draw together towards a common gray base. This phenomenon of assimilation of line and background has

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1/ For a general discussion of patterns giving visual disturbance, see McKay, D. M., "Interactive Processes in Visual Perception," in Sensory Communication (W. A. Rosenbleth), MIT Press and Wiley, 1961.

long been known and used by engravers. As early as 1510, Albrecht Dürer was experimenting with the effect of fine hachure lines to produce a middle gray to achieve a longer range of tones from highlight to shadow on woodcuts and engravings. 2/

Gray-Tone Scaling

To have any control over map production processes, the map designer needs a scale for measuring equal intervals of contrast. Recent work suggests that such a scale can be developed, with line weight the most significant element. As I have indicated, there appears to be a dividing line or zero position at around 0.02" line weight from which intervals of contrast can be measured. I am working on this problem now at the Topographic Command.

The psychologist, Dr. Harry Helson, has experimented with the effect of different width lines and intervening spaces on perception of the lightening or darkening of the tone of the surrounding paper. 3/ He has used the method of paired comparisons, which could be used in map reading measurement study and for black and white printed maps, though it would be rather difficult for colored maps. Unfortunately for my purpose, he used a much longer distance between the object and the viewer than that appropriate for map reading. His work, nevertheless, has considerable interest. Helson interprets increasing and

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2/ Panofsky, Erwin, Albrecht Dürer, Princeton University Press, Vol. 1, 1943, p. 134.

3/ Helson, Harry, Adaptation Level Theory, Harper and Row, 1964, pp. 282-294.

decreasing contrast as along a continuum, with a zero position of no contrast change, midway between extremes. Whether further work would substantiate this view or indicate discontinuities in scaling--at least for map design purposes--remains an open question.

Recent work at the National Bureau of Standards 4/ indicates an increased contrast just either side of a middle gray base--called the crispening effect--which could be interpreted to mean an increase in the number of steps of visible gray contrast for design based on a gray middle ground.

Shaded Relief and Map Reading

Shaded relief in a map results from a combination of modulated gray tones patterned to bring out the salient features of the terrain. Such shading provides a ground for interpretation of all other map symbols in two ways, (a) because modulated tone is a peripheral phenomenon any way (it needs an extended area to be seen), and (b) symbols show ground position of objects.

To understand the effect of shading and of excessive contrast or negative eye noise, it will be helpful to consider in some detail just what it is that takes place in map reading. We are concerned here primarily with general purpose maps. A good map makes it easy for the reader to see, and reconstitute, patterns that are designed into the map. It also permits him to reorganize elements into a pattern that more directly serves his use need.

4/ Judd, Dean B., "Ideal Color Space," in Palette, No. 29, 1968.

Map reading is a process ~~in a process~~ in real time, during which a series of events result in the construction of map reading patterns. Several stages can be distinguished--although they may occur so closely upon one another that the observer is not ordinarily aware of anything other than the end result. Furthermore, the several stages or physiologic motions are all influenced by feedback from one another, sometimes negating each other.

Let us start, however, by examining the phenomenon of eye fixation and peripheral enrichment. The kind of eye fixation involved in map reading is the so-called saccadic fixation, or the quick jumps from one fovial clarification of a detail to another. The first thing to notice about the result of this motion, as far as the physiologic image is concerned, is that it is negated, or subtracted. The map does not appear to move as we cast our eyes over it. What does happen is that the detail of the map begins to be enriched all around in the periphery of any one fixation. The clarification of peripheral detail accumulates as a process in time following each fixation.

The enrichment of any one previous fovial detail, when it becomes peripheral, involves a double action play, which happens so fast that, except under unusual circumstances, we are not aware of the two steps involved. It is something like the Cheshire Cat~~s~~, which Alice saw first as a real embodied cat with a grin on its face (the fovial fixation on the cat), and then saw just the grin without the cat (the unclear peripheral image of the animal, but enriched with its characteristic grin from the previous fovial fixation).

