

# COMPROMISING CONTEXTUAL CONSTRAINTS AND CARTOGRAPHIC RULES: APPLICATION TO SUSTAINABLE MAPS

Charlotte Hoarau

COGIT Laboratory, IGN. 73, Avenue de Paris 94160. Saint-Mandé France - first.name@ign.fr

**KEY WORDS:** Constraints, Semiotics, Colors, Sustainable Maps

## ABSTRACT:

The necessary adaptation of mapping applications generates new constraints which should be considered in addition to the traditional cartographic rules used to design maps. Particularly, colors used in the legend could be optimized regarding those constraints. A big stake of such optimization is to preserve the semiotic quality of maps. Therefore, we propose a quantification of the cartographic quality of a map regarding a given reference map and considering semantic rules of association, differentiation and order supposed to be conveyed by the colors of the map.

Some mobile devices required more energy to display dark colors than lighter ones. Our example of contextual constraint is then the optimization of the colors in order to lower the energy required to display a map. Three map samples have been designed, while taking more or less into consideration conventional uses of colors for relevant themes: hydrography, vegetation and the background layer.

We discuss on how to find the best compromise between a contextual constraint (the energy required to display a map on a screen of a mobile device in our example) and the cartographic consistency on colors regarding the initial semantic relationships in the legend. This supposes to evaluate how far a map supposed to follow cartographic rules can be altered while preserving its semiotic quality.

## 1. INTRODUCTION

The diversification of the mapping demand has increased and sped up the supply of mapping applications. User needs has evolved at the same time. A big stake for cartographers and map designers is thus to adapt their maps (i.e. their contents, their representations, etc.) to different contexts of map use and different users.

In order to adapt a map, it is often useful to add a constraint to the traditional cartographic rules: depending on the context, maps should sometimes not be too complicated, too luminous or should not use some colors for example. Cartographers should pay attention to these aspects while creating the map, in order to design the most suitable map regarding a given context.

Nevertheless, the symbolization of a map is chosen consistently with semantic relationships between themes and makes sense. This paper aims at evaluating how far one can modify a given map designed following cartographic rules according to a given constraint without losing that which makes sense to understand the map. Therefore, we propose an evaluation of the semiotic quality of a map regarding a reference map. Such evaluation quantifies the relative respect of the existing semantic relationships of association, differentiation and order in the initial map.

Our approach is based on map samples designed respecting more or less cartographic rules. Let us introduce this approach by an example: adapting the map to its display on a mobile device. The constraint is to lower the energy required to display a map by modifying its legend and especially its colors.

Firstly, both estimations of the semiotic quality and the energy required to display a map on a mobile device are detailed. Then, three map samples are studied to qualify the relative compromise between traditional cartographic rules and our contextual constraint, i.e. the lower of the energy.

## 2. SEMIOTIC QUALITY OF A MAP

### 2.1 Cartographic rules.

Theories of cartography give a detailed formalization of graphical semiotic. Bertin [1967], MacEachren [1995] describe different graphical variables and correct ways to use them during the cartographic conception. In our work, two of the most relevant cartographic rules are considered:

- Conventional color uses, called conventional rules in this paper.
- Semantic rules structure the organization of the legend by semantic relationships of association, differentiation and order.

Conventional rules limit the color space for some thematics, like illustrated in Figure 1: hydrography should be represented by a color of the blue family, vegetation by a color of the green family and the background layer by a light color.

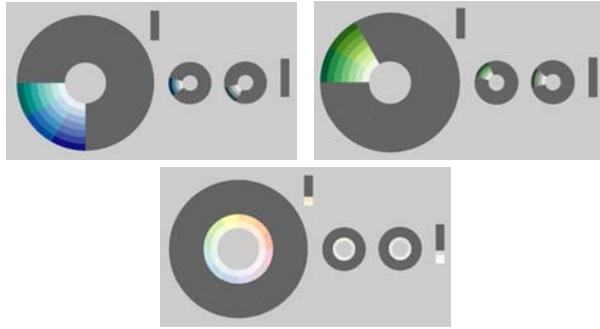


Figure 1. Blue and green color families and lights colors in color wheels.

