

COLOURS HARMONY IN CARTOGRAPHY

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Quality of cartographic message depends on qualities of chosen data and symbols. During map design process, symbol specification is often uncertain. Graphical signs choices may be unsuitable to tastes, needs and context of use.

Colours use is of special relevance to environmental, topographic and thematic maps whose primary purpose is to create a mental image of main characteristics conveyed by the map. Communication in colour is more effective if the colours used are appropriate. Colours choices, as mistakes or misunderstandings, are often highlighted: too many colours, colours un-adapted to user's data, too meaningful colours, etc. involving disturbances when readers try to understand its cartographic message.

Visual variable colour is powerful, but users face difficulties when they have to use it. In particular, colours combinations uses on map are not something easy to manage. This assessment leads us to the issue of colours harmony. We assume that proposing colours harmony on a map facilitates its reading. But what does mean colours harmony for a map?

This paper presents an explorative research work about colours harmony in cartography. First, we try to specify why such a research work is essential in current semiotics thought. Then, we present our approach and quantitative method, through a proposition of our definition and characterisation of colours harmony. Finally, we present some examples of the evaluation of colours combinations and harmony on maps.

1. COLOURS HARMONY IN CARTOGRAPHY: AN ESSENTIAL ISSUE FOR GRAPHIC SEMIOTICS

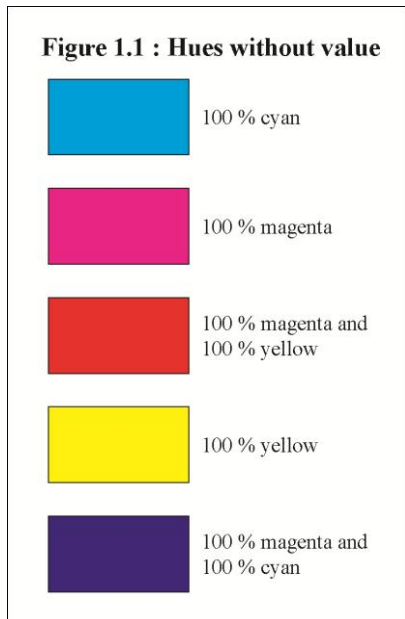
Colours uses in cartography seem simple and precise. Printing in colours is not anymore dealing with high cost or any delay. Various colours conversion sites generate colour schemes or harmonies . But cartographers know that selecting effective colours for maps is still a challenge.

1.1 Colours issues

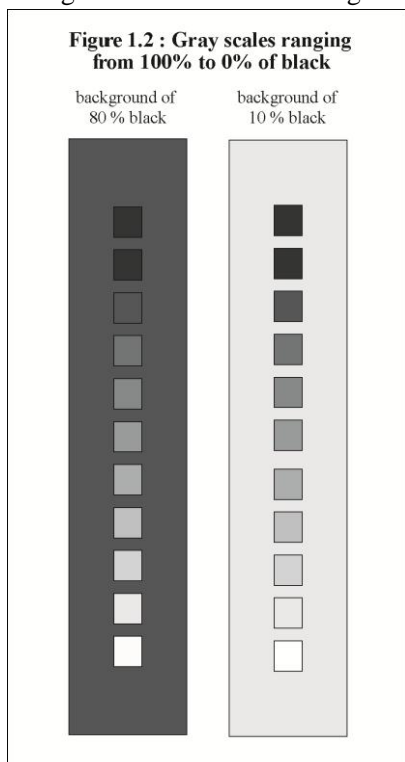
Colour is physiological sensation resulting from all radiations received by the eye when looking at an object lit in solar light. We can define colour as a personal impression but it is difficult to measure it, because variations in human perception are big, and it's quite impossible to make standard, objective observations or develop standardized or quantitative rules for using colour (Zanin 2003). However, we can make some general statements about the ways map users perceive colour, thus to develop better ways to apply colour to symbol design and other design aspects of maps.

Purpose of Bertin's graphic semiotics (1967) is to establish visual variables and rules for correct visual representation of qualitative or quantitative information. Graphic semiotics is widely used in cartography: the complexity of designing map concerns the selection of visual variable which would be the most appropriate to represent selective, associative, quantitative or hierarchal information.

The colour dimensions include hue, value and saturation. Hue can be defined like the various colours we perceive e.g., red, blue, green, etc. (Figure 1.1). It is possible to create millions of hues by combining various percentages of the primary hues and altering their value and saturation.

