PROCESSES FOR IMPROVING THE COLOURS OF TOPOGRAPHIC MAPS IN THE CONTEXT OF MAP-ON-DEMAND

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Abstract

The growing availability of digital geographical data induces a growing need for producing Maps on Demand. In this context the aim of this paper is to present three original methods to automatically improve existing legends. At the current step of our research we are focusing on colour change only but the results are already very positive.
A legend is composed of legend-lines and the aim of the processes is to change the colours of legend-lines to improve colour contrasts while respecting the relationships of Association, Order or Difference each legend-line has with the others. Thus we follow Bertin's approach (Bertin, 1967) of decomposing a legend into a set of couples relating the sign and its meaning.
In our approach, we distinguish 1/ the cartographic rules, 2/ the data modelling that hold this knowledge and 3/ the solutions proposed for legend improvement. Three methods are proposed: one based on Constraints Solving Problem method, one based on Multi-Agent System and the last based on Local Search. The two first are limited to an analysis of contrast between legend-lines whereas the last computes the contrast on the map between cartographic symbols which is more accurate. The quality of the results of course mainly depends on the understanding of cartographic rules and their balance. These methods could be used to propose new cartographic services on the web.

1-Introduction

More and more web sites are proposing map services where users can either select existing maps in raster format or build a map from vector databases. Most solutions today consist of selecting existing map scans, choosing a page size and a scale, selecting a title, adding a picture and some additional information (see http://www.xyzmaps.com/MoD.htm or http://loisirs.ign.fr/AccueilALaCarte.do). Maps are prepared off-line and sent by post to the user in few days. The process is technically simple as it consists of printing an existing raster file on a predefined map sheet templates. Very soon many websites - including institutional ones - will propose to create maps on line from on line geographical databases.

However, if technical solutions are emerging to extract data from databases and to map them according to predefined legends, the industrial community does not pay much attention on the complexity of legend design. In the research community some are proposed for choropleth maps (see for example the work of Cynthia A., Brewer (2003) on http://www.ColorBrewer.org), few studies are focusing on the conception of topographic map legends in the context of maps on demand.
In this context, the COGIT laboratory - a research laboratory of the French NMA- is working on the conception of new methods to help users to build their own map legend. Since 2005, two strategies have been investigated:

- the first one is to help the user building step by step his own map legend by means of an appropriate dialogue, using either painters' palette or map samples (Christophe, 2008a,b);
- the second one consists in improving the colours of the existing legend of a user (Chesneau, 2006; Buard and Ruas, 2007).

Both approaches can jointly be used: 1/ a system helps a user to build his legend step by step (approach 1) and 2/ the system analyses and improves the built legend (approach 2). The COGIT laboratory is also investigating on the conception of a set of appropriate web services for map making (Jolivet, 2008).
The aim of this paper is to present original methods to improve existing legends (approach 2). The paper begins with the presentation of the core of our approach: the analysis of semantic relationships and their impact on colour choice. Then in section 3 we present different processes conceived at the COGIT laboratory.
At the current step of our research we are focusing on colour change only which means that we do not change the shape or the size of symbols. A colour (e.g. light blue) is represented by a hue (e.g. blue) and a value which represented either the percentage of white added to the hue, or the percentage of black added to the hue. Future COGIT PhD research might hopefully include these graphical variables in our approach.
All methods presented in this paper have been implemented at the COGIT lab in Java on GeOxygène (Grosso and Bucher 2009; Brasebin, 2009), the OpenSource GIS platform (http://sourceforge.net/projects/oxygene-project/). In 2009, we wish to release a new OpenSource GeOxygène module centred on the legend improvement process. This is presented in section 3.3.