Semantic rules link two themes and their color as describe in [Domingues, Christophe, Jolivet 2009]:

- Two themes involved in an association relationship should be represented by similar colors
- Two themes involved in a differential relationship should be represented by distant colors.
- Themes involved in an ordered relationship should be represented by a color shading of the same hue.

The symbolization of the legend, and especially the colors of the layers, makes sense in the representation. They ensure the semiotic quality of the map. For example, the ColorBrewer [Brewer 2003] provides color schemas adapted to thematic cartography. Christophe [2009] proposes a cooperative method to design customized and original legends, by helping users to select suitable colors. These works show the importance of color choices. The stake of our work is then to preserve the quality of the map through preserving the relationships existing in the initial map between the layers, their semantic and their representation (i.e. their colors among graphical variables).

## 2.2 How to modify an initial map being aware of those rules?

Let us consider an initial map supposed to be cartographically correct. Our issues to preserve the quality of color changes are the following: Which initial colors must be kept? And which ones can be modified? How can we evaluate the final semiotic quality of the map? We propose two strategies of preserving the quality of the color choices made on purpose in the legend: one is useful to keep the colors chosen by virtue of conventional rules, the other one is useful to estimate if the relationships between colors resulting from semantic rules have been kept.

In the one hand, the initial map is supposed to respect conventional uses of colors. Thus the initial colors of hydrographic and vegetation themes and of the background should have been chosen as illustrated in Figure 1. Therefore, our first strategy consists in preserving the original colors of some or all those relevant themes according to the comprehension of the map.

In the other hand, colors of all the themes of the map are supposed to transmit the existing semantic relationships between the corresponding themes. As a consequence, it is necessary to look for the relationships between the colors used in the symbolization of the different themes. With that in mind, we propose here a first quantitative estimation of the cartographic

similarity of two legends. We use it to qualify the semiotic quality of a map according to a given reference map as a control of the preservation of initial semantic relationships.

## 2.3 Estimation of the respect of the semantic relationships

A reference palette is build from the colors existing in the initial map like the palette on the left of Table2. Our goal is to evaluate the semantic quality of a second palette, i.e. the relative respect of the color relationships.

In order to do that, the first step consists in calculating the binary distance matrices between colors for each palette. The distances between the colors of each palette are first evaluated by means of the Euclidean distance in the CIE Lab Color Space. This color space gives an independent device color definition and has been designed by the International Commission on Illumination to be perceptually uniform as detailed in [Fairchild 2005]. The compatibility of CIE Lab with human color is the reason why we use the Euclidean distance in the CIE Lab Color Space. Then, a threshold is introduced: colors are considered close enough if the color distance is smaller than 50 and distant if it is bigger. As shown in Table 1, binary distance matrices are then filled by 0 if the two colors are close enough and by 1 otherwise.

	0	0	0	1	1	1		0	0	1	1	1
	0	0	0	1	1	1		0	0	1	1	1
	0	0	0	1	1	1		1	1	0	0	0
	1	1	1	0	1	1		1	1	0	0	0
	1	1	1	1	0	0		1	1	0	0	0
	1	1	1	1	0	0		1	1	1	1	0

Table 1: Binary distance matrices of Reference Palette and a new given palette

In the second step, an indicator is calculated to quantify the distance between both palettes with the following equation:

$$\frac{\sum_{i,j=0}^p |M_{ij} - N_{ij}|}{p^2} \quad (1)$$

where  $M$  = binary distance matrix of the reference palette,  
 $N$  = binary distance matrix of the second palette,  
 $p$  = number of colors in each palette.

Equation 1. Distance between two palettes ranging from 0 for two close palettes to 1 for two distant palettes.

