PSYCHOPHYSICAL RESEARCH AND MAP READING ANALYSIS

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In his monograph on "Method-Produced Error in Isarithmic Mapping," 1/ Joel Morrison described four possible sources of error which could seriously interfere with the cartographic communication process. These were: errors in the collection of the data to be mapped, errors produced by the cartographic methods employed, errors in map construction and reproduction, and map reading errors. If we assume that the original data to be mapped is error free, and that no errors are committed in map construction and reproduction, then we are left with "two potentially fertile areas for cartographic research," to quote Professor Morrison: method-produced error and map reading error.

A concern for method-produced error has long been shown by cartographers but has become of critical importance with the advent of computer-assisted cartography. In order to program computers to perform certain cartographic techniques, the techniques must be well defined in mathematical terms. This forces the cartographer to analyze his methods in terms of accuracy, efficiency, and communicative effectiveness.

A knowledge of map reading error is necessary in order to evaluate the communicative effectiveness of a cartographic technique. The study of map reading error should probably be the responsibility of educators, but it has long been neglected by cartographers and educators alike. Thus, we are gathered here for the purpose of discussing map reading error, how to analyze it and how to correct it. For my part, I am here to report on one approach to the problem, a systematic and experimental approach called frame-of-reference psychophysics. This approach is based on a very broad and far-reaching theory of behavior, the theory of adaptation level, developed by the psychologist Harry Helson. 2/

For several years now, cartographers and psychologists have been using various psychophysical methods to determine perceptual errors in reading map symbols. Perhaps the best known methods are those developed by the late S. Smith Stevens and his associates at Harvard University. These are generally called scaling methods because they generate scales in the form of generalized equations from the perceptual responses of individual test subjects. Stevens is best known for his insistence that all perceptual responses should follow a generalized power law expressed by the equation $R= S^n$ or response equals a constant, k, times the stimulus raised to an exponent, n. 3/

The problem with Stevens' view of psychophysics is that it is too rigid, too narrow. Ironically, just as Stevens' view replaced the narrow views of Gustav Fechner and his followers, we must now replace Stevens' view with a broader more systematic approach. Specifically, two arguments may be brought to bear against Stevens. First, the sacred exponent, n, in his power law varies with the conditions of the experiment. Although Stevens accepted this fact, he never offered a sound explanation for it. A second, more powerful argument stems from the fact that the general form of the psychophysical law depends upon the measurement scales employed. As pointed out by the psychologist R. Duncan Luce in 1959,4/ if an ordinal response scale is used with a ratio stimulus scale, then the resulting graph is of the general form of a logarithmic equation. If a ratio response scale is used, as Stevens advocated, then the graph may be in the form of an exponential equation. A more general approach to psychophysics was needed to account for the different exponents in the power law and the differences in psychophysical methodology resulting from the use of different measurement scales.

Before discussing the results of my work with frame-of-reference psychophysics, let me briefly describe the adaptation-level theory. Adaptation-level theory is based on two principles: the bipolarity of responses or judgments, and the pooling of stimuli. Bipolarity means that judgments of any phenomenon are made along a bipolar scale, that is, along two scales which extend in opposite directions, such as hot and cold, bright and dark, or heavy and light. Where each pair of scales meets there is a point or locus of points which is neutral. This neutral reference point is called adaptation level. As distance from adaptation level increases along either of the two scales, the intensity of the sensation increases; so for example, we can go from a purely neutral response to one that is dark, very dark, extremely dark; or in the other direction one that is bright, very bright, extremely bright.

The location of adaptation level, the neutral response, with respect to any given stimulus scale varies from individual to individual, and from one test condition to another. This dynamic aspect of adaptation level is a direct result of the pooling of stimuli. By pooling I mean that adaptation level is the product or pooled effect of all stimulation both past and present. All available stimulation is taken into account before a judgment or response is made. If the condition of the stimulus changes, then the adaptation level will change. Since individuals have been exposed to very different stimuli in the past, their response to a given situation in the present is going to vary with their own level of adaptation.

Certain kinds of visual stimuli may be classified as follows: focal stimuli are those which the individual focuses on; contextual stimuli are those which form a background for the focal stimuli; anchoring stimuli are those which are used as a basis of comparison with other stimuli; and residual stimuli include past stimulation recalled from memory, and any emotional of affective influences which may occur in perception and cognition. In short, the theory postulates that the prevailing adaptation level is the basis for an individual's perceptual judgments and behavior in general.

Adaptation-level theory was first proposed as a possible explanation for map reader response to graduated circles by Kang-tsung Chang in 1969.5/ My first experiment was simply designed to show that the theory of adaptation level could be used to explain the effects of anchoring stimuli on map reading in general. Since Professor Chang had used graduated circles, I chose to test visual map complexity and found results very similar to Chang's.6/ Different anchoring stimuli caused different group responses, and the differences could be explained quantitatively by adaptation-level theory.

