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Functional Efficiency, Effectiveness, and Expressivity of Bertin's Visual Variable Colour Hue in Thematic Map Design

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Abstract: *Notions of functionality of thematic maps that were built around Robinson's seminal work 'The Look of Maps' were later redefined to include questions of efficiency and effectiveness. The possibility of the use of digital technology in map creation and reproduction widened the scope of map design research from evaluation of whole maps to the evaluation of basic graphic elements – the graphic or visual variables. The paper attempts to asses and validate one of the variables of Bertin's model of visual or graphic variables- the visual variable colour hue on the basis of available experimental evidence related to the functional efficiency, effectiveness and expressiveness of the variable at different perceptual/cognitive levels and the experimental evidence from design research in thematic cartography. The analysis of results both from psychology and design research in thematic cartography show that the two levels association and selection have adequate empirical support in the above two areas. However, the experimental results for the level order are contrary to formulations of Bertin. In case of both hues ordered in spectral progression and hues ordered around a unique hue variability expanse or range which extend to either of its limits in a limited ambit of ordered steps adequately perform at the level of order.*
Key Words: *Semiology of Graphics, Visual variables, Map design, Hue, Spectral Hues, Unique Hues*

I. Introduction

Notions of functionality of thematic maps that were built around Robinson's (1952) [1] seminal work '*The Look of Maps'* were later redefined to include questions of efficiency and effectiveness in map design research when the empirical evaluation shifted from the stimulus response correspondence in psychophysical approach to questions of both efficiency and effectiveness in cognitive information processing approach. The availability of Bertin's (1983) [2] '*Semiology of Graphics'* in its English translation and the possibility of the use of digital technology in both map creation and reproduction widened the scope of map design research from evaluation of whole maps to the evaluation of the functioning of basic graphic elements – the graphic or visual variables which are used in building the map sign vehicles and designing the tangible map image. An added impetus to this trend was the technology of Geographic Information Systems (GIS) which ended the era where the maps were limited to their presentation function only and a single map was supposed to serve different uses. The development put more emphasis on the efforts in map design research at different levels more so in terms of usability.

Bertin's visual (*retinal**) or graphic variables are generally treated as graphic expression traits giving form to map symbols which contain information on contents i.e. meaning and an expression in the form of a visible appearance (Schlichtmann 2009) [3] as tangible graphic marks with meaning and perceptible attributes. These attributes are used to build semantic and syntactical relations in map texts. In addition to Bertin, Robinson and his co-workers (1995) [4] later, in spite of certain differences, have treated these in almost the similar manner in this respect.

II. Bertin's Visual Variables

Bertin is (1983) [2] credited as the first cartographer to systematically formulate conceptions on a set of basic visual or graphic variables and a system of rules for their use. These formulations have been regarded as dogmatic in approach. However, a number of cartographers treat them as a theory or model. The image conceptualisations and sign-vehicle syntactics which is treated as given in Bertin's formulations, when taken as a

*Bertin originally named them 'retinal' variables. In later use these were called either visual or graphic variables. With the exclusion of *X, Y* geographical locations in the two dimensional plane these variables are commonly called 'graphic variables' by most of the cartographers (Robinson 1995), and (MacEachren 2008) [6]. The term 'retinal' in this context has been translated by Garalandini and Fabrikant (2009, p. 196) [7] as 'preattentive' denoting an attribute in the form of a cognitive functionality that contributes more at the first cognitive level i.e. preattentive level of visual information processing.

theory or model, invite criticism that it is not based on empirical evidence. Nevertheless, these formulations can be considered as constructs, which opens possibilities that the constructs can enter into theoretical schemes and that the constructs can be subjected to empirical verification (Figure 1).

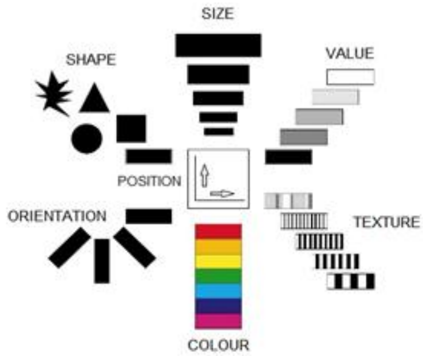

Figure 1 Bertin's visual variables (*after MacDonald, Lindsay W.*)

The dimension of colour *Hue* which forms the subject matter of the present study was identified by Bertin as *colour* in the form of hue as one of the visual variables while the achromatic value is named as another related visual variable in his formulations.