With the purpose of being aware of the relative importance of the layers, it is necessary to consider the covered area on the map by each theme. This area depends on the implantation mode of the geographic objects: it is necessary to take into account the actual area of symbolized object on the map, and not only their geographic geometry. The width of the linear objects symbolization and of the contour of polygonal objects is

considered for such representations. For punctual symbols the covered area is estimated by the area of the square containing the symbol. Furthermore, the background layer is under all the other layers. Thus, for the background layer, only the visible area must be considered. For the other themes overlays are disregarded. The refined equation below shows how covered areas are used as a weighting in the calculation of the distance between palettes:

$$\frac{\sum_{i,j=0}^p |M_{ij} - N_{ij}| \times a_i}{p^2} \quad (2)$$

where M = binary distance matrix of the reference palette,  
 N = binary distance matrix of the second palette,  
 p = number of colors in each palette,  
 a<sub>i</sub> = visible area on the map of each layer

Equation 2. Weighted distance between two palettes from 0 for two close palettes to 1 for two distant palettes.

In the example of Table 2, the reference palette is on the left. The other four palettes are compared to it.






Reference Palette	Palette 1	Palette 2	Palette 3	Palette 4
				
Weights	Distance from Reference Palette	Distance from Reference Palette	Distance from Reference Palette	Distance from Reference Palette
0.5 0.1 0.05 0.2 0.145 0.005	0.0	0.1388889	0.0	0.1666667

Table 2. Estimation of the cartographic distance between two legends from 0 for close palettes to 1 for distant palettes.

Palettes 1 and 3 have a similarity equal to 0; this means that they are cartographically similar to the reference palette regarding the semantic and color relationships. Indeed, the three palettes contain three close colors with the same hue (respectively red, green and pink), two close color with a same hue (respectively blue, red and green) and an isolated color (respectively yellow, purple and blue).

### 3. ENERGY REQUIRED FOR DISPLAYING A MAP

For some emerging display technologies, the energy required to display an image is directly linked to the colors of this image. Therefore, a map can be more sustainable using dark colors rather than light ones. Our first issue is then to evaluate the energy consumption of a mobile device. This estimation is considered as a quantification of the suitability of our map according to its display technology.

### 3.1 Estimation of the energy for displaying colors.

Colors displayed on a screen are usually described in an RGB color space. Therefore, RGB coordinates are used to evaluate the energy required to display each color. Johnson Chuang [2006] describes the energy required to display pixels on a mobile device according to their color. Two different equations estimate the energy depending on the type of screen of the mobile device:

- The sum of the maximum of the R, G, and B color components of each pixel is an appropriate estimation for HDR (High Dynamic Range) displays.

$$\max\left(\frac{r}{255}, \frac{g}{255}, \frac{b}{255}\right) \quad (3)$$

where r, g, b = RGB color components of the color of layer i

- The sum of the sum of the R, G, and B color components of each pixel is an appropriate estimation for OLED (Organic Light Emitting Diode) displays.

$$\frac{r}{255} + \frac{g}{255} + \frac{b}{255} \quad (4)$$

where r, g, b = RGB color components of the color of layer i  
 Let us apply those energies on some chromatic wheels illustrated in Figure 1 (see [E. Chesneau 2006], [E. Buard and A. Ruas 2007]) and used in COGIT works concerning map improvement and conception. This reference color system gives a discrete and structured space of colors,

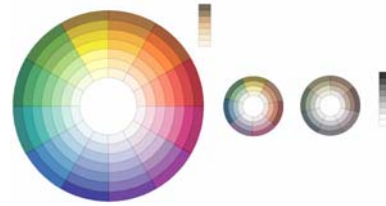


Figure 1. Color reference system of COGIT Laboratory.

The illustrations below show the value of both energy estimations for those colors. The left image shows a gradient of the estimation of energy (from 0 to 1 for the maximum of the RGB components computed with equation 3 and from 0 to 3 for the sum of the RGB components computed with equation 4) and the second one gives a 3D view displayed.

