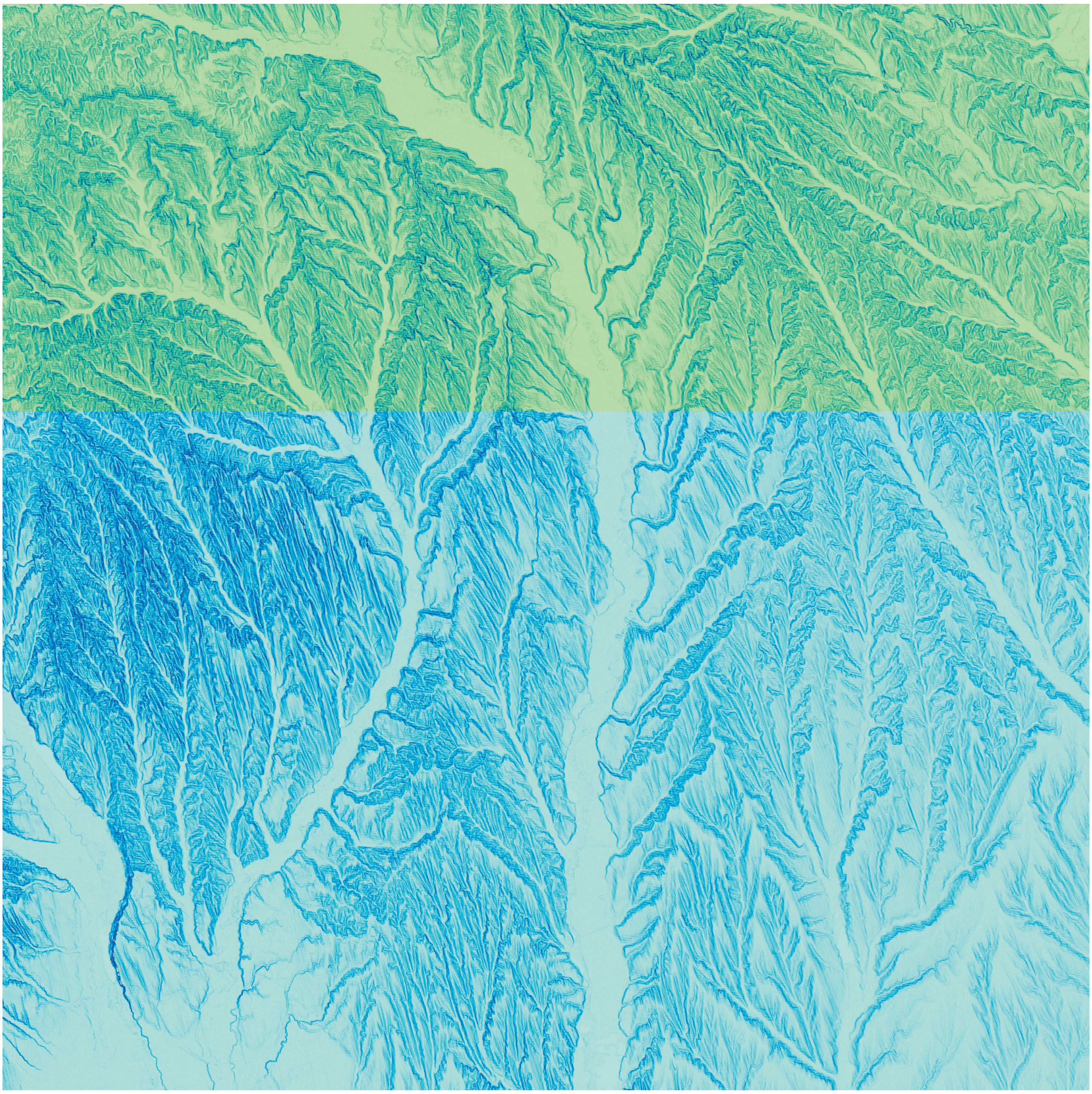
SMART CARTOGRAPHIC SYMBOLIZATION

BRINGING CARTOGRAPHIC KNOWLEDGE TO ONLINE GEOPORTALS



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Smart Cartographic Symbolization: Bringing Cartographic Knowledge to Online Geoportals

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Abstract

The democratization of cartography over the last two decades has opened numerous opportunities for the general public to participate in the mapmaking process. However, while simple cartographic tools and geospatial data for creating maps have transitioned beyond the traditional field to the online world, cartographic principles and know-how are not as accessible. We call this discrepancy in availability the cartographic gap and it is the initial drive of this thesis. The main goal of the thesis is to bridge the cartographic gap in order to support a sound and successful neocartographic practice, more specifically by bringing cartographic knowledge to geoportals.