However, it has also to be mentioned that Rittschof et al. (1998) [5] and some others have pointed out that graphic designers including cartographers use colour *Hue* in symbolic presentations in order to enhance the expressivity, the clarity and usability of the created display, and their choices are mostly based on intuition independently of any given set of models, theory or rules. Despite this, the existing scenario presents a compelling situation in map design research that makes it a relevant effort to examine the validity and usability of these long held design formulations about the use and effect of colour hue as graphic variable in thematic map presentations.

Peucker's [8] use of spectral hues, as an ordered series in displaying successive variations in hypsometric data on relief maps can be seen as an example of the use of colour hue as visual variable in some early works. This use is based on the Peucker's theory of landform representation and his adaptive spectral colour scale. The mechanism responsible for organisation of an ordered sequence, in his scheme, was considered to be the compensatory physiological reaction of the eye to the differential refraction of wavelengths of light. The resultant effect is known as advance and retreat of hues in which colours evoked by a progression of longer to relatively shorter wavelengths appear to progressively recede and look further away. In addition to this hues were used extensively in presentations and visualisations of nominal category data sets with the development of offset lithographic printing technology.

III. Objectives

The paper will attempt to asses and validate Bertin's model and his conceptualisations in respect of the visual variable colour hue on the basis of available experimental evidence related to the functional efficiency, effectiveness, and expressiveness of the variable at different perceptual/cognitive levels when used in symbolisation of two dimensional static maps. Hue defines one of the three dimensions or aspects of the dimensions of the chromatic sensation from different wavelengths of light reflected back from the colourant substances and surfaces and reaching the human visual system. The dimension of hue plays the most important role in giving a recognisable distinct character to colour sensation

This assessment will be made by the use of this variable in thematic map symbolisation. This efficiency effectiveness and expressiveness will also be determined keeping in view the map use situations relevant to the information carried by this variable. Such studies are expected to lead towards better map design solutions resulting in an increased usability of the maps designed for specific tasks in different map use situations in GIS environments. The study can, as well, be used to provide the answers to the questions 'why a particular design approach failed to deliver the results in terms of usability or functional effectiveness, efficiency and expressivity?

IV. Bertin's Graphic Semiology

In Bertin's (1983) [2] formulations, the syntactical rules of map graphics derive from the levels of the visual dimensions of the graphic variables, and of the two planar dimensions of the representational space. This viewpoint comes quite close to the way in which the obtained syntactical structure at local level meets the requirements of human visual processing system for an easy comprehension of information displayed on the map Schlichtman, H. (2009) [3].

4.1 Levels of the Visual Variables

Bertin (1983), on the basis of the availability of visual information and extent of the functional role of such information in visual processing, has classified these visual dimensions into four perceptual or visual levels. Such levels have been named by Bertin as, *association*, *selection*, *order* and *proportion* or *quantity.* The six (excluding 2 planar dimensions) identified graphic variables have been organised by Bertin in an order on the basis of different levels of visual properties. These properties of graphic variables, in such an organisation, are seen to be inclusive. These perceptual levels appear to be analogous to the classification of a variable into four levels on the basis of measurement scales (Figure 2).

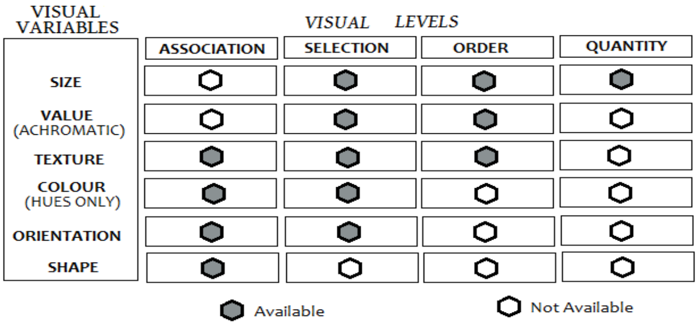

Figure 2 Bertin's visual variables with their visual levels

The perceptual or visual levels and their defining characteristics serve as a basis for the proposed rules for the appropriate use of visual variables in Bertin's (1983) [2] formulations. These rules attempt to specify how the modulations in different visual variables can be matched to corresponding variations between referent attributes with reference to measurement scales used for the referent attributes i.e. nominal, ordered, or ratio. A mismatch between the two results in erroneous design of cartographic presentation and leads to errors in local syntactical structure resulting in difficulties in visual processing of the map image and its comprehension.