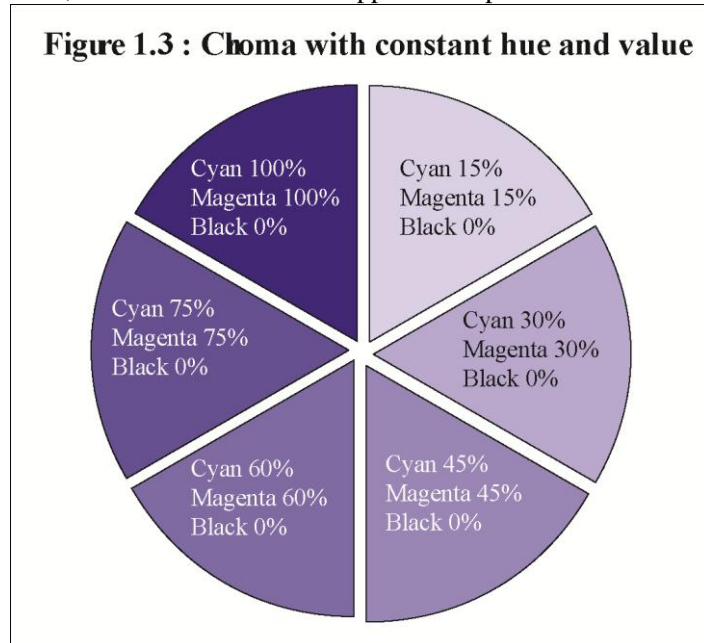


Value is the lightness or darkness of a hue and can be understood by looking at a gray scale which shows the proportion of black ink ranging from 0% black to 100% black in steps of 10%. Value is affected by background: the value looks lighter when surrounded by darker shades of gray (Figure 1.2).



Saturation means intensity or purity of a colour and refers to the comparison to a neutral gray. For any given hue, saturation ranges from 0% (neutral gray) to 100% (maximum saturation). At the maximum

level, the colour appears pure and contains no gray (Figure 1.3).



Colour perception has physiological, psychological and subjective aspects and it's important to study its perceptual aspects before attempting to select and apply colour to maps: acuity, colour shape and area size, light source, colour contrast, background influence or cultural aspects.

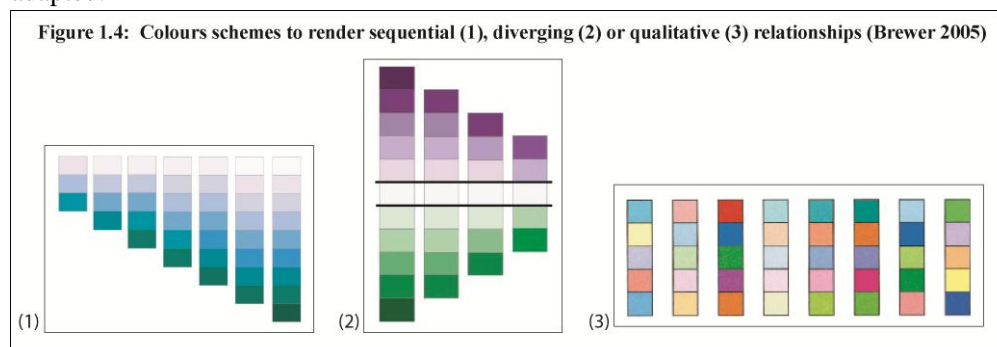
For instance, lighter colours require larger map areas to be visible and identifiable relative to darker colours, and darker colours appear much more dominant than do lighter colours within the same area size. Some colours permit to perceive less contrast than others (Kraak and Ormeling 2003) because two or more colours interact and influence the appearance of one another. Simultaneous contrast can cause problems in map design when several different values/saturation of the same hue are juxtaposed. Successive contrast can also cause confusion in interpretation of colour on a map or in matching a map colour to its appropriate key colour.

While some colours combinations can adversely affect map interpretation, there are other combinations that create nice effects which are complimentary and pleasant to look at, or accentuate figure and subdue background. Finding right colours combination or colours harmony is not a trivial issue, especially when we deal with onscreen maps which explore further visualization restrictions.

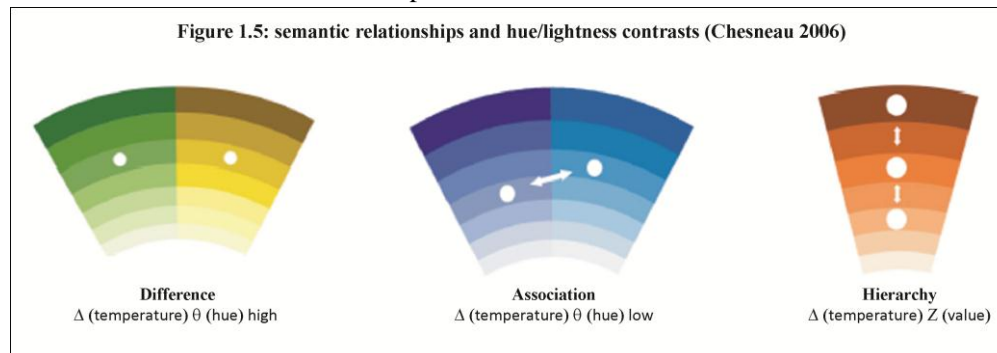
1.2 Related research works on colours choices in map design process

Some research deal with propositions to help users to make better colours combinations choices but work on harmony colours, on maps, is relatively new.