A second element in map reading is the transformation of adjacent series of fixation points or symbols into a temporal sequence. In contrast with written language, where one moves always from left to right (in English), the temporal order of the map is multidirectional. The same pattern takes me to A from B or to B from A. This multidirectionality is important in relation to the reader's ability to project into the map, design patterns of his own.

The process of pattern projection in map reading involves a series of groupings of past fixation points, all peripheral except one, on a background. The psychologist talks of figures--constellations that help one pick out a design. It is significant that ~~they~~ we do this best when there is less contrast between ground and pattern.

Map patterns have the special characteristic that they must always appear to be on the surface of the ground. The representation of ground surface is most effectively produced by shading and modulations of shading. The surface is a function of peripheral not of fovial vision. While the shaded relief or shaded surface becomes the background on which map symbols can be laid, it also can be a locating device. Because it is a larger area than any single symbol, it can be seen better on the periphery and can both locate and suggest direction.

Effective map design draws both on the positive effects of eye assimilation in creating a common gray-tone background, and on the use of contrast in a controlled way to achieve the direction that only a marked line can give.

Pattern Formation

There is a very definite motion that connects together peripheral detail to form map reading patterns. It consists in a rapid shift of attention from one peripheral detail to another. With some effort, one can become consciously aware of it. It is difficult to become aware of, for the tendency is to see completed patterns, simultaneously, as though full blown, and not the construction of them. We call this motion 'apparent' since it need not be associated with the sacaadic fixation motion of the eyes, and the map itself does not move. It is pretty much under our control, and we can connect together map elements of low, as well as high contrast, depending on our map reading purpose, the extent of peripheral enrichment, our ability, and the design itself. It is highly directional in character: as the attention shifts definitely from left to right, or right to left, etc. The sequence by which the pattern is first constructed, is not the only sequence for construction, and may not be the sequence in which it is 'read' for the map reading purpose.

Now I will select as an example, a type of map reading and its associated pattern, which is a most severe test of the quality of the design of a topographic map. Suppose we wish to plot a course across terrain from a starting point, where the starting point, as well as other points along the way, may be relatively unaccented by the design itself. In other words, we have to eliminate in whole or in part, prominant existing patterns, as well as amplify others of low contrast, to get a new combination.

The starting point where we are can be anywhere on the map sheet, and go out in any direction of our choosing. The possibilities are infinite, and all determinate. The resulting pattern is not only definitely linear and directional, but realistic, in that it portrays in correct temporal order a series of events in time. We see the point of departure, the place to stop for lunch, and the point to stop at night fall, in an adjacent patterned order, and also as a successive order in time of a series of events, with a time schedule.

I would like to stop here for a moment to point out the importance of a thorough understanding of this concept, of the equivalence of space and time on a map, or the transfer of an adjacent order in a pattern, to a serial order in time, or vice versa. It is especially important for the scientist who sets up map reading problems to test the design quality of a map by reading speed. 5/ It is equally important to the designer.

A good deal of work was carried out in the first half of this century, as reported by M. D. Vernon (1952), 6/ and more has been accomplished since then as reported by Elinore Gibson (1969), 7/ on

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5/ For a thorough discussion of this concept see Gibson, James J., Perception of the Visual World, Houghton Mifflin, 1950, and also his, The Senses Considered as Perceptual Systems, Houghton Mifflin, 1966.

6/ Vernon, M. D., A Further Study of Visual Perception, Cambridge University Press, 1952.

7/ Gibson, Elinore, Principles of Perceptual Learning and Development, Meredith, 1969.

the levels, fluctu tions and strategies of voluntary attention on the periphery of visi n, nd the successive focusing of awareness on different parts o ects of the field. This knowledge, which seems to me to be now su ficient for a description of map reading, has not been thoroughly a plied to this purpose, nor has it been applied to the devising of te for the readability of map designs, as far as I can discover.