2- Knowledge for legend design

2.1 What is a good map?

In order to improve the legend of a map, we have to define its required quality.
To sum up the famous semiologist Jacques Bertin (1967) and the cartographer Mark Monmonier (1991) the main quality of a map is to describe as faithfully as possible the organised information contained in the data to map. In other words, to help readers understanding the information, the cartographer organises the information and then chooses a legend that respects and even more enhances this organisation.
Following Bertin (1967), organising information is a cognitive process. Basically it consists in identifying and describing relationships between elements. In our case the

elements are the legend-lines, the set of couple (sign/meaning) that define the legend. To organise the data, the concept of *theme* is also important: the cartographer segments the information into themes which structure the cartographic message. Consequently the legend lines are grouped into themes. The relationships between legend lines belong to one of the three following relations: Association, Order or Difference with the following rules:

- If two legend lines belong to a same theme, they are in association (meaning) so their signs should be visually close. For example their signs could share the same hue.
    - If these two legend lines are ordered, they are still in association (so their sign should look close) but one is more important than the other so one sign should be more visible (remarkable) than the other.
- If two legend lines belong to very different themes, their signs should be visually very different.
    - but if one theme is more important than the other, then the sign of its legend lines should be more visible than the sign of the legend lines of the other theme.

These relationships are summed up in Figure 1:

ASSOCIATION If A and B are in association
Then their signs should be different but **visually linked**
for example they could have different shape (line or symbols) but the same hue

ORDER If A and B are ordered
Then their signs should be **visually ordered**
for example they could have the same hue with different value (area) or size (line or symbols)

DIFFERENCE If A and B are not in association
Then their signs should **not be visually linked**
for example they could have very different hues

Figure 1: Relationships between two legend lines (A and B) in a legend

So the art of the cartographer is to find signs that make visible the hidden organisation between legend lines. But the signs should also follow complementary rules:

- in order to optimise the association sign/meaning, conventional association rules should be used as much as possible. For example representing the vegetation in green optimises the understanding of the legend because the association green/vegetation is in everyone's head,
- in order to allow the perception and recognition of the signs, they should respect minimum size criteria such as the one defined by (Spiess, 1995). Small objects such as buildings should be darker than large extend objects such as forest.

To sum up, in order to build a process that improves automatically the map legend we have:

- to organise the information into themes and describe the relationships between themes and between legend lines,

- to find signs that respect and enhance these relationships while following other cartographic rules such as respecting minimum sizes and the existing associations sign/meaning.

2.2 Implementing the knowledge for legend making

For the automation process we have to represent the knowledge described in the previous section in our legend design process. We propose to represent the elements of a legend by means of objects as well as the knowledge associated with colours and themes:

- an object *legend* is composed a set of object *legend-theme*,
- an object *legend-theme* can be composed of other *legend-theme* objects or a set of legend-lines,
- a legend-line is described by an object *legend-text* and an object *sign*,
- an object *sign* is described by an object *colour,*
- an object *legend-theme* is related to an object *theme* that describes the usual knowledge associated with this theme,
- an object *colour* is linked to an object *colour-family* and reversely an object *colour-family* associates a set of objects *colour* together on visual principal. For example the object *blue-family* groups blue colours objects together,
- some relationships exist between *theme* and *colour-family* objects. For example the object theme *vegetation* is linked to the colour-family *green-family*. Different types of relationships exist: a *family-colour* is "often used", "never used" or "may be used" to represent a *theme*.

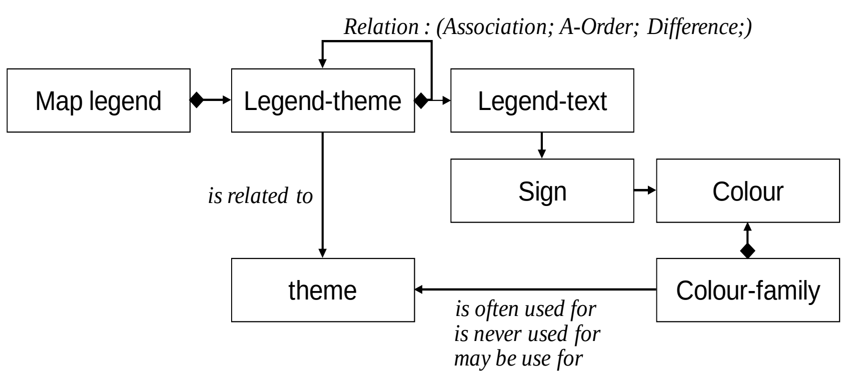

Figure 2: UML representation of legends, themes and colours

Figure 2 presents an UML representation of this information. This data model is very convenient as it allows easily representing and updating our cartographic knowledge. Today we limit our sign analysis on colour only which explains why the description of signs is limited to colour only. In order to describe the relationships between Legend-themes a graph structured as a tree can be added and stored. On top of the hierarchy is the map-legend, the first level (first leaves) is composed of the main legend-themes. Each legend-theme is then gradually described forming a legend-hierarchy.

