Sharing Cartographic Knowledge with the Crowd: on the Complexity of Cartographic Rules

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Abstract. Cartographic knowledge consists of principles, expertise, conventions and rules of thumb that trained cartographers learn how to use and understand. As cartography enters a new era with the advent of Web 2.0, enabling neogeography and crowdsourcing, the map-making process opened up to a wider audience, which thus is often referred to as neogeographers. These cartographic-laypersons create and modify maps online by combining various resources and cartographic tools available. However, the integration of cartographic principles for the visualization and combination of existing spatial data within geoportals trails behind in its transition to Webmapping 2.0. This integration requires the formalization of cartographic principles and heuristics. For this purpose, we need to have a grasp of the complexity of the cartographic principles. This is realized by looking at the numbers and types of parameters as well as the numbers of relation between them that are required for the formalization and integration of each principle. We discuss here two cartographic principles based on their complexity. First, we look at the formalization of the drawing order of layers and second at the visual hierarchy. The first principle can be formalized by analyzing pair-wisely the layers composing the map and determining whether the order should be reversed or not. The realm of acceptable solutions is limited. The second one involves adjusting the color scheme and contrast between background and foreground information to support the visual hierarchy and not only requires more parameters but also these parameters are more tightly interwoven. Additionally, the realm of solutions is vaster that the few acceptable configurations of layers. Thus, the formalization and integration of those two principles should follow different paths. The first one might require little user input, because it gathers information from the state of the geoportal, whereas the second one might require a more important user involvement in fine-tuning the process. As a conclusion, we show that the type of implementation best suited to share cartographic knowledge on a geoportal can differ from one principle to another due to their complexity and solution realm.

Keywords: Cartographic Principles, Geoportal, Complexity

1. Introduction

Cartographic knowledge consists of principles, expertise, conventions and rules of thumb that trained cartographers learn how to use and understand. However, cartography is entering a new era with the democratization of cartography (Rød et al. 2001), which can be seen in the new aspects found in neogeography, Webmapping 2.0 and crowdsourcing. Indeed, thanks to Web 2.0 and improvements in computer technologies, the map-making process opened up to a wider audience, which thus is often referred as neo-geographers. As explained by Haklay et al. (2008), the map-making process has transitioned from the linear model controlled by the professional cartographer into "*an inter-networked, participatory model where users also collaboratively create, share and mash-up data [...]*". The most important changes lies in the fact that map users are now mapmakers, or map "*prosumers (producers + consumers)*" (Hoffmann 2013) and furthermore, they generate their own content (Haklay et al. 2008), which is called crowdsourced content or volunteered geographic information (VGI), in the form of newly structured maps, but also of actual spatial data (Graham 2010). This new generation of mapmakers creates and modifies maps by combining various resources and cartographic tools available, mostly online. However, the integration of cartographic principles for the visualization and combination of existing spatial data within geoportals trails behind their prolific map-making. This phenomena represent a barrier to the idea of further democratizing cartographic visualization tools as a means to increase general understanding of the role of maps as exploration and communication tools (Rød et al. 2001). Additionally, cartographic functionality adds value to geoportal by helping reveal knowledge within the available data (Fiedukowicz et al. 2012).

This paper aims at discussing specific aspects relevant to the complexity of cartographic principles, their formalization, and how it relates to their integration within an graphic interface. We take as example the integration of two cartographic principles in the geoportal of the GEOIDEA.RO project (GEodata Openness Initiative for Development and Economic Advancement in Romania). The project aims at bringing cartographic knowledge to the data visualization, but also at assisting the user in creating custom and cartographically sound maps using the data on the geoportal with the help of a smart cartographic symbolization wizard. The latter requires the formalization of cartographic principles and heuristics pertaining to cartography and map design.

However, due to the complexity of cartographic knowledge and the subjective aspects that enter into the map design process, it is foreseeable that some of this knowledge cannot be practically formalized. Therefore, this paper raised the question of the complexity threshold at which one should use alternative approaches for the integration of cartographic functionality rather than a traditional and too complex formalization of principles. Furthermore, it leads to the challenge of moving away from the integration of functionality in a black box and towards an open integration of knowledge within the geoportal. Grasping the complexity of the principles to be implemented can give clues about the type of adequate implementation options.