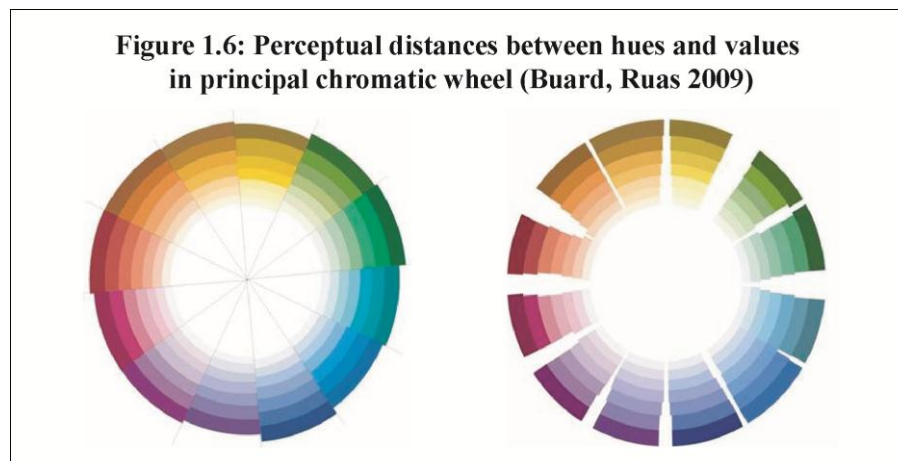
The ColorBrewer (Brewer 2005) is an online interface database of colours schemes to render relationships between represented data, based on the chromatic wheel of Itten (1967). It allows users to select colours schemes in order to graphically represent thematic classes, depending on the number of classes, the nature of relationship between them (sequential, diverging, qualitative), and the ones that are adapted to usual supports (Cf. Figure 1.4). This tool is very useful for mapping choropleth maps. Numerous solutions of colours combinations are possible, but generally we have to time to test them all. We also notice that user's data characteristics (semantic, size, etc.) are not taken into account and colours schemes are not adapted.



Chesneau (2006), Buard and Ruas (2009) propose a colour reference system based on chromatic wheels to manage colours contrasts from Itten's chromatic wheel (1967). Chesneau (2006) describes colours contrasts and works specifically on the hue, value and saturation parameters. If we consider two objects, chromatic wheels may be used applying following rules (Cf. Figure 1.5): the more distance is big between 2 hues, 2 value levels, or 2 saturation levels; the more the themes represented with these tints are going to seem different, ordered, or more important than the other.



Buard and Ruas (2009) measure perceptual distances between each colour in chromatic wheels, through users' experimentations, in order to get more accurate measures of hue/value contrasts: results are hue/value matrixes. Figure 1.6 presents how hue/value contrasts are perceived in the principal chromatic wheel.



Those researches have been experimented to evaluate and improve colours contrasts in an existing map, adapting them to existing relationships – difference, association, and hierarchy– between data. Another purpose is the aim of, Christophe's PhD thesis (2009). She tried to identify and formalise knowledge on colours in cartography – graphic semiotics, visual perception and artistic uses – assuming that quality of colours specification is an important part of the quality of the cartographic message conveyed by map. Her COLorLEGend tool helps users to make personalised and original colours choices during mapping process (Christophe and Ruas 2009).

The research explore colours harmony comparing colours composition in painting art on one hand and cartography on the other: it consists in extracting colours and specific colours uses – repartition, proportion, total area, and proximity relations – from famous paintings, thus building some painter's rules. The rules associated with cartographic rules (conventions, hue/value contrasts) allow building a diversity of maps, more or less conventional, contrasted, or original, depending on the predominance of painter's or cartographic rules (Figure 1.7). This work highlights the importance of the general feeling perceived by mapmaker and readers of maps, through the use of artistic colours combinations and leads to the issue of needed characterisation of colours harmony in cartography.