Three shortcomings which participate in keeping the gap open are identified: low quality of user map symbolization; absence of proper cartographic functionality to improve this quality; and insufficient understanding of user interaction design of cartographic functions for opening up cartographic principles. This thesis tackles issues of online cartographic symbolization for casual mapmakers (or neocartographers) by defining three research questions associated with these shortcomings: Which (and how) cartographic conflicts found in user maps on geoportals can be resolved with the help of cartographic principles about symbolization? How to formalize cartographic principles into actionable functionality for their integration within a geoportal? How can interactions and interfaces be designed to support opening up cartographic knowledge in a geoportal?

In the four scientific papers belonging to the core chapters, this thesis answers the research questions by covering aspects pertaining to cartographic conflicts, knowledge formalization, and cartographic interaction design. A novel approach was developed to resolve specific cartographic conflicts in the context of map mashups and user maps in online mapping platforms, such as geoportals. For this purpose, we defined a contextual map model to formalize and open up cartographic principles in the form of smart cartographic functions implemented directly within a geoportal and in relation to actual maps created by users. These functions optimize the drawing order of layers, check for content incompatibilities and improve the visual hierarchy in maps. More specifically, we designed a styling function to improve contrast between back- and foreground layers and compared it to existing methods. We tested different approaches to interaction design for cartographic functions and knowledge by implementing the framework into an existing geoportal. The results of a usability study allowed the definition of valuable guidelines. They demonstrated the importance of providing different ways to access information and to explore the content and actions of the functions. Furthermore, participants displayed a preference for dynamic interaction and on-the-fly visual changes on the map.

Finally, as this thesis only touches parts of the broad topic of online map design by casual mapmakers and open cartography, we provide the framework as an open source library. The framework can be used and expanded to further formalize cartographic principles into functions for the practice of neocartography and for bridging the cartographic gap.

Résumé

La démocratisation de la cartographie au cours des vingt dernières années a offert de nombreuses opportunités au public de participer aux différentes activités cartographiques. Cependant, bien que des outils simples de cartographie et des données géospatiales pour la création de cartes aient été transférés au-delà du champ traditionnel vers le monde en ligne, les principes et connaissances cartographiques ne l'ont pas fait dans la même mesure. Ce décalage d'accessibilité, ou fossé cartographique, constitue la motivation première de cette thèse. Le but principal de ce travail est de clore ce fossé cartographique dans l'optique d'une pratique néocartographique avisée et réussie, et plus précisément en intégrant du savoir cartographique dans les géoportails.

Nous identifions trois points faibles qui entretiennent ce fossé: la qualité insuffisante de la symbolisation des cartes d'utilisateurs; l'absence de fonctionnalité cartographique permettant d'en améliorer la qualité; et le manque de connaissances concernant le design d'interactions permettant d'ouvrir le savoir cartographique. Cette thèse traite de problèmes de symbolisation cartographique en ligne pour des utilisateurs novices en définissant trois questions de recherche associées aux trois points faibles: quels problèmes cartographiques présents dans les cartes d'utilisateurs dans les géoportails peuvent être résolus à l'aide de principes cartographiques concernant la symbolisation (et comment)? Comment formaliser des principes cartographiques en des fonctions pour géoportails? Comment concevoir des interfaces qui participent à l'ouverture du savoir cartographique dans un géoportail?