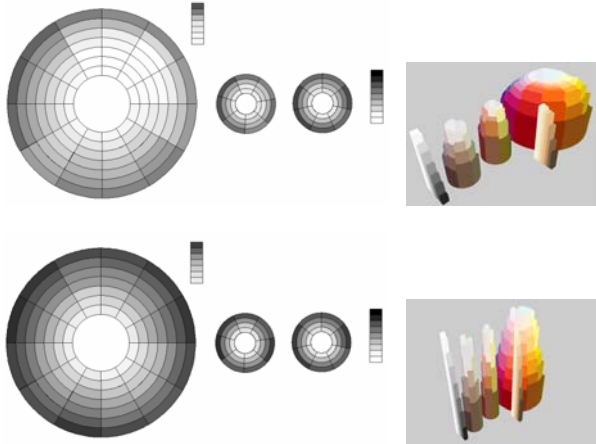


Figure 2. Energy requires by two different screens for each color in the COGIT color wheel.

Figure 2 shows that globally bright colors use less energy to be displayed than dark colors. Moreover, grey tints use less energy too.

### 3.2 Extension of the estimation for a map.

The second step to estimate the energy required to display a map is the consideration of covered areas on the map by the cartographic symbols as for the estimation of the distance between two palettes. In our estimation of the energy required for displaying a map, the covered area is used as a weighting of the energy required to display each color. The equation below shows the estimation of the energy for an entire map:

$$\sum_{i=0}^n \max\left(\frac{r}{255}, \frac{g}{255}, \frac{b}{255}\right) \times a_i \quad (5)$$

$$\sum_{i=0}^n \left(\frac{r}{255} + \frac{g}{255} + \frac{b}{255}\right) \times a_i \quad (6)$$

where  $a_i$  = visible area on the map of layer  $i$   
 $r, g, b$  = RGB color components of the color of layer  $i$   
 $n$  = number of layers in the map

The geographic area considered to calculate the energy is the entire useful area for the user, not the visible area on the screen of the mobile device. Indeed, the legend can not change every time while user moves. So, the energy is calculated once and for all and then users are able to pan or zoom in his mapping application as they need.

The geographic area used for our study when computing energy and semiotic quality estimations is the whole French department of Isère. It is important to note that this global area is rural, i.e. it presents an important part of vegetation and of non-use land represented by the background layer. Therefore, these two themes are relevant in our study because of their important role in the weighting matrix used for both estimations of the cartographic quality and the energy required to display the map.

Illustrations below show a focused zone symbolized with different European legends coming from [Jolivet 2009]. Let us see which country proposes the more sustainable map!



Figure 3. Symbolizing our zone with a Dutch legend.



Figure 4. Symbolizing our zone with a Norwegian legend.

The map with a Dutch legend requires a weighted energy of 0,77 whereas the map with a Norwegian legend requires a weighted energy of 0.80. Therefore, Netherlands presents the most sustainable map. This was expected because of the very light colors of the background and the vegetation theme on the Norwegian legend. For the same themes, the Dutch legend uses darker colors without respecting the common use of a light color for the background layer.

## 4. EVALUATION OF THE CARTOGRAPHIC LEEWAY THROUGH THREE MAP SAMPLES

In order to evaluate how far we can alter a map supposed to be cartographically correct, three map samples have been designed while considering more or less cartographic rules from an initial map cartographically correct: colors of this initial map have been changed to optimize the energy constraint. We discuss here where



it is possible to go in the way between maps cartographically correct and sustainable maps.

Let us first says that the weighting of both estimations of energy and cartographic quality increases the importance of the background layer. Respecting conventional rules, the background layer is generally represented by a light dark color. Therefore, darkening the background layer is a good way to lower the energy required to display a map. Nevertheless, it is a relevant semiotic component to give sense to the map too. As a consequence, it is a stake for further optimizations.