This paper is organized as follows. *Section 2* shortly reviews the most important points from previous works regarding the formalization of cartographic knowledge. *Section 3* discusses aspects related to the complexity of cartographic principles and functionality. *Section 4* concretely covers the integration of the two examples. *Section 5* considers the trade-off between complexity and efficiency. Finally, *Section 6* opens the discussion on aspects that need additional examination.

2. Cartographic Knowledge and Formalization

First attempts to fully formalize cartographic knowledge for automation purposes followed the emergence of expert systems in the late 60's (Jan et al. 2009). Models for the formalization of cartographic knowledge abounded and their comprehensive integration in expert systems has been attempted (Hutzler & Spiess 1993, Forrest 1999, Jan et al. 2009, Xiao & Armstrong 2012, Smith 2013). We present here a short review of aspects pertaining to the formalization process.

As a general remark, it is important to state that no comprehensive expert system to deal with any kind of cartographic aspects has been realized, however the attempts at it provided knowledge bases and functionality for specific aspects of the map design process that can be useful to non-cartographer (and cartographers alike – see the acclaimed ColorBrewer[1] and its siblings MapSymbolBrewer[2] and TypeBrewer[3]) for the production of

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[1] Online at http://colorbrewer2.org/

[2] Online at http://www.carto.net/schnabel/mapsymbolbrewer/

maps (Jan et al. 2009). Indeed, many considered the cartographic design an 'ill-structured problem' and thus unlikely to be solved because difficult to formalize completely (Forrest 1999, Smith 2013), mainly due to the vastness and complexity of the problem (Jan et al. 2009). A later trend towards the formalization of cartographic knowledge is found in cartographic ontologies (Iosifescu Enescu & Hurni 2007, Xiao & Armstrong 2012, Smith 2013, Penaz et al. 2014). The different models suggested in the above-mentioned paper focus on explicitly declaring cartographic concepts on a sematic level, defining their relationship and imposing restrictions on those relationships (Lemmens 2008) and with the goal to enable computers to reason with those concepts.

3. Complexity of Cartographic Functionality

Complexity refers to the idea of a large amount of intricate information pieces that interact with each other. Complexity in a map can come from the intrinsic complexity of the depicted phenomenon or from the complexity of the graphics on the map (intellectual vs. graphic complexity) (Castner as cited in Fairbairn 2006). Insight from the information theory tells us that complex phenomena hold higher information content than simple ones (Shannon 1948, Boisot 2011). The complexity increases as each piece of data brings additional information (Bateson, as in Boisot 2011). Additionally, Llyod offers three dimensions along which the complexity of an object or a process can be measured: how hard is it to describe, how hard is it to create, and what is its degree of organization (as cited in Mitchell 2011). Nevertheless, there is no single or unified theory of what complexity is, but rather many notions of what it means (Mitchell 2011).

We suggest using the number of parameters and their interaction to each other to evaluate the complexity of a cartographic principles or functionality in combination with the type of solution that is expected. So far, we encountered and addressed two main types of solutions, which we grouped in our defined taxonomy in:

- Well defined solution realm (i.e. it is easier to tell right from wrong), highly correlated to the characteristics of data themselves, and with a handful of optimal solution expected (e.g. layer order or representation methods[4]), or

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[3] Online at http://www.typebrewer.org/

[4] E.g. single symbols, graduated symbols, proportional symbols, repeated symbols, choropleth map, and charts.

- Loosely defined solution realms, largely influenced by the subjective aspects found in the cartographic process and with a multitude of acceptable solutions expected (e.g. color choices to support the visual hierarchy or labeling).