There are so exceptions. F. C. Bartlett, formerly Director of the Cambridge I chological Laboratory, has in his book Thinking, a very interesting tudy on the readability of road maps. He turned up a point of no re urn, after which map readers, once having selected the wrong road, lost the ability to correct their course, and continued on the lo g way round. The lively Journal of Typogra hic Research sponsors interes articles on readability applied to typography. But my feeling is t what we most need now is a demonstration of the formation of ma eading patterns. There is no better medium for this than motion pi res, perhaps in slow motion and by the animation process, and using, certainly, computer graphics for solution of configurations of the physiologic image.

An attempt to show graphically, and in motion, what happens in map reading, is a rigorous discipline in itself. I know this from a motion picture portraying the resultant of motions due to binocular pursuit fixation, and its effect on rivalry of the visual globes, which I produced some time ago. But neither pursuit fixation nor

rivalry are of first importance to map reading, so I have not discussed the results of the film here. But this work has convinced me that the motion picture study method of approach, would be most profitable in application to a fundamental map reading study.

Up to this point we have focused on theoretical background. As I indicated earlier, experimental work on psychophysical scaling for the contrast-assimilation phenomenon as it effects map design, is now under way at Topocom. While I cannot report final results, I can indicate what I now see as the major elements of the experiment. First is the construction of scales, and next a rather simple experimental map, tackling first the line problem and the use of shaded relief.

Map Line Scaling

To establish a scale for our purpose with a zero eye noise value and then equally graded steps of contrast on either side of zero, for the measure of negative and positive eye noise, I suggest the following approach:

1. Choose a middle of the range Munsell value, such as Munsell 5, density 0.7, or eye middle gray for a solid printing of the gray base for the scales and the same gray after the scale construction, for an experimental map with map line and shaded relief.

2. For scales, use the same type of line patterns Helson used, that is straight parallel lines, equally spaced but at different equal intervals and width and changing to different but equal line weights

and widths from 0.003" to 0.03". Scales are prepared for viewing at map reading distances around 12 inches. Each pattern is ~~painted~~ printed twice, in black and in white, side by side, on the gray base, which is at least as large as a map sheet, say 20 x 30 inches, in order to fill the surrounding field of vision.

3. Repeat as in 2. with about the same area density of lines, but compose the pattern in lines of random direction, more like the fine criss-cross of road lines on many of our maps. There is some evidence that random direction lines are harder to see through for the discovery of patterns than parallel lines of the same density. 8/

4. Dot tint screens in black and white on gray, at about the same lines per inch as illustrated in Prof. Robinson's third edition of Elements of Cartography, 9/ illustration 11.4, would also be a most useful kind of scale for this purpose. Robinson uses a range of 27.5 to 85 lines per inch screen but on a white paper base. Especially for use in our experimental map, shaded relief in white and black on the gray base is necessary for shade control.

## An Experimental Map

We could continue with additional scales, and undoubtedly will have to return to them for black-white line mixtures before finding the

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8/ Munsinger, J. H. and Gummerman, K., "Identification of Form in Patterns of Visual Noise," Journal of Experimental Psychology, Vol. 75, No. 1, 1967, pp. 81-87.

9/ Robinson, Arthur, Elements of Cartography, third edition, Wiley, 1969.

most useful ~~ever~~ ones, but now let us turn to an experimental black to white (one color) map with a Munsell gray base. Our scale study so far will have shown that the gray base extended the range of assimilation, or positive eye noise, so that the gray base tended to become lighter with white line, and darker with black line, extending our usable map line range with both black and white line without running into negative eye noise. But our line weights still will have to be kept limited, for other reasons. We will now have to contend with a close mixture of white and black line in its effect on the gray base, and in addition, we want the major effects of modulating the tone of the gray base, to rest with the modulation of our shaded relief drawing, and will attempt to use it, both above and below the Munsell 5 base. This will take a special kind of shade drawing when the drawing is halftone, which I will discuss presently.