Les quatre articles scientifiques au centre de cette thèse répondent aux questions de recherche en se penchant sur les problèmes cartographiques, la formalisation de connaissances et le design d'interactions cartographiques. Une nouvelle approche est utilisée pour résoudre des problèmes cartographiques spécifiques dans les cartes d'utilisateurs sur des plateformes cartographiques en ligne, telles que des géoportails. Pour cela, un modèle est défini pour formaliser et ouvrir les principes cartographiques en tant que fonctions intelligentes intégrées à un géoportail et en relation directe avec la carte de l'utilisateur. Ces fonctions optimisent l'ordre de rendu des couches, vérifient la compatibilité du contenu et améliorent la hiérarchie visuelle de la carte. Concrètement, une fonction a été développée pour améliorer le contraste entre les couches d'arrière et de premier plan et elle a été comparée avec des solutions existantes. Différentes approches pour la conception d'interactions avec les fonctions et les connaissances cartographiques ont également été testées dans le géoportail. Les résultats d'une étude d'utilisabilité ont permis de définir des directives. Ils ont aussi démontré l'importance d'offrir différentes manières d'accéder à l'information et d'explorer le contenu des fonctions. Les participants ont également montré une préférence pour les interactions dynamiques avec répercussions immédiates sur leur carte.

Cette thèse n'aborde que certains aspects du vaste sujet de la conception de cartes en ligne par des utilisateurs profanes et de la démocratisation de la cartographie. Pour cette raison, les fonctions cartographiques sont mises à disposition en tant que logiciel libre et peuvent être utilisées et développées pour formaliser d'autres principes cartographiques dans le but de clore le fossé cartographique.

Zusammenfassung

Die Demokratisierung der Kartografie in den letzten zwanzig Jahren hat es der breiten Öffentlichkeit ermöglicht, sich selbst kartografisch zu betätigen. Obwohl jedoch einfache kartografische Werkzeuge und Geodaten dank des Internets für jedermann frei verfügbar sind, bleiben kartografische Prinzipien und Fachwissen unzugänglich. Diese Diskrepanz, *cartographic gap* genannt, ist der Ausgangspunkt dieser Arbeit. Das Ziel ist das Schliessen eben dieser Lücke, um eine solide und erfolgreiche neokartografische Herangehensweise zu unterstützen, insbesondere durch die Integration kartografischen Wissens in Geoportale.

Es können drei Mängel, die zur Aufrechterhaltung der Lücke beitragen, identifiziert werden: die geringe Qualität der durch den Nutzer vorgenommenen Symbolisierung; das Fehlen angemessener, kartografischer Funktionalitäten um diese zu verbessern; sowie ein unzureichendes Verständnis für die Gestaltung kartografischer Funktionen in Benutzeroberflächen, um kartografische Prinzipien nutzbar zu machen. Die vorliegende Arbeit befasst sich mit den Schwierigkeiten von Gelegenheitskartografen bei der webbasierten kartografischen Symbolisierung. Hierzu werden drei Forschungsfragen formuliert, die jeweils die zuvor herausgestellten Mängel adressieren: Welche kartografischen Konflikte treten in mit Geoportalen erstellten Karten auf und wie können diese mithilfe kartografischer Prinzipien gelöst werden? Wie können diese Prinzipien formalisiert werden, sodass sie in Form nutzbringender Funktionalitäten in Geoportale integrierbar sind? Wie können Interaktionen gestaltet werden, um kartografisches Wissen in Geoportalen zugänglich zu machen?

Die Forschungsfragen werden in vier wissenschaftlichen Artikeln beantwortet, welche Aspekte zu kartografischen Konflikten, der Formalisierung von Wissen sowie der kartografischen Interaktionsgestaltung umfassen. Es wird ein neuer Ansatz entwickelt, um spezifische kartografische Konflikte in Bezug auf Mashups und Karten, welche mittels webbasierten Kartierungsplattformen erstellt werden, zu lösen. Zu diesem Zweck wird ein kontextbezogenes Kartenmodell definiert, das es erlaubt, kartografische Prinzipien zu vereinheitlichen und diese dem Nutzer in Form intelligenter, in ein Geoportal integrierter Funktionen, zugänglich macht. Die Funktionen optimieren die Darstellungsreihenfolge von Ebenen, prüfen, ob inhaltliche Inkompatibilitäten bestehen, und korrigieren die visuelle Hierarchie in Karten. Insbesondere wird eine Funktion zur verbesserten Darstellung des Kontrasts von Vorder- und Hintergrundebenen entwickelt und mit