Figure 1.7: 'Original colours' specification from "Montagneà Collioure" André Derain, 1905, John Hay Whitney Collection, National Gallery of Art Washington, USA



1.3 Our objectives

Our first hypothesis is that colour specification during mapping process is a complex problem: it consists, not only in selecting independent squares of colours in the whole of possible colours, but also in combining them in a map. In the cartographic context, we have to handle with the semiotic triangle: the map (signifier), the message (signified), the real objects (referent). Colours combination must be considered as colours associations, between them and with specific geographical objects. In addition to semantic associations between colours and objects (conventional colours associations for instance: blue for sea), the problem of choosing a colour concerns the message conveyed by visual perception of this colour in combination with all other colours (contrasts, proximities, quantities, etc.). The colours work is another way which the cartographer could improve readability and efficiency of maps.

We assume that visual perception of harmonious map facilitates its legibility and improves its quality. We consider that a harmonious map relies on harmonious uses of colours. A main issue is to propose a definition of colours harmony in cartography and to identify main criteria to evaluate it on a map.

2. COLOURS HARMONY: A SPECIFIC DEFINITION FOR A SPECIFIC EVALUATION METHOD

Evaluation of colours harmony in cartography needs a very clear definition. Shape of geographic objects, position, size, semiotics etc. made the harmony concept both complex and delicate. Here we try to state on a definition for colours harmony in the mapping process.

2.1 Colours harmony according to common sense

‘Harmony’ derives from the Greek *harmonia*, latin *harmonia* and old french *armonie* meaning “joint, articulation, agreement, concord”, and from the verb *harmoizo*, “to fit together, to join” . The term was often used for the whole field of music, while “music” referred to the arts in general and it defined the combination of contrasted elements. Current dictionary definitions, while attempting to give concise descriptions, often highlight the ambiguity of the term. The Webster Dictionary define it like “the just adaptation of parts to each other, in any system or combination of things, or in things, or things intended to form a connected whole; such an agreement between the different parts of a design or composition as to produce unity of effect”. French dictionaries specify that “harmony is a specific combination of various and separate elements linked with a convenient ratio which brings satisfaction and agreement, and even a feeling of beauty”.

In fact harmony could be defined by three aspects:

- It organizes creation and progression of chords;
- by the right balance of the different elements;
- whose automatic correlation brings a pleasant sensation.

2.2 Our definition of colours harmony

Definition of harmony that best suited to this work could be that “harmony is the art of how to bind a variety of colours in a “good” equilibrium of threshold contrasts (intrinsic and spatial), giving a sense of

understanding particularly subjective” (Roussaffa 2009). Applied to cartography, this definition brings us to chromatic scales, creation and progression of chords.

A colour palette may be a monochrome or a colour combination associating different or opposite colours, and it’s always nicer to do it with colours of the same ‘harmony’ dealing with a nice equilibrium in colours areas, colours energy or light degrees (Sutter 1858). So, colours characteristics may be perceived well balanced or not. Some intrinsic colour’s contrasts may then interfere like hue and value, colour temperature or complementary colours.

These aspects are enforced by a series of principles:

- The link between elements allows to show diverse elements which articulate with others in a composition forming a whole.
- Unity of opposite: connection of two opposites set in a harmonious system (eg, black and white).
- The measure: colours must be measure in a scale of human capacity perception.
- The equilibrium: harmony is balance and symmetry. We can reach the balance thanks to the creation of a proportion system allowing quantifying elements, i.e. contrasts.
- The simplicity is neatness and brightness participating in well comprehension of the message.
- The aesthetics: Harmony is all relative and subjective.
- The rationality: relations between tones, colours brightness or saturations in a set are subordinated to the formal logic of contrast and balance, but also to the logic of contents and function.
- The order: The reading of the map is simplified thanks to correct graphic semiotics; it’s especially true since the message is organized by some harmony (to avoid the important contrasts which take aback the reader without reason).

A map is harmonious if it can associate all these principles and if semiotics and conventional rules are used in proper way, but not only. Its main objective is to associate or opposite elements between them. Our objective is to propose some criteria for a measure of colours harmony. These criteria lead on the idea of linkage between colours, bringing to colours cohesion of the user, and the balance between these colours, bringing contrasts quality.