There is also an image screen of a special kind for a photo based map, already containing the image of the aerial photography from which it was made, which automatically obtains a middle gray tone for the image screen in the first place. This image screen will reproduce a shade drawing made in the conventional manne as well as add black and white lines, and no halftone screen is needed. I have described this process of incorporating an artists shaded relief in aerial photography, in my paper in the Cartographic Journal for July 1965, "Conversion of Aerial Photography to Symbolized Maps," and shall not discuss it further here.

I should like to insert here some of the reasons it is important to take up first the study of a black to white (or one color, or monochrome) map. There is a largely unsatisfied need for a black-gray-white all purpose topographic map which will maintain its contrasts under any color illumination. A multicolor map can never do this. Five to ten percent of the male population is partially color blind, especially in red-green. Gray value perception is universal. The experiment I will propose here will take two press impressions per sheet, but there is the possibility of one press impression, using the image screen mentioned in the last paragraph. This also opens up the possibility of limited editions without presses, with reproduction in one color using office duplicating equipment. So far this has been successful using Ozalid duplication only, and a special positive working diazo press plate is needed for the one press impression, one color reproduction of the monochrome topographic map.

There are in addition, several design reasons for focusing the attention again on the all black to white map. We have mentioned that the gray base probably gives us a longer gray scale range for symbolization. Psychoshysical scaling of the gray value dimension of the three dimensions of color, needs modification to incorporate the new knowledge on color vision such as the crispening effect (Judd). It is perhaps significant to mention here that the one control check printers always use during a run, for production control, is the gray

scale value of their color printing. Thus there are many advantages to be gained by concentrating now on a monochrome, black to white map.

The experimental map can have contours and drainage, and other thick and thin or double line and names, to the point where they interfere with the shading. All must appear to rest on the raised surface portrayed by the shading.

The map will take two printing plates, one for a solid density middle gray with block out for white, and a plate for the black. It is essential to start the experiment with a solid print and not a screen gray, in order to carry our line weights, in white, down to 0.002" or 00.003" without screen interference, for the scaling study.

For the construction of the shaded relief drawing, I would recommend the same method described by J. P. Curran, in the Cartographer for June 1967, which was used for the beautiful Orillia 1/125,000 sheet, compiled by the Surveys and Mapping Branch, Department of Mines and Technical Surveys, 1962. This drawing method is recommended for the new experiment because it produces a separate highlight drawing, for separate white halftone dot printing on the light side of the base gray. This goes on the first plate as a white dot screen blockout on the gray base. The dark side of the Canadian shade drawing is halftoned for black dot printing on the second plate.

I would also call attention to two books which are really in the nature of handbooks for our study. The first is Professor Eduard

Imhof's Kartographische Gelandedarstellung, 10/ (The Map Graphic Rendition of Terrain), which is most thorough on the reasons and the techniques for placing first emphasis upon the direct picture of relief surface, as the essential graphic for coordinating all map elements, in our construction of map reading patterns. The second, is Professor Arthur Robinson's third edition of his Elements of Cartography. 11/ It has a special interest to us, because of the dozens of beautifully designed and printed map graphics, using a gray base.

## Summary and Conclusion

This paper has focused first on the relation between eye noise and the qualities of map design. I have advanced the proposition that the sort of voluntary attention which we use for constructing map reading patterns, can be inhibited by too much line contrast, and is aided by assimilation (as defined by Helson), and that psychophysical scaling is a possibility as a control for the design. The importance of a middle gray base and the effect of shaded relief have been briefly described. The experimental work outlined and now well under way at the U.S. Topographic Command offers the promise of an advance in black-white map design that will effectively make use of the positive aspects of eye noise to create a more readable general purpose map.

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10/ Imhof, Eduard, Kartographische Gelandedarstellung, Walter de Gruyter & Co., Berlin, 1965.

11/ Robinson, op. cit.