4.1.1 Association

Association is that perceptual level of a visual or graphic variable that allows the perceptual grouping of all categories or instances of symbols formed by that visual variable. In terms of human visual cognition it allows the visual processing to mediate immediate grouping of all categories or occurrences of the symbols formed by the variable in the visual field by identifying and preserving the relations of similarity engendered by that variable. The stability of the similarity relations achieves compelling groupings in spite of the simultaneous presence of distracter variations in the visual input. The property appears to arise because the information, in question, has precedence in visual processing and thus pre-empts all other information. In this way, the visual dimension appears to be more primitive as compared to the next property of selection.

4.1.2 Selection

A visual variable has the perceptual level of selection if all instances of symbols formed by that visual or graphic variable can be easily selected or isolated perceptually to form a group of similar symbols. This visual level of a graphic variable is seen to enable the visual processing system to perceptually select i.e. differentiate and segregate the map symbols to form a group of similar symbols constituted by the variable. The basis of such isolation or segregation and grouping based on it is the separateness of dissimilar parts from one another. These perceptually selected and differentiated parts tend to cause these parts to be seen as belonging more closely together than others and are recognised instantly as pertaining to a particular and specific group of similar variable. The processes of perceptual selection leading to segregation and grouping here operate as complementary processes (Arnheim 1969,[9] Olson and Attneave 1970 [10]). These groups of similar variables are marked by maximal separateness or dissimilarity between the different groups and maximal uniformity or feature similarity within the groups.

4.1.3 Order

A graphic or visual variable has the perceptual level of order if it makes it possible to perceptually rank all cases of symbols formed by it. This perceptual level of graphic variable is taken to carry information through which the segregated information in the visual input is organised and ranked in an ordered sequence. Such sequences are spontaneous and mediated without the help of any external cues and at the same times are seen to be unambiguous and universal. This visual dimension does not exist in the visual dimension of *colour hue, orientation* and *shape.* These ordered sequences too are generated during the preattentive processing by the relative dominance of segregated image elements or areas and their organisation in the available three-dimensional space of depth. This relative dominance can be taken to be engendered by differentials of local contrast in the segmented fields.

4.1.4 Quantity

The visual variable has the perceptual level of quantity if the degree of variations in the symbols formed by it can be assigned a quantity. It is that perceptual level in any visual or graphic variable where the variations in all instances in a symbol formed by it are measurable and allow the discrimination, immediate recognition, and quantification of visual distances between the ordered categories of symbols from the visual input in the form of numerical intervals or ratios. Such quantitative intervals or ratios translate into quantitative relationships between various elements of the visual input. These visual distances and their numerical intervals or ratios are capable of being provided with some kind of `unit' of a measurement system that can be used with in all such distances. These distances can be measurable dimension of a graphic form.

4.2 Length of Visual Variables

Another important characteristic of the visual dimensions of graphic variables is related to those aspects of the visual information carried by them, which determine the availability of discriminable differences in the variable and allow the detection of visual difference between two elements of the map image or in other visual environments. In other words length of visual variable refers to the number of categories or steps distinguishably different in colour hues, and brightness levels, etc. These at the same time are also involved in the discrimination of steps of visual distance between two given extremes of a variable. Bertin (1983)[2] has described these as the 'length of a variable'. In his formulations these characteristics are not inherent and invariant to a variable. They vary with the environmental conditions of their use, such as the kind of symbolization in which they are used, the physical extent of the mark formed by the variable and the relative position of the graphic marks.

In Bertin's graphic semiology any visual variable should have a length which is equal to or is more than the discriminable steps it represents. If the number of data categories is more than the number of discernible steps in the visual variable, then the representation of data would not be properly processed visually to the extent of its comprehension.