2.3 Changing colours according to themes and contrasts

The principle of our method for legend improvement is to analyse the colours and to change one or several ones if they do not respect the following rules:

- the colour of a legend line should be coherent to the colour family associated to the theme of the legend line;
- the relationship between two colours should respect the relationship of association, order or difference which exists between the two legend lines they are representing.

In order to compute the relationships between colours, we compute distances between them by means of the notion of contrast which reflects the perceptual distance between colours. This work is inspired by Itten studies (1967) who described seven types of contrast between colours and (Brewer 1992). In order to simplify the problem, we do not analyse all contrasts but only the *contrast of hue* and the *contrast of value* (which represents the dark/bright contrast).

Thus each colour of the legend is described by a couple (hue; value) and we compute hue and value contrasts between all legend signs. In order to compute the hue and value contrasts between colours we first used the HSL (Hue, Saturation and Lightness) colour code, and we modified and improved the measurement by a series of tests performed by cartographers (see Buard and Ruas 2007).

When colour distances are computed, we analyse if each distance is coherent with the relationships it should describe:

1- If two legend-lines are associated but not ordered, their hues should be close, so *their hue-contrast should be low*. At least they should belong to the same family colour.
2- If two legend-lines are associated and ordered, their hues should if possible be the same (*their hue-contrast should be as low as possible*) but their values should be different (*their value-contrast should be higher than a minimum threshold*)
3- If two legend-lines belong to non-associated themes, their hues should be very different, so *their hue-contrast should be higher than a minimum threshold.*
4- If two legend-lines belong to non associated themes but if these themes are ordered, their hues should be very different and one should be more visible than the other one. *their hue-contrast should be higher than a minimum threshold and their value-contrast should be higher than a minimum threshold*

Moreover each colour should be visible so we also compare each colour to the background colour (often the white or a very light colour) to be sure that each colour can be seen (*each colour should have a minimum hue or value contrast with the background colour).*

Although these rules are simple, taking them into account greatly improves the quality of the map legend. In the following section we present different solving methods for implementing legend improvement process.

3- Solving methods

In order to compute contrasts and to choose a new colour for a legend-line we use a specific chromatic circles composed of 163 colours (see (Chesneau, 2006; Buard and

Ruas, 2007) for the description of these circles). In all methods presented hereafter, the aim of the process is to find a good location for all the legend-lines on these circles while respecting the relationships of each legend-line with the others: If the legend is composed of n legend lines, each legend-line has a specific relationship of Association, Order or Difference with the n-1 other legend-lines. To implement this process according to the rules presented in section 2, different solving methods can be used.
We distinguish two main approaches:

- we analyse the contrasts between all the legend-lines whatever the position of symbols on the map. We call this approach "Analysis of colour contrast in the legend" because we do not need the map but only its legend.
- we analyse the contrasts only between symbols that are close to each other on the map. We call this approach "Analysis of colour contrast in the map" because it requires the computation of object neighbourhood on the map. This method is more accurate but the computational cost is higher.

Three solving methods implemented are presented in the following subsections: one by means of Constraints Solving Problem techniques (CSP; 3.1); one by means of Multi-Agent System (MAS; 3.2) and the last one by classical local search (3.3). Only the last one analyses the colour contrast in the map.