Next came a more challenging task, that of reformulating Stevens' power law to include adaptation level as a parameter. Professor Helson had already reformulated Fechner's logarithmic law,7/ but a simple substitution of adaptation level in place of the constant, k, in the power law could not be validated empirically. It was necessary to make another important substitution before the reformulated power law could be empirically equivalent to Stevens' formula. If the stimulus value is redefined in terms of its distance from adaptation level, then this new value, called S_a, may replace the original stimulus value in the power law, and adaptation level may replace k, so we have $R=(AL)S_a^n$ as the formula for the reformulated power law.8/ In essence, we are saying that an individual judges a stimulus in terms of its distance from adaptation level.

To demonstrate this empirically, I went back to our old reliable stand-by, the graduated point symbol, and tested both circles scaled according to apparent value, and squares conventionally scaled.9/ Once again it was shown that anchoring stimuli, in the form of different map legends, caused a shift in the adaptation level of test subjects, and their overestimation and underestimation of the graduated symbols followed the general form of the reformulated power law. One other consequence of this most recent experiment was empirical evidence that the construction of graduated circles according to an apparent value scale, such as devised by James Flannery, does not correct for the underestimation of circle size ratios. It was shown that the assimilation effects of a single anchoring stimulus were the cause of overestimation and underestimation, so that scaling the graduated circles was not as effective in correcting the problem as using several differently sized circles in the map legend.

Many problems have been encountered during the course of my research, and not all of them have been solved. The most persistent problem seems to be in defining adaptation level quantitatively in terms of the different kinds of stimuli that contribute to it. However, this is simply a mathematical problem, an empirical problem that will be worked out in time. With the data we now have from Jon Kimerling's experiments on the equal-value gray scale,10/ I think we can come to grips with the relationship between focal and background stimuli, and their respective contributions to adaptation level.

A second problem area, which I feel is a tremendous area for research, concerns what I call the map gestalt, interpretation of the map as a whole. What psychophysical research has come up with so far is little bits and pieces of a much larger puzzle. Each piece of information gathered in our research has a much larger meaning when placed in the context of the map as a whole. Our experiments have, of necessity, been conducted in isolation; we isolate particular elements of a map for testing, and we discover how the map reader reacts to this particular map element. The map reader's reaction may be different when that element is placed within the context of a very complex map. Map complexity itself requires a gestalt approach because many different factors contribute to both visual and intellectual complexity. I think most cartographers would agree that a multidimensional approach must be taken in this area, but there is probably little agreement beyond that point.

The role of past experience is an especially bothersome problem. How do we measure it, or take it into account? We assume it is responsible for individual variation, but just how does it work? Through education and training we can control to a large extent the experience of map users. This is already an important justification for map reading instruction in the public schools. If we can modify individual adaptation levels to a greater or lesser extent through training, then we ought to be able to get map readers to react similarly to our cartographic products. By similarly I mean each individual should be able to grasp the basic meaning of any given map. That is one purpose of cartographic education. The map reader may interpret the map in many other ways as well, but the basic meaning of the map ought to be conveyed to every individual who picks up the map and reads it.

Finally, one of the most interesting applications of adaptation level may lie in the general problem area of cognitive mapping and spatial behavior. Again if we can modify an individual's adaptation level, then we can probably predict the individual's response to any given situation. The mental conception that an individual has of a place depends on his attitudes, preferences, and experience; in other words, it depends on his level of adaptation to his environment. As his preferences, attitudes, and experience change (as his adaptation level changes), an individual will change his cognitive map. Nowhere is this more evident than in the work of Denis Wood,11/ who travelled through Western Europe with a group of naive young mappers, college-age students. As their knowledge and experience in various European cities grew, their cognitive maps and spatial behavior changed dramatically.

If we assume that an individual's spatial behavior is based on his mental conception of space, then the changing role of adaptation level has obvious consequences. The problem is in determining adaptation level by measuring preferences, attitudes and experience. This is the problem we should be attacking first. If we know an individual's level of adaptation, we can predict his response to any given environment, and we can reconstruct his cognitive map on this basis. The same logic should apply at the group level. The solution is not a simple one by any means, but it is only one other area of research to which the adaptation-level theory may be applied.

With this in mind, we as cartographers should apply the knowledge gained through frame-of-reference psychophysics to our map design. Those of us who are educators should apply this knowledge to our instruction. The widespread applicability of adaptation-level theory and its frame-of-reference methodology offers cartographers the unique opportunity of developing a "New Cartography" based on principles of map perception and cognition, a cartography which is more responsive to map users both in the classroom and in the environment at large.

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