Bertin's formulations are not based on any scientific experimental evidence. Map design and map design studies are often faced with the issue how the variables relate to one another and how these relationships might be made to correspond with the relations existing between referent attributes? Given the multiplicity of the basic rules that relate to question of the 'appropriateness' of the correspondence between visual variable differentiations with the referent attribute variations, experimental appraisals from a visual cognitive point of view, in terms of functional effectiveness, efficiency and expressivity, appear to be the best answer to these questions.

A number of workers have attempted to answer these questions through empirical verification of Bertin's constructs about visual variables both in cartography and psychology. However, much of this empirical verification has been done in highly controlled situations with simple graphic displays structured with simple and isolated geometrical graphic signs mostly in psychology. Examples of complex graphics such as thematic maps, or other two dimensional visualizations are very limited in number.

V. Hue and the Functional Evaluation of its Role as a Visual Variable

Though Bertin used the term colour to denote hue, the words "colour" and "hue" are not understood as synonymous. Hue is a specific dimension of colour and is the visual quality or attribute by which colours are

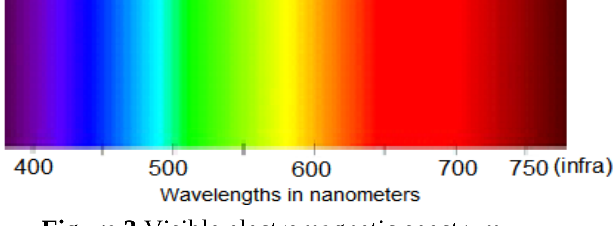

Figure 3 Visible electromagnetic spectrum

distinguished are distinguished from one another. It is the traditional colour names of specific wavelengths reflections of visible light and their different combinations. Different hues are perceived from individual wavelengths of visible white light. These hues are called spectral colours or hues. Following Newton the visible electromagnetic spectrum, which is visible white light, when divided into seven sectors proportional to seven musical tones, varies from long wavelength to medium wavelength and to short wavelength that are respectively perceived as red and orange, yellow and green to blue, indigo and violet Fig. 3.

Unique hues reflect the unmixed response of a single opponent process. They are perceived by the observers as a pure hue without any tint of the other hues or a mixture of two hues. Psychophysical tests provide evidence to these experiences (Hurvich and Jameson, 1955) [11]. These colours are red, green, blue, and yellow and originate from opponent colours theory proposed by Ewald Hering in 1878 which postulates two chromatic processes of red-green and blue-yellow, and the third achromatic process of white-black. The Commission Internationale de l'Eclairage (CIE) defines a 'unique hues to be the perceived hue that cannot be further described by the use of hue name other than its own' Figure 4E.