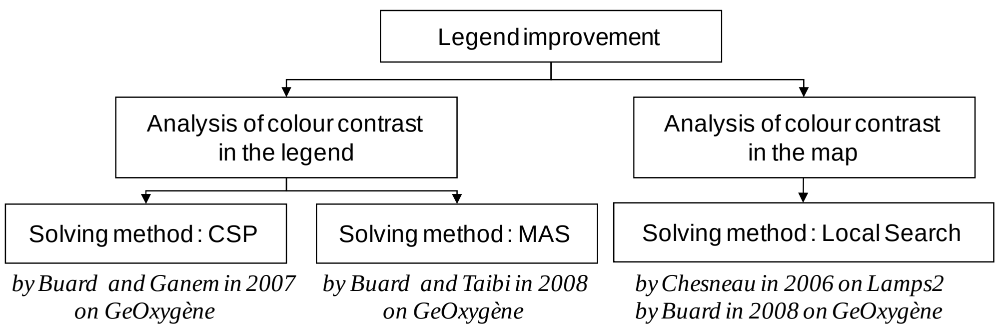

Figure 3: Legend improvement methods implemented at the COGIT Laboratory

In the first method (3.1) the process computes the position of the legend-line objects on the circle taking into account the initial choice of the user (the user-ideal colour), while both other processes (3.2 and 3.3), the legend-line objects are already located on the circles according to the user initial choice and are moved to improve the legend. The use of these circles reduces the number of colours and consequently the problem solution space. We name 'initial colour' a colour set by the user for a legend-line.

3.1 Analysis of colour contrast in the legend by CSP

This approach uses the Multi-Agent System module Madkit (Gutknecht and Ferber, 2000) and the Constraint Solving Problem software named CHOCO (Laburthe, 2000). Both modules are open-source softwares. For the CSP we used an Arc-Consistence solving method.
In this approach the system starts by solving the hue constraints (by a specific Hue-CSP) and then the value constraints (by another specific Value-CSP). Each CSP-process uses two steps and orders: 1/ each CSP sequences the legend-line order for colour set

and 2/ in case of non satisfaction, the system changes the constraints of a single legend-line and restarts a CSP.

- For the Hue-CSP, each legend-line computes its colour-domain defined by its colour-family and its initial colour. The domain is ordered: if the initial colour is within the colour-domain, it is ordered first. The Hue-CSP tries to find a colour for each legend-line, starting by the legend-line that has the smallest colour-domain: the first takes a hue (the closest to the initial hue value). The second line does the same while respecting its relationship with the already treated line and so on. If the system can not find a colour for each legend-line, it enlarges the colour-domain of one legend-line and starts the process again until it finds a solution for all legend-lines.
- For the Value-CSP, the process is the same but when the system does not find a solution instead of enlarging the colour-domain, it relaxes some constraints related to the respect of relationships between legend-lines according to a predefined order of importance.

Figure 4 illustrates the results of this method. On top, some legend-lines representing very different themes have close hues like Trees and Water Flooding. Moreover, the initial colours are not classical so the understanding of the map is not easy. After processing, the map looks more familiar and themes can be visually identified. However, the drawback of this method is certainly the weight of the colour-family in the process. As a consequence the resulting legend map might be always the same, whatever the initial preference of the user.