Moreover, when lowering the energy required to display a map, dark colors are favored relatively to lighter ones or yellowish ones. But result maps can not be entirely dark nor grey. It is important to keep distinct tints choosing new colors. In his work, Jonshon Chuang [2006] sets a minimal distance between the different colors and a range of lightness. In our work, the colors of the legend are guided by the semantic of the map.

The initial map used in our example is presented in Figure 5 and the corresponding palette and surface weights in Figure 6.



Figure 5. Initial map, to be adapted to a mobile device while limiting energy waste.

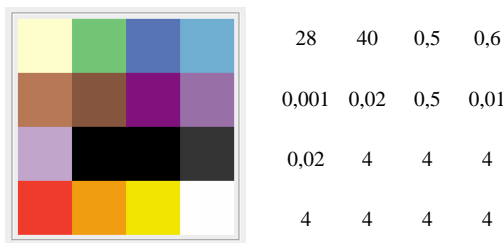


Figure 6. Corresponding color palette and surface weights in percentage of the initial map.

This map requires a weighted energy of 0,77. In this part, the energy required to describe the map is computed with equation 5. It ranges from 0 for a sustainable map to 1 for an energy consuming one.

#### 4.1 Keeping the background color.

In the next map presented in Figure 7, the original color of the background layer has been kept whereas others colors have been modified.



Figure 7. Only the background color has been kept.

This map requires a weighted energy of 0,67 i.e. it saves 13%. It is a moderated economy thanks to the dark color of the vegetation theme and because the light color of the background have been kept. At first sight the map seems not too far from a common map even though it is not quite so easy to understand it. The background layer has a powerful visual impact at the first level. But it seems not enough to design a real easily readable map.

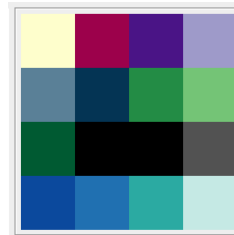


Figure 8. Corresponding palette of the map of Figure 7.

The cartographic distance between palette of Figure 8 and the reference palette (computed with equation 2) is equal to 0,00355. Semantic relationships between roads, building, railways and hydrography have been preserved. Colors have not been kept, nor their tint, but the map still presents association relations between layers in the same theme, differentiation relation between layers in different themes and order relationships for the hierarchical representation of the road for example. Resulting map is not conventional but its legend still presents a hierarchical structure.

#### 4.2 Keeping colors of hydrographic and vegetation themes.

In the next map presented in Figure 9, original colors of the hydrographic and vegetation themes have been kept whereas others colors have been modified.



Figure 9. Hydrographic and vegetation themes have been kept.

This map requires a weighted energy of 0,65 i.e. it saves 16%. The economy has increased because of uses of dark colors for both the background layer and the vegetation theme. But the map has lost efficiency and readability. Indeed, the cartographic distance between palette of Figure 10 and the reference palette (computed with equation 2) is equal to 0,01665. This map presents definitely a worth cartographic quality than the precedent map.

Keeping the colors of the hydrographic and vegetation themes may be difficult because it takes away a lot of colors. It is also difficult to find colors which are both well contrasted with the background layer and aware of the semantic relationships between themes.



Figure 10. Corresponding palette of the map of Figure 9.

The conventional rule concerning the background layer is widely used to improve the color contrasts [E. Chesneau 2006]. Indeed, if the background color is light enough, geographic objects are well contrasted with it. Nevertheless, this conventional rule is not inevitable or can be used reversely.

For example, some GPS navigation systems offer visualization modes adapted to night time. These visualization modes try to be darker than the daily mode in order to not disturb the driver.

The background layer is definitely a powerful way to lower the energy required to display the map. Such power to save energy has been used in Blackle [HeapMedia 2010], a version of the famous search engine Google with a black background. But, this power can turn against the first aim of map design, i.e. the efficiency of the map.

### 4.3 Free optimization

In this last map, all the colors have been modified.