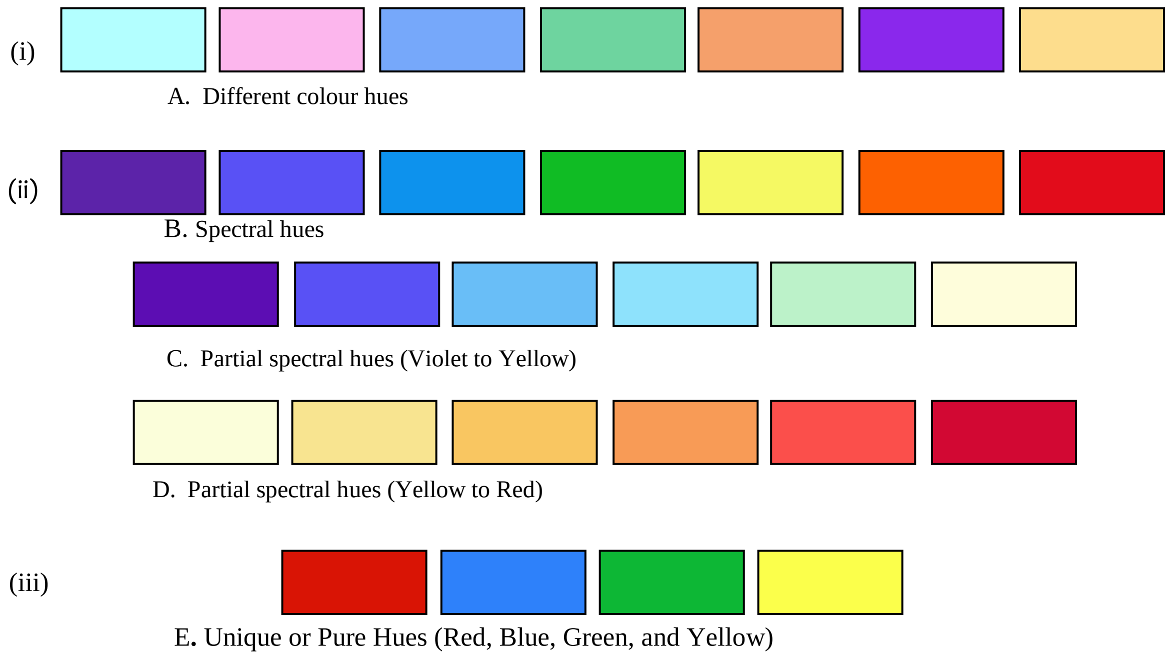

Figure 4 Colour dimension *Hue*, expanded to Spectral hues, Partial spectral and Unique hues

5.1 Hues: Association and Selection

Association The graphic variable of hue has the perceptual level of *association*. The availability of hue information to the processing system at the earliest stages due to preemption of this information in processing (Banks and Barber 1977) [12] is seen to be the reason for associativity in hues. Associativity in hues allows the visual processing system to mediate grouping in the visual field by identifying and preserving the relations of similarity engendered by the dimension in spite of the presence of variations in another visual dimensions. The hue based similarity groupings engendered by the visual level of association have precedence over the effects of the distracting variations in other visual variables. The visual level of hue, in this way, evokes similarity relations, which inhibit the effect of those feature dimensions that are carrying information on another visual variation. The property thus achieves compelling groupings even in those circumstances where a given distracter variation is simultaneously available to the system from the input. Such groupings are as strong or compelling as to overcome the effects of both locational separations and proximity due to the availability of this additional similarity information (Arnheim 1969: 73) [9]. In this way the possibilities of the emergence of alternate groupings on the basis of locational proximity or locational separations are almost eliminated. This property appears to be more primitive as compared to the next property of selection. The best example of the working of this dimension can found by looking at a hue on any of the pages of the Munsell's Book of Colours. It would be appropriate to quote Pomerantz (2006) [13] here: "Just as with other stimuli - - - with colour *too** one perceptual organization of wavelengths proves so strong it simply dominates any alternatives *(*italics added)*".

This preemption and precedence in processing of hues at the earliest stages of the preattentive stage is supported by the experimental results of Banks and Barber (1977) [12] which provide evidence which shows that this processing originates at the sensory stage which is believed to be the initial processing stage in the visual cognitive information processing. Other experimental results, in addition, provide further support to this view (Haber 1971 [14], Wessels 1982 [15]), and Merikle (1980 [16]).

Selection The selectivity in hues appears to arise because of the high discriminability between them. Selection as a visual level is seen to enable the information processing system to differentiate and segregate the visual field on the basis of the separateness of dissimilar parts from one another. It simultaneously causes some of these differentiated parts to be seen as belonging more closely together than others. Due to such togetherness in the isolated parts these are recognised instantly as pertaining to a particular and specific group. The processes of segregation and grouping here operate as complementary processes (Arnheim 1969, [9] Olson and Attneave 1970 [10]). When used as a graphic variable hue enables the map percipients to make important distinctions between the symbols with similar hues. These distinction between similar hues and the resultant hue based similarity groupings are produced by visual processes, which are alike in nature and are carried out simultaneously for a set of varied hues and over a relatively large spatial field. Hues, in this way add to selectivity of symbols because of their separateness and mutual exclusiveness (Arnheim (1969: 328 [9]). Hues are thus expected to have the most powerful effect on chunking of symbols in the map image space

Moreover, the presence of visual variable of colour hues, as area fills, adds to the saliency of symbols and resultant discriminability. This effect is ascribed to their functional role as visual primitives. Experimental evidence in support of the expectancies for increased discriminability can be seen in the early work of Erikson and Hake (1955) [17] and observations of Arnheim (1969: 323) [9].

5.1.1 Experimental Evidence from Design Research in Cartography

John (2007) [18] in her experimental evaluations has reported that the hue information available to global level analysers creates enhanced distinctions due to the presence of spectral hues in symbolisation in redundant mode. It was observed that hues provide improved and strong similarity relations that tend to result in unequivocal selections at faster rates and effectively in terms of lesser errors as shown in the results obtained for preattentive processing. Such selections, as a result, lead to the construction of unambiguous chunks more efficiently. .