This provides an indication of the complexity of the problem and, as will be shown later, of the integration possibilities. This complexity must not be interpreted as the complexity of the algorithm, but as the problem complexity, even though the two are linked. Indeed Saalfeld (2000) explained that "*the complexity of a problem is the complexity of the best algorithm that solves it*" but that this algorithm if often not known, and thus we try to have a better understanding of this problem of complexity in an alternative way.

The first category of problems has a lower complexity and this enable a detailed and precise implementation that delivers an optimal solution within a reasonable amount of time (will be discussed in more detailed in *Section 5*). However, for the second category, the implementation must use heuristics, approximations of the problem, and user input to restrict the scope of the problem and determine the optimal from suboptimal solutions, within a reasonable amount of time.

4. Implementation

4.1. Complexity Estimations

In this section, we estimate more concretely the complexity of two cartographic functionalities and their required parameters, and illustrate them with examples. Furthermore, we look into the type of solution that is expected for each example and explore the significance of these complexity estimations for the integration of the functionalities within the geoportal interface.

Drawing Order

More than a cartographic principle, the drawing order of layers is linked to the structure of spatial data that follows the GIS concept of the layer as the organizational unit for a collection of similar geographic features.

The drawing order influences the readability of the map by preventing features on top from hiding the ones in layers below in an unwanted manner. The layer drawing order must be thus optimized so that features on a layer do not prevent the reading and understanding of the layers beneath.

In a web environment, here a geoportal, in which similar features are organized in layers, the drawing order requisite can be formalized by analyzing pair-wisely the layers composing the map and determining whether the order should be reversed or not.

To create a satisfactory logic of rules (see *Figure 1*) to determine the drawing order of the layers within a map, one critical parameter is the *geometry type* of the features. We assume here that there is one geometry type per layer: one among raster, polygon, line and point. As a general rule of thumb (although exceptions to this rule can be allowed), raster and polygon layers are drawn first, then line layers, then point layers to avoid overlapping features hiding the others (step 1). To achieve a finer order between the different geometry types, but mostly within layers of the same geometry type, and to handle exception to the general rule, a parameter related to the semantic content is needed and we call it here *layer theme* (step 2 and 3). Additionally, we need the *position* of each layer in the layers stack to determine whether the order must be changed or not (see 4 and 5).

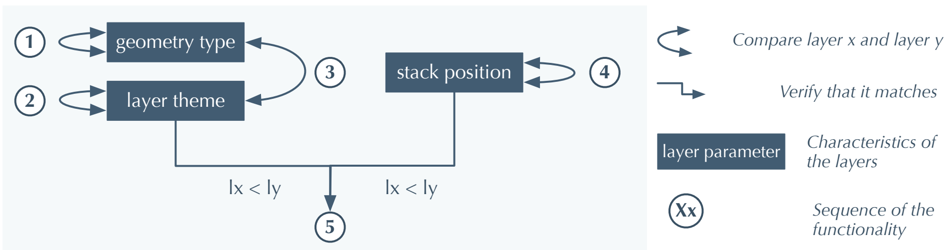

Figure 1. Drawing order: conceptual implementation of the functionality.

Visual Hierarchy

The figure-ground principle, which is one of the “Gestalt principles” (Ware 2004), is often mentioned as contrast, visual hierarchy or “levels of visual prominence” in cartography (Robinson et al. 1995). It pertains to the “perceptual organization” (Slocum et al. 2009) of the map, allowing the user to perceive a difference between information that compose the foreground (figure) and the information that support it by offering a background (ground). Different options are suggested in the literature to apply this principle; as for example, making points and lines in the role of figure darker than the surrounding information. However, for areas it was show that using dark and light features is not a sure way to indicate figure or ground (MacEachren & Mistrick 1992). As a general rule, large brightness differences are a good practice, as well as playing between thick and thin lines separating features in the foreground from the background.