Figure 11. All the colors have been modified in order to lower the energy required to display the map.

This map requires a weighted energy of 0,46 i.e. it saves 40%. The freedom for the modification of all the colors allows giving priority to dark colors for the background layer and the vegetation theme (which are the most extended layers) and light colors for the others themes. Thanks to it, color contrasts are good and help the understanding of the map highlighting important geographic objects. The map results look as a “reverse” map but keep some efficiency.



Figure 12. Corresponding palette of the map of Figure 11.

The cartographic distance between palette of Figure 12 and the reference palette (computed with equation 2) is equal to 0,007888. Like for the map designed keeping the background layer in Figure 7, semantic relationships between themes have been respected using less energy-consuming colors.

## 5. CONCLUSION AND PERSPECTIVES

The first conclusion of this study is the highlighting of the importance of the background layer. It should be well contrasted to all the other themes but it does not have to be light. It can be represented by a dark color as long as other colors can be easily differentiated.

A second result is the importance of semantic relationships and therefore of color relationships. The structure of the legend must be transmitted by its symbolization. But it is not even necessary

to respect conventional uses of colors. They help to the comprehension of the map at first read level but are not essential. An application for automatic improvement of colors is under development in the GIS platform GeOxygene [Bucher an al. 2009]. It will allow to design more sustainable maps. It will be useful to test different optimizations in order to study user feelings about those original maps.

Furthermore, others constraints could be studied. For example, if we limited the use of some tints, maps could be adapted to partially sighted persons, especially color blind users.

Finally, it will be interesting to study the sensitivity of optimization of the colors regarding the type of geographical zone. Urban zones present more built-up areas whereas rural zones like ours present more vegetation areas and a prominent background layer.

## REFERENCES

Bertin, J., 1967. *Sémiologie Graphique: Les diagrammes, Les réseaux, Les Cartes*. Paris.

Brewer, C. A., 2003. <http://colorbrewer2.org/>, (accessed 10 Sept. 2010).

Buard, E., Ruas, A., 2007. Evaluation of colour contrasts by means of expert knowledge for on-demand mapping. In: *23rd International Cartographic Conference (ICC'07)*, 4-10 August, Moscow, Russia.

Bucher, B., Brasebin, M., Buard, E., Grosso, E., Mustière, S., 2009. GeOxygene: built on top of the expertness of the French NMA to host and share advanced GI Science research results, In: *International Opensource Geospatial Research Symposium 2009 (OGRS'09)*, 8-10 July, Nantes (France)

Chesneau, E., 2006. *Modèle d'amélioration automatique des contrastes de couleur en cartographie - Application aux cartes de risques*. PhD Thesis, University of Marne-La-vallée, IGN, France, 372p.

Christophe, S., 2009. Making Legends By Means of Painters' Palettes. In: *Cartwright W., Gartner G., Lehn A., Cartography and Art. Lecture Notes in Geoinformation and Cartography series*, Springer.

Chuang, J., 2009. *Energy aware colour mapping for visualization*. Master Thesis of the Simon Fraser University.

Domingues, C., Christophe, S., Jolivet, L., 2009. Connaissances opérationnelles pour la conception automatique de légendes de cartes. In: *20èmes Journées Francophones d'Ingénierie des Connaissances (IC'09)*, 25-29 mai, Hammamet (Tunisie).

Fairchild, M. D., 2005. *Color Appearance Models (2d Edition)*. Wiley-IS&T Series in Imaging Science and Technology, England, pp185-191.

Heap Media. Black background version of Google search engine. <http://blackle.com/> (accessed 10 Sep. 2010)

Jolivet, L., 2009. Characterizing maps to improve on-demand cartography - the example of European topographic maps. In: *17th Conference on GIScience and Research in UK (GISRUK'09), poster session*, 1-3 April, Durham (UK).

MacEachren, A. M., 1995. *How Maps Work: Representation, Visualisation, and Design*. The Guildford Press, NewYork, pp 244-309.