Garlandini and Fabrikant (2009) [7] in their experiments employing a flicker paradigm in change detection in choropleth maps and using hue as a visual variable utilised the measures of *efficiency* and *effectiveness* too. These were measured in terms of speed and accuracy in visual processing for hue changes through isolation i.e. visual selection. Their results show that in terms of efficiency the response time measured as the speed in detecting change was respectively 0.92 second and 3.43 seconds was the time for the first fixation to area where a change takes place. The effectiveness measured in terms of the accuracy of change detections was 96 percent.

The property of selection leading to discriminability in hues, in addition is supported in John's (2007) [18] experimental results with the use of partial spectral hues as area fills in graduated circle maps. During visual search the scheme shows quicker visual information processing during preattentive stage of processing (1.2 seconds) which has resulted in a marked increase in efficiency in symbol discrimination. The use of partial spectral colour scheme had also shown a faster average processing speed in symbol discrimination (2.9 seconds) with only 04 per cent errors in discrimination showing a higher effectiveness of visual cognitive processing. Mersey's (1990: 66) [19] results, where the task was based on the efficiency of the property of selection, show that subjects performed better on those hues based colour scheme where the hues were ordered on the basis of their inherent value differences as is the case with hues arrayed in a partial spectral sequence. In the discrimination based on selection tasks in case of this sequence the mean scores on a three-class map were 89.44% and in case of seven-class map the average scores were 95.26% while the average score for all maps was 96.15%.

5.2 Hues: Order and Quantity

Implication of magnitudes by a graphic variable entails the organisation of its visual dimensions at the levels of both order and quantity in Bertin's (1983) terminology. Though the graphic variable of hue carries associative and selective information, no expectation for implication of order or magnitudes was seen by Bertin (1983) in the information available from this variable. This was taken as the support for the established conventional view that hues as a graphic variable do not have the level or property of either order or quantity. Thus the functional role of the visual variable colour hue on maps has to be seen to be limited to characterising nominally scaled data only. The reason for this conventional viewpoint and practice can be ascribed to the view that hues carry no information that is capable of organising different hues in an ordered sequence and which likewise are not effective in allowing the recognition of visual distance as quantitative intervals in absolute or relative terms. Contrary to this view it has been pointed out that hues vary in terms of their inherent lightness and darkness (Robinson 1952) and the later studies have shown that Hues in some instances have the trait to carry ordered information to a limited extent.

Order

One of the major deviations to this conventional view is the use of spectral hues, as an ordered series in showing successive variations. The inherent value differences of partial spectral hues and the surface gradients produced by these differences have, however, been used for obtaining a hue based ordered sequence in which the ordering follows the variations in referent magnitudes. Such ordered hue sequences are obtained by using only those parts of the visible spectrum where the evoked hues visually appear to be ordered from dark to light due to their inherent luminosity variations. These partial spectral hue series either follow the spectral progression directly or follow it in a reversed order. The visual ordering of such a hue series is, in addition, seen to be reinforced by either the learned order of the spectral progression or by the recalled arrangement of hues in the legend. The efficiency of such hue series has been established experimentally.

5.2.1 Experimental Evidence from Design Research in Cartography

Cuff (1973 b) [20] in his experiments related with subjects' perception of the magnitude denotations of various chromatic sequences found that subjects' ranking of hues was relatively consistent when using a partial spectral series of hues. Similarly spectral and partial-spectral schemes were tested by Kumler and Groop (1990) [21] experimentally in their use for continuous-tone representations of smooth and continuous statistical surfaces. Their results show that that subjects scored better with spectral hues than partial-spectral hue schemes in case of maps using isarithmic symbolisation. As far as the expressivity was concerned 73 percent of subjects rated spectral schemes better than other schemes.

Another experimental evidence of the effectiveness of this kind of partial spectral ordering is found in the performances on the two tasks related to discrimination and determination of relative magnitudes in Janet Mersey's study (1990) [19]. In case of tasks related to determination of relative magnitudes the average on a three-class map was 98.89% and 98.58% on a seven-class map. These experimental results can be explained in terms of another mechanism of visual ordering of hues where the ordered sequences result from a hierarchical organisation engendered by combined effects of edge gradients and surface contrast gradients obtained from the inherent luminosity differences of spectral hues.