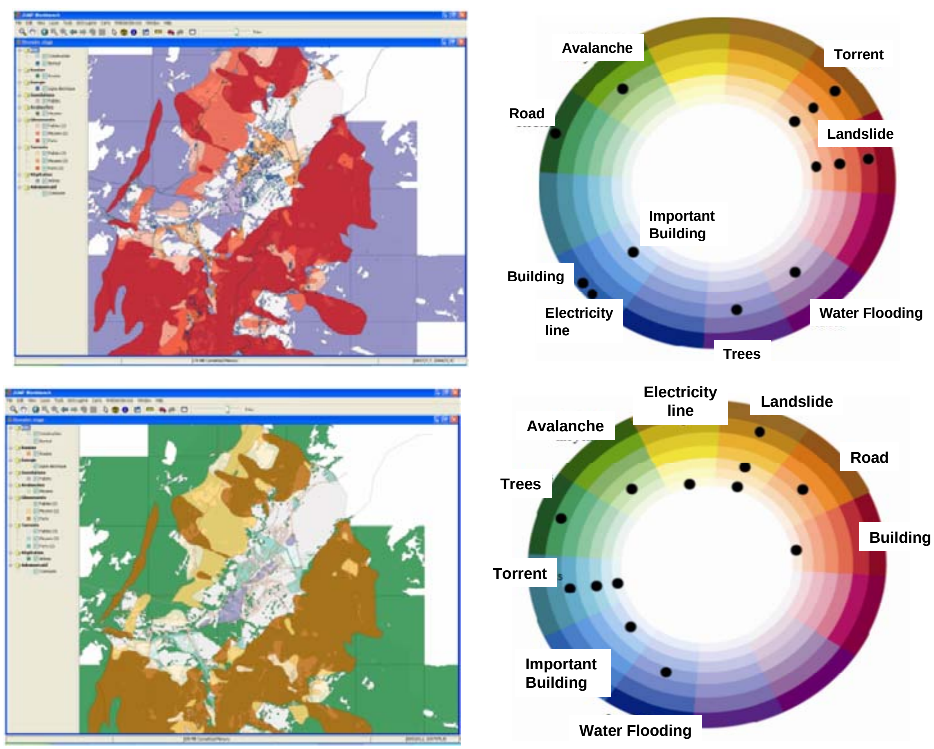

Figure 4: Legend improvement by CSP- Top: initial data; Bottom: Final map.

3.2 Analysis of colour contrast in the legend by SMA

This approach uses the Multi-Agent System module Madkit (Gutknecht and Ferber, 2000) and GeOxygène. In this solving method, each legend-line is an agent. Each agent computes its non-quality according to:

- the coherence between the relationships and the hue and value contrasts it has with each other legend-line,
- the coherence between its hue and its theme (by means of the colour-family).

A hierarchy of conflicts is defined and used to compute non-quality mark, from the most important to the least:

- two ordered legend-lines do not have the same hue,
- a legend-line has a colour far from its family-colour,
- two associated legend-lines have very different hues,
- two different legend-lines have hues that belong to the same colour-family,
- two ordered legend-lines do not have an appropriate value contrast.

Each agent aggregates its non-quality marks to compute its global non-quality and the worst agent moves on the chromatic circle in order to improve its state. The system always starts to solve its worst conflict according to the same conflict hierarchy. After each agent movement on the chromatic circle, each agent revaluates itself and the process carries on up to a global satisfaction.

In the mean-time the legend-map computes its global quality which is the mean of the quality of its legend-lines agents. Each time the worst agent moves to improve its state, the legend-map re-evaluates its quality. This evaluation can be used to stop the process in case of global stagnation.

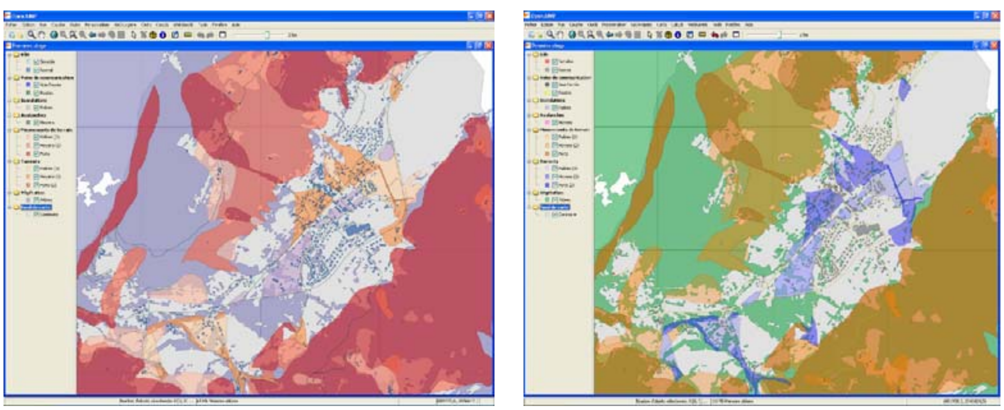

Figure 5: Legend improvement by MAS- Left: initial data; Right: final map.

Figure 5 illustrates some results of this approach. It is not very different from the previous one because the knowledge used is the same. Here again, the colour-family certainly plays a too important role. However the main advantage of this approach is that colour change is driven by the conflict, so it is always a necessary change. The progressive colour changes process offers a better control on the final quality. A visual comparison with the final map of Figure 4 enlightens the better readability of this solution. The drawback is that eventually the system might not converge towards a solution.

3.3 Analysis of colour contrast in the map by local search

The main drawback of both previous methods is that the analysis of the colour contrast is done between all legend-lines whatever the real proximity of symbols on the map. Consequently these processes might change a colour of a legend-line due to a conflict with another legend-line event if the symbols are never close one to another on the map.
The approach presented in this section consists in computing the colour contrast on the map between symbols to evaluate in a more accurate way the readability problems on the map. This approach was first proposed by (Chesneau, 2006) during her PhD at the COGIT Laboratory under the direction of Anne Ruas and Gilles Palsky. The module has been rewritten on GeOxygène and improved by Elodie Buard in 2007 and 2008.
In order to compute the contrasts between objects on the map, we introduce the concept of *cartographic object*. A cartographic object is a symbolised object on a map.

Step 1. Each cartographic object computes 1/ its neighbourhood 2/ the hue and value contrasts it has with its neighbour cartographic objects and 3/ a qualitative interpretation of the hue and value contrasts according the relationships of Association, Order or Difference the objects should have. After this step, all the cartographic objects of the map have a hue-mark and a value-mark.

Step 2. The second step consists in aggregating the hue and value marks for all the cartographic objects of the same type, i.e. symbolised in the same way. This step enables to find the worst legend-line, i.e. the one for which the cartographic objects on the map have the poorer visual quality. Moreover it describes implicitly if the colour conflict is on hue or a value. The map also computes a global quality mark.

Step 3. Then the selected legend-line changes its colour based on the cartographic knowledge presented in section 2, and all quality mark are updated. If globally the map is improved, the last colour change is validated and the process carries on. If not the selected legend-line has to choose another solution.

Step 4. The process ends either when the map is cartographically perfect or when the quality of the global map stops to improve.

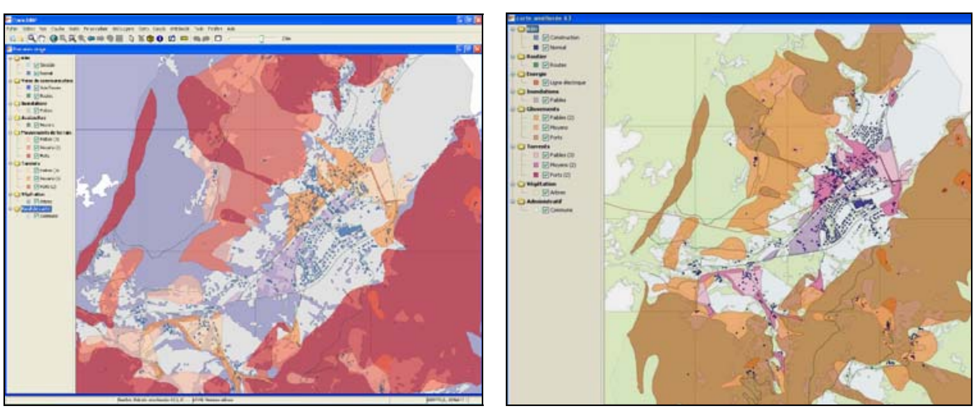

Figure 6: Legend improvement by means of map analysis- Left: initial data; Right: final map.

Figure 6 illustrates a result computed from the same initial map than the on in figures 4 and 5. Here the initial user choices are more respected and the map is well contrasted. The colours changed as little as possible and the contrast is computed on the map and not on the legend (for 1226 graphic objects, 27000 local contrasts are computed).
Today even if the solving method used is very simple, as it is a local search approach without accepting local state degradations, the result are interesting. Using hill-climbing or simulated annealing would certainly improve the results.
However we think that the quality lays above all on the knowledge: In 2007 and 2008 we improved the quality of the reference chromatic circles and the contrast computation (Buard and Ruas, 2007). We should also improve the role of colour-family in the convergence: if it is too strong the initial choice of the user is minimize, if it is too weak the understanding of the map may suffer. The relationship between the colour-family and the theme is also today too basic: a semantic distance would certainly help.

4- Conclusion

The experiments presented in this paper show that it is possible to automatically improve a legend by means of colour contrasts analysis. We hope it opens the way to new cartographic modules or services for map improvement.
The processes presented lay on the identification of cartographic rules, the implementation of this knowledge based on object paradigm (figure 2) and the choice of an appropriate solving method for legend improvements (section 3.3). After working on contrast computation, the core of the success now lays on the identification of the appropriate cartographic rules and their balance: we should precise and complete them.
As Bertin stated (1967) legend making is furthermore a cognitive process.

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