However, before adapting the symbolization, we need to determine the potential background and foreground layers with the help of the following parameters: the *main topic* of the map, the *main layers* of the map, the *layers themes*, the layers *geometry types*, the *priority* of the layers, and the *number of layers* for each ground. Once a ground (foreground, middle ground, or background) is assigned to each layer using a weighted system, other parameters are needed to assess what need or can be changed to the initial symbolization in order to support an adequate visual hierarchy: parameters such as color (hue, lightness, chroma), line thickness, luminance, position in the stack. This second part will not be further discussed here. *Figure 2* shows how the implementation logic. First, certain layers hold parameters that exclude them from potential background (see 1a and 1b), then the layers are further analyze to determine the ones having the role of figure (see 2a and 2b). Finally, some layers are deemed belonging to the background and other left in the middle ground (see 3a, 3b, and 3c).

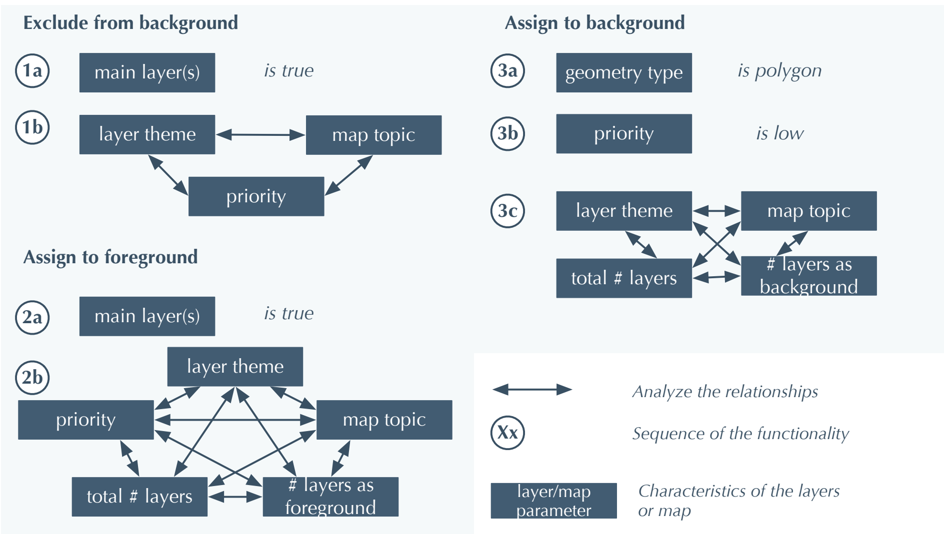

Figure 2. Visual hierarchy: conceptual implementation of the functionality.

4.2. Interface Integration

Different types of integration of cartographic functionalities are possible within the geoportal. A cartographic functionality can be integrated as a black box to the user that only launches the function and return a result, but, with the exception of outputting the reasoning to the user, this option helps little toward sharing knowledge.

An alternative can be found in a dialogue-oriented step-by-step approach, which allows not only to integrate user input at different stages of the reasoning but also to integrate subjective aspects via the users. These subjective aspects should be informed choices from the user and that could be realized by opening the knowledge and rules behind the functionality at every step.

Another important aspect is to offer overriding capabilities to the users at critical decision points in the cartographic workflow, so as to allow flexibility in the functionalities. However, the system logic should warn the user when trying to set up parameters that violate cartographic principles.

Drawing Order

The drawing order is integrated in the symbolization wizard of the geoportal after the two first steps (layer selection and map definition). The next step allows the user to validate and modify the drawing order as suggested by the wizard (see *Figure 3*).

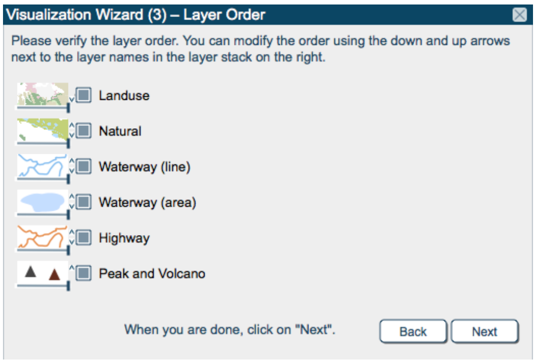

Figure 3. The user can override the drawing order suggestion made by the wizard. The geoportal uses the painter's model, thus the layer on top of the list is the first drawn on the map.