Hyslop's (2007) [22] results show the subjects in his experiments performed about six percent better on the surfaces portrayed by spectral colour in comparison with the gray scale symbolised surfaces. The results of chi-square tests show that subjects' performance was significantly higher on spectral colour maps as compared to gray scale maps (p.46). Summarising the results it was observed that 'subjects performed significantly better on the spectral colour maps than on the gray scale representations. The highest average score was on maps in the blue-to-red spectral colour scheme and the worst performance was observed on the white-to-black' colour scheme (p. 53).

In addition, the experimental results of John dealing with the levels of order and quantity for magnitude estimation (2007) [18] with the use of partial spectral hues as area fills in graduated circle maps, during ordered symbol discrimination, show similar improvements with a faster average processing speed of 2.94 seconds and an accuracy of 96 per cent while in case in case of the magnitude identification the processing speed was 5 seconds. As far as expressivity of partial spectral hues is concerned Brewer's results (1997) [23] show that in terms of expressiveness partial spectral hues were rated as most easy to read and more pleasant by 56 per cent subjects who participated in the experiments.

Ordered hue sequences can also be constructed from unique hue's variability expanse or ranges. Unique hues are the perception of the pure hues red, green, yellow, and blue which can further be described as

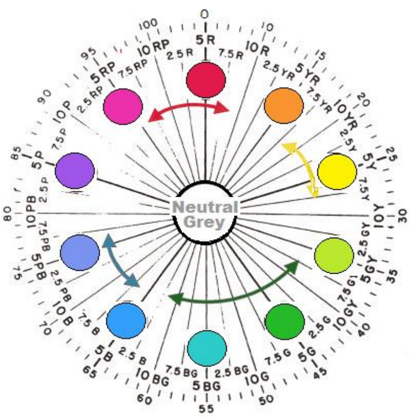

Figure 6 Munsell Hue Circuit with circle segments showing the approximate unique hue ranges based on Kuehni (2004)

ranges of unique hues are defined by discontinuities in discriminability at the colour category boundaries. The categorical perception of colours implies that category boundaries of colour experienced in an uninterrupted colour spectrum are linked with regions of optimum discrimination. These variabilities vary for each unique hue.

Colour ranges for unique hues are shown on the perceptual Munsell hue circuit by Kuehni (2004) [24] figure 6. An ordered hue scheme could therefore be constructed around a unique hue extending to either of its limits. Green justifies the logic such use on the basis of empirical evidence from Farnsworth-Munsell colour vision test (Green 1998)[25].

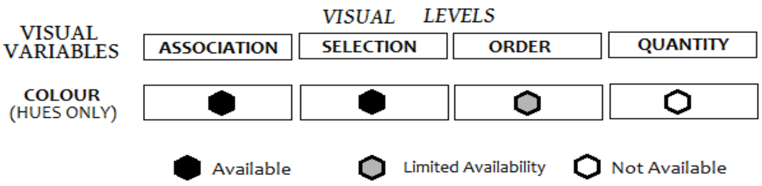

Figure 5 Bertin's extended visual variable colour hue with its visual levels

5.3 Hues: Length of Variable

The discrimination of differences has been defined as capability to detect a difference (Keats 1982) [26] while Fellows (1968) [27] defines discrimination as the process by which human beings responds to differences between stimuli like hues. Discrimination depends on the human visual system's physiological reaction of sensitivity to hues. These sensitivity functions are constrained by the wavelength differentials that evoke the sensation of hues and by positional adjacency of colourant patches in the visual field.

The modern understanding of colour perception, as reflected in Hurvich and Jameson's work (1957) [11], provides an opponent mechanism based analysis of the hue discrimination that follows the same logic as the analysis offered by the component process theories. Hurvich and Jameson postulated that when the chromatic responses are changing rapidly as a function of wavelengths, discrimination is very efficient and becomes poor when these changes are slow. As expected, discrimination is good at wavelengths, which are near the unique hues. Discrimination becomes poor in gamuts at the ends of the spectrum.