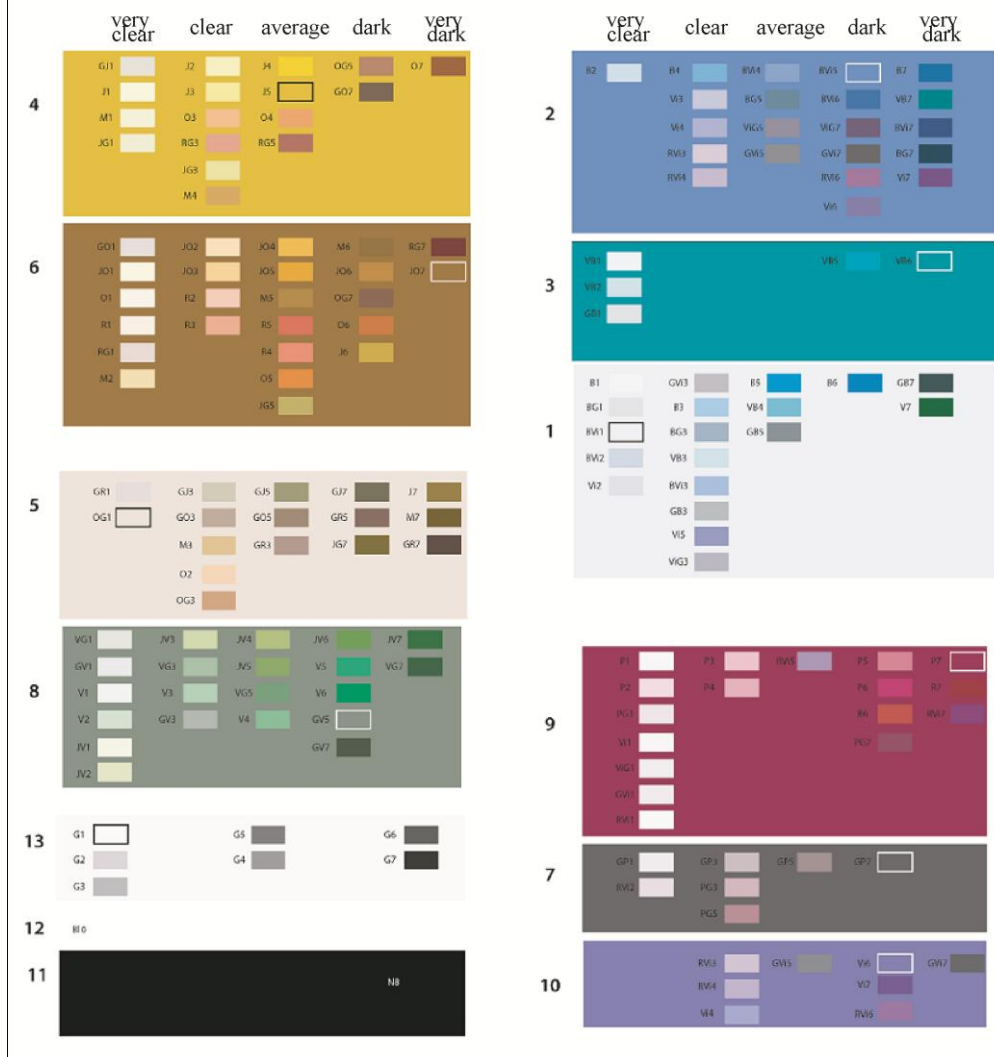
2.3 Our method

To propose criteria to measure harmony level out of a set of colours chosen by a user, we need to measure colours harmony of a map through 2 concepts: linkage of colours (highlighting distances between them), and balance between colours (highlighting quality of contrasts). Therefore, we propose to build groups of closed colours that we call chromatic families: such a system allows characterising linkage and balance and thus harmony, through distances measures.

An Ascending Hierarchical Clustering (AHC) was applied on both hue and value matrixes of Buard and Ruas (2009), gathering all measures of perceptual distances respectively between hues and between values . Two criteria are necessary for the classification, the criterion of distance (Euclidean distance) and the criterion of aggregation (criterion of Ward).

The AHC realised on the hue matrix lead to thirteen hues clusters. A second one is applied on the value matrix and five value clusters are obtained. Inside the thirteen classes of hues, colours are grouped together according to classes of value: we define a chromatic family as a set of colours to which hues are very close and the value vary according to five levels (very clear, clear, average, dark and very dark). Thirteen chromatic families are thus created. Figure 2.1 presents them: grey-blue (1), blue-purple (2), cyan (3), yellow-orange (4), brown-ochre (5), orange-ochre (6), grey-mole (7), green (8), magenta (9), purple (10), black (11), white (12), grey (13). These families are not homogeneous in terms of resemblance between families and between colours.

Figure 2.1: Chromatic families according to an Ascending Hierarchical Clustering (Roussaffa, 2009)



Colours are thus associated and dissociated in families. These AHC permit the measure between colours, first of linkage levels, second of a global link.

2.3.1 Characterisation of linkage levels between colours

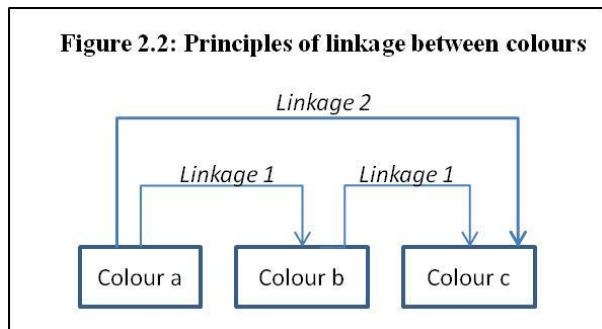
The level of linkage between colours, one to one, is a synthetic measure of relative 'closeness' between colours. We consider three levels of linkage :

- Colours belongs to the same family (linked by definition): linkage scores 0;
- Colours do not belong to the same family but are linked (relative proximity): linkage scores 1;
- Colours do not belong to the same family and are not linked (no proximity): linkage scores 2.

For instance, yellow-orange (4) and orange-ochre (6) are the closest classes (distance $d=2.8$) and they are the farthest to the grey-mole (7) ($d=25.5$). Distances lower than this threshold highlight linked classes (linkage 1), while greater distances highlight non-linked classes (linkage 2). For instance, yellow-orange (4) has a linkage of 1 with brown-ochre (5) and orange-ochre (6) and a linkage of 2 with blue-purple (2).

2.3.2 Global link between colours

The knowledge of linkage level allows us to link all colours between families, one to one. Figure 2.2 explains this notion of global link: for a given class (a), we can use its closest class of linkage 1 (b), to play the role of a key, if they have themselves close classes of linkage 1 (c): classes (a) and (c) are linked by linkage 2. It's the case of yellow-orange (4), which is of linkage 1 with orange-ochre (6), itself of linkage 1 with (4), (5) and (8): therefore (8) has a linkage 2 with our yellow-orange (4). We may obtain various possible links from the initial class to others.



We thus rely on key classes to ensure cohesion of colours: a global link and a related distance between colour hue classes and colour value classes may be obtained. With these chromatic families, we have now thresholds to manage hue and value contrasts, but also temperature contrasts. These contrasts can be included in what we call intrinsic contrasts between colours.

3. QUANTITATIVE EVALUATION OF COLOURS HARMONY IN CARTOGRAPHY

From classification explained in previous section, three criteria to evaluate a user's colours combination are highlighted in the following paragraphs. Evaluations of those criteria allow us to a final score of harmony. We give examples of how each criterion can be evaluated and finally how harmony score can be given to a user's map, through their colours choices.

3.1 Criteria to evaluate user's colours

We define the three following criteria to evaluate a user's colours combination:

- The level of linkage between colours;
- The balance between colours;
- The balance of the relation between intrinsic and spatial contrasts.

3.1.1 Criterion 1: level of linkage between colours

With the help of the chromatic families, we are able to analyse a set of colours chosen by a user in:

- Associating each colour to its related chromatic family;
- Assessing colours distances;
- Qualifying their level of linkage.

For a given colours combination, we may find that no linkage exists between a couple of hues or a couple of values: a key colour is missing. In such a case, we cannot say that this colours combination is linked. We decide to attribute two kinds of score:

- If all hues are linked, we give a hue score of 1.
- If all values are linked, we give a value score of 1.

Linkage score of a colours combination is sums of the hue and value scores, thus is 0 to 2.

3.1.2 Criterion 2: the balance between colours

The balance may be characterised by certain diversity between user's colours: it consists in verifying that colour hues and colours value are sufficiently contrasted.

A hypothesis to compute the balance for a given colours combination is that this combination is linked, thus the previous score of linkage is 2. For instance :

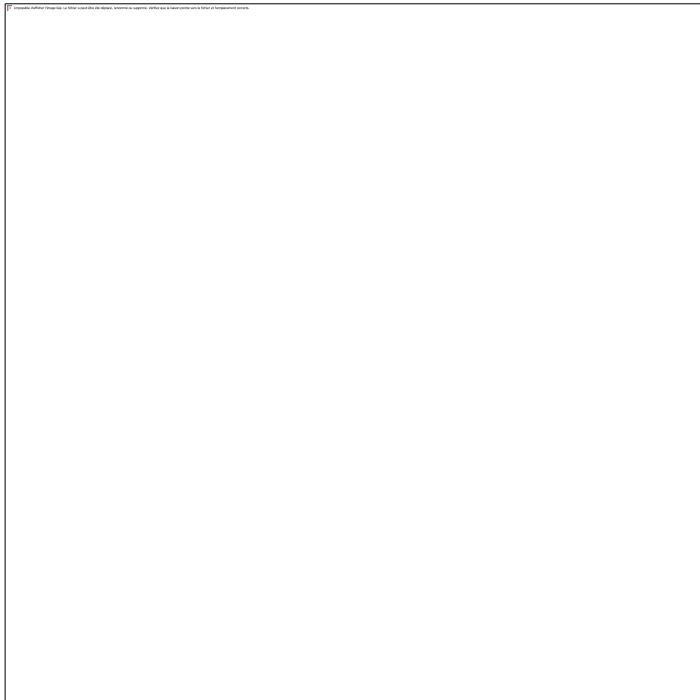
- If hues/values are of linkage 0, it means that all hues/values are in same families: we consider they are not balanced and we give a score of 0.
- If hues are of linkage 0 and values of linkage 1 and 2, it means that colours from a same hue class are value shaded: we consider there is a balance in value and we give a score of 1.
- If hues are of linkage 1 or 2 and values of linkage 0, it means that colours from a same value class are hue shaded: we consider there is a balance in hue and we give a score of 1.

3.1.3 Criterion 3: the balance of the relation between intrinsic and spatial contrasts

Perception of a colours combination as squares of colours and perception of the same colours combination applied to data, thus to cartographic objects, may be totally different: other visual variables play a role in colours perception, and thus in colours harmony. Therefore, we propose to analyse contrasts of colours quantity in a map.

We assume that colour harmony depends on a relation between intrinsic contrasts (hue, value, etc.) and spatial contrasts (shape, size, proximity, distribution, etc.). Nevertheless it's difficult to establish the type or even the degree of relation who could exist between these two contrasts. From Itten's (1967) work, we

consider that the modification of area ratio between colours is function of the level of hue and value contrasts: Figure 3.1 shows this effect: the increase of the value contrast involves the perception of an increase of the area ratio.



We thus propose a simple measure of this relation, between contrasts of hue and value (for the intrinsic contrasts) and surface (for the spatial contrast): more the area size ratio is strong between two objects, more hue or value contrast must be strong to bring some balance on the dominant colour. From (Chesneau 2006)'s work, we consider three thresholds for area ratio:

- Balanced ratio is 1 to 4;
- Moderately balanced ratio is 4 to 16;
- Not balanced ratio: area ratio is superior to 16.

To evaluate the area/contrast relation, on a map, we need to consider the largest object (the dominant colour), and we focus on two parameters: area ratio and contrast level, for each ratio.

3.2 Examples of colours harmony characterization

Based on evaluations of previous section, a score for harmony level of a map can be built, in summing all scores of the three criteria.

3.2.1 Evaluation of linkage and balance of colours combinations

Figure 3.2 shows some examples of coloured combinations chosen by user, and whose criteria of linkage (C1) and balance (C2) have been evaluated:

- (1) Hues/values are not linked (C1=0).
- (2) Values are linked, but not hues (C1=1).
- (3) Hues/Values are linked (C1=2), well contrasted:
 - (3a) this blue shade provides diversity between different values but is low hue diversified: the combination is balanced (C2=1).
 - (3b) this hue variation provides diversity between different hues but is low value diversified: the combination is balanced (C2=1).
- (4) Hues/values are linked (C1=2) and balanced (C2=1): we notice a great diversity both in hue and value.



(4a) and (4b) are the same colours combination but presented in different orders: we highlight that the perception of the same colours combination is different between both presentations, just because of the choice of ordering and proximities between colours.

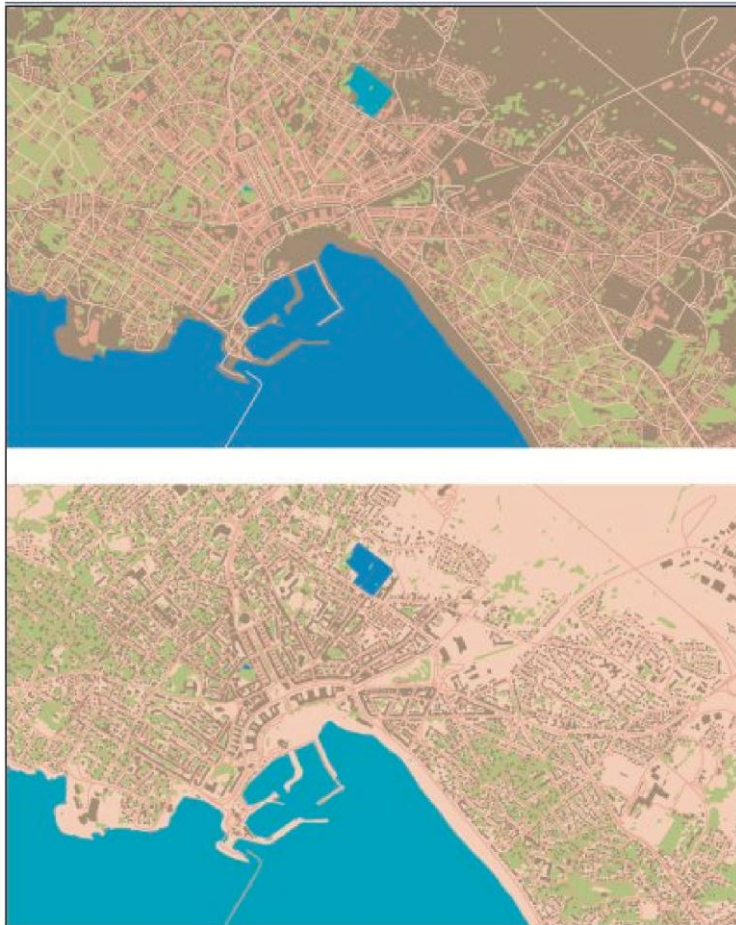
3.2.2 Evaluation of the balance of the relation area/colours (C3)

Once colours combination has been considered as linked and balanced, thus harmonious, the question is the following: are the map(s) rendered by this colours combination harmonious?

For this evaluation, we use the colours combination presented above (4a/4b). The application of this combination to user's dataset, i.e. the use of these colours to render user's objects, is presented Figure 3.3. On top map, darkest blue colour is used to render the sea, while it's used to render the cemetery on the bottom map; on the top map, brown colour is used to render background while it's used to render buildings on bottom map, etc. Two different maps are thus obtained, given clearly different colours perceptions.

To evaluate the balance of the relation between contrasts, we have to first compute total areas occupied by each cartographic object and the total area on map. The user's dataset has five types of objects: wooded area, cemetery, sea, building and background (Cf. Figure 3.3). We compute the area ratio between each represented type, considering only the area ratio referring to dominant area, i.e. the background area. We also compute number of objects, and their density. Building, wooded area and sea have similar total areas : their area ratios are balanced. Roads are more difficult to analyse: we consider network length and thickness and decide to manage them as buildings, because of their similar type of spatial distribution (little objects, high density).

**Figure 3.3 Differential utilization of same coloured combinations
(Roussaffa2009)**



Then, we use the relation “more the ratio is strong, more the hue/value contrast must be strong” to give a score to each relation between area ratio and hue/value contrasts.

For the top map (a):

- sea/background: area ratio is balanced and colours are too contrasted (C3=0)
- wooded area/background: area ratio is moderately balanced and colours are moderately contrasted (C3=1)
- cemetery/background: area ratio is not balanced and colours are not enough contrasted (C3=0)
- building/background: area ratio is moderately balanced and colours are moderately contrasted (C3=1)
- roads/background: area ratio is moderately balanced and colours are moderately contrasted (C3=1)

3.2.3 Final score of harmony for users' maps

The final colours harmony score is given by: <score of linkage> + <score of balance> + <score of relation>. For the previous map (a), the final score is (2 + 1 + 3), 6 out of 8, 8 being the highest possible score.

Figure 3.3 presents another map (b) whose final colours harmony score is 7 out of 8.

So, we can assume that map (b) is more harmonious than map (a).

Colours harmony was considered through specific relations between colours -- linkage and balance – and between area of cartographic objects and their colours. We obtain promising results to evaluate the user's colours choices in a map.

Colours harmony was considered through specific relations between colours -- linkage and balance – and between area of cartographic objects and their colours. We obtain promising results to evaluate the user's colours choices in a map.

PERSPECTIVES FOR HARMONY IN CARTOGRAPHY

Finding harmony in colours may be defined as a visually pleasant arrangement of colours and can simply be achieved by the use of complementary, analogous or monochromatic colours. In the map design reality, colours harmony is a complex and ambivalent challenge. Harmony could be defined more like a special way to mix colours but in a linked and balanced contrast in chromatic scales and map surfaces.

Instead of working on delicate qualitative aspects, we proposed quantitative method to define and characterise colours harmony. We demonstrate that dealing with harmony consists in trying to find “good” contrasts equilibrium. In maps, colours harmony depends on intrinsic colours contrasts and spatial contrasts. We assume that we can link area (for the spatial contrast), and hue and value contrasts (for intrinsic contrast): more the factor of size is high between two objects, more the hue and value contrasts should be high to balance the dominance proportion.

We thus proposed criteria to intrinsically and spatially evaluate users’ colours combinations, and a score of colours harmony for user’s maps. First results are encouraging. Experimental users’ tests to validate those criteria and harmony scores have been driven and are under analysis. Further characterisation is in progress. In particular, the best way to use a colours combination is still in question: is it possible to plan a combination colours in order to have a better final score of colours harmony?

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