Warnings might be issued if the user tries a conflicting combination. As opposed to error messages, the user can ignore warning and overwrite the wizard suggestions. Error messages are issued when a parameter or value is incompatible with the system logic, for instance, if the user chooses the same layer twice as mains layers (i.e. layers holding the main information on the map) of the maps (see *Figure 4*). Conflicting combinations are defined generally and when a specific case follows a general conflicting combination rule, the alert is issued.

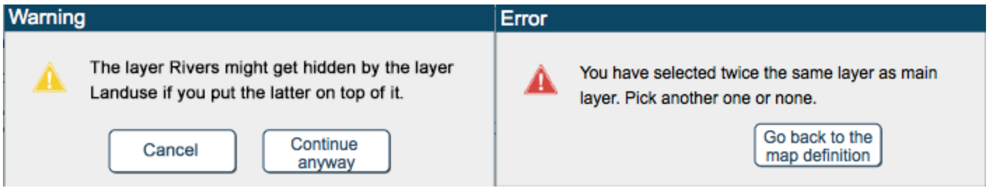

Figure 4. Warning (left) and error (right) message examples.

Detailed evaluation and decision points of the functionality are printed out (in a human-readable format) if asked and thus the user has access to the knowledge implemented behind the functionality. Because the expected solution options are few and because it is rather easy to assess whether a layer visually covers another, a straightforward approach for the integration, in the form of an input-run-output simple pipeline, is adequate.

Visual Hierarchy

The integration of the visual hierarchy functionality requires a bit more out of the box thinking. We decided to provide the user with two modes for interacting with the function at the input stage. First, a traditional approach and similar to the implementation of the drawing order function: we call it black box and the user only enter general input information and then sees the results which can be fine-tuned. Alternatively, the user can have access to more detailed input parameters (see *Figure 5*). Furthermore, the user can choose between a "black-box" method that does not ask for more input and a "white-box" (see *Figure 6*) that allows a more interactive influence on the functionality, especially in the second part, when changes in symbolization are generated.

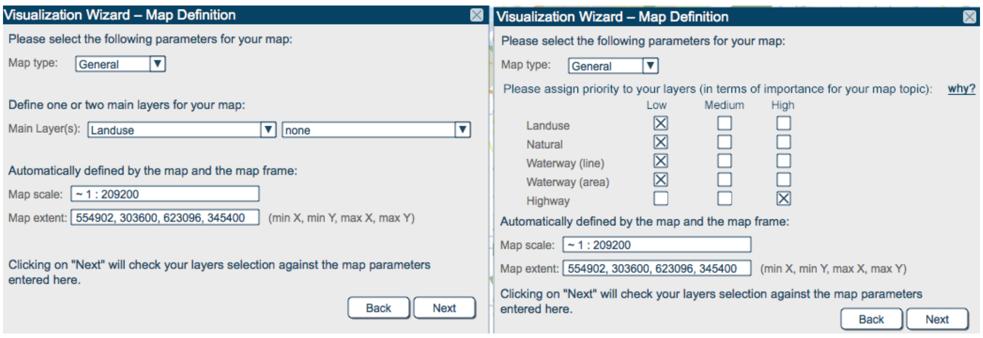

Figure 5. Two possible modes for the integration of the input parameters needed for the visual hierarchy functionality: simple (left) versus detailed (right).

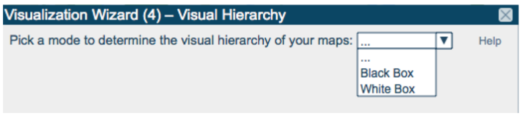

Figure 6. Pick the method to analyze the visual hierarchy.

The "white-box" method enables the user to fine-tune the intermediate results of the functionality (see *Figure 7*), before symbolization changes are suggested. As the complexity of the function is higher and the solution realm much wider and more difficult to assess, additional options must be added to allow the user to gain finer control of the function.

Figure 7. Result of the visual hierarchy analysis, with overwriting capabilities for the user before going to the next step.

Other alternatives could be to integrate sliders in order to define the visual importance of the layers on a continuous range instead of the three positions suggested above or to link the assignment to one of the ground directly to the second part of the functionality, allowing the user to see on-the-fly the transformations, instead of a two-step approach. However, non-cartographers might find the former too complicated.

5. Complexity and Efficiency

As mentioned during the introductory section, when facing complexity, one often reaches the point where adding complexity to a function renders it unpractical, or unusable or where it cannot be implemented. Thus, it raises the question of where should the formalization stop and cede its place to the integration of alternative approaches such as user input and approximations of the map design problem.

Efficiency can be estimated in two ways, qualitatively and quantitatively. Qualitatively the function should lead to a satisfying cartographic visualization (e.g. can be measured by experts panel on a sample basis) while providing the user with an easy and friendly interface (e.g. can be measured by satisfaction survey), whereas quantitatively indicators, such a response time and usage statistics can be used to measure the efficiency.

A "reasonable" amount of time is determined by human perceptual abilities. When the functionality has a response time from 0.1 second and below, the user perceives it as an instantaneous reaction of the system (Millard 1968, Card et al. 1991, Nielsen 1993, as confirmed in his later studies (1997, 2010)). A 1 second response time represents the limit at which the user's flow of thought stays uninterrupted (Nielsen 1993, 1997, 2010). Finally, stretching to 10 seconds is the limit for keeping the user's attention according to Nielsen (ibid.), whereas Zona Research (1999) places the limit at 8 seconds for maximal loading before a user leaves for another page. The response time of the first category of problems should be at the one-second limit so that the user feels it as part of the workflow of the application. Even though the second category should aim at responding within 1 second, a 8 to 10 second response time could be envisaged for the more complex functionality.

6. Conclusion and Outlook

This paper discusses selected aspects relating to the complexity of specific map design problem. It suggests an approach to estimate the complexity of a cartographic principle as help to decide on their integration design. It only touches the fringe of the subject, but gives some insights on how the complexity of the problem and solution types might influence the design choices for the implementation of the corresponding functionality in a geoportal interface (see *Figure 8*).

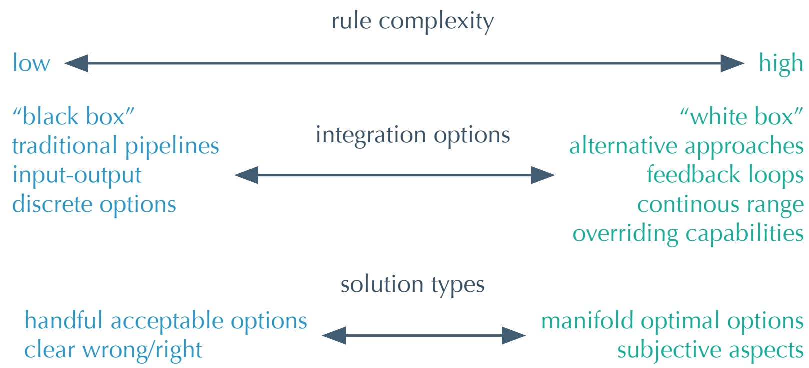

Figure 8. Ranges of rule complexity and solutions types in comparison with integration options.

Moreover it raises additional questions regarding the optimal integration of subjective aspects from cartographic functionality within a geoportal or other cartographic applications. With increasing complexity of the functionality, it is crucial to think about the integration at the interface level, the interaction or control possibilities for the user (discrete vs. continuous), and the efficiency of the functionality in terms of response-time especially. Indeed, this allows minimizing interruptions in the users flow of thoughts, which can impede their understanding of the process. Additionally, it is important to take into account user-centered design best practices for the interface.

Further research directions include the assessment of the complexity of other cartographic principles and map design problems as well as the refinement of the elements taking part in the complexity evaluation. Moreover, alternatives for the integration design within the interface should be sought taking inspiration outside the traditional cartographic and GIS applications.

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