The human visual system possesses a high degree of sensitivity to different hues when these are arranged side by side against a medium neutral gray background. The Munsell system identifies 100 different visually distinct hues (Figure 7A & B). Evans (1951) [28] reports the existence of 125 just noticeable differences

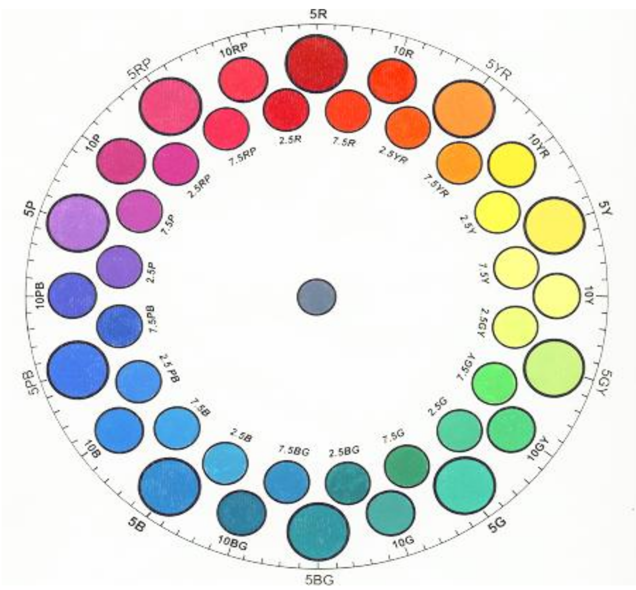

Figure 7.A Munsell's Colour Hue space

(JNDs) of hues. However, even when the hues are not arranged adjacently, the human visual information processing system emphasizes similarity between different hues of a family. But the exact matching of a hue in terms of sameness remains dependent on the adjacency between the two patches of the colourant (Luke 1996) [29].

5.3.1 Experimental Evidence from Design Research in Cartography

In case of the use of hues on maps as graphic variable the meeting of adjacency criteria is dependent on the mode of symbolisation and is not always met. The other condition of the surrounding neutral gray background

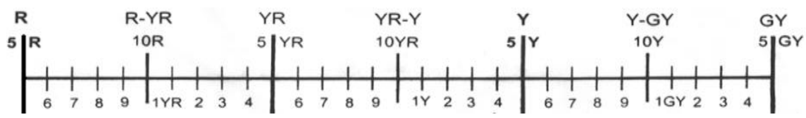

Figure 7.B Expansion of the Munsell hue circuit showing the perceptually equal spaced positions of 100 hues and the provision for their further subdivisions through the use of decimals

can never be fulfilled in such uses. Under these conditions the capacity of the visual system to either match or discriminate between hues on maps is somewhat restricted. The reported findings differ in respect of the number of hues, which could thus be discriminated absolutely to identifiable extents on thematic maps. According to Wood (1968) [30] a majority of viewers can distinguish at least 15 hues in this way without training while Potash (1977) [31] is of the view that map users can recognise up to eight or nine hues. Converging evidence from operations on other visual displays, though limited, supports these findings. These findings suggest that under normal viewing conditions 5 to 8 hues can be distinguished on the basis of absolute discrimination. These limits were reported to go up to 9 to 12 under optimal condition (Smith 1962) [32].

Experimental evidence in support for increased discriminability can be seen in the early work of Erikson and Hake (1955) [17], and observations of Arnheim (1969: 323) [9]. Mersey's (1990) [19] study, in case of the hue discrimination task, shows that the mean scores on a three-class map were 95.45% while in case of seven-class map the average scores were 87.61%. In case of the supplementing role of the colour dimension of hue vis-à-vis its role in increasing the discriminability reliance can also be placed on the empirical discrimination functions derived by Munsell (1991) [33] in case of 'hues'. This enhanced discriminability of hues and particularly those that are ordered in a partial spectral progression as evidenced empirically by John (2007) [18] reduces the possibilities of tentative circle size based differentiation in case of graduated circle symbolisations and as a result also eliminates the chances of ambiguities in the bidimensional chunking of circle symbols in the map image.

VI. Conclusions

An analysis of results both from psychology and design research in thematic cartography shows that the two levels of association and selection have adequate empirical support in the above two areas of psychology and design research in cartography. However, the experimental results for the level order are contrary to formulations of Bertin in case of both hues ordered in spectral progression and hues ordered around a unique hue variability expanse or range which extend to either of its limits in a limited ambit of ordered steps adequately perform at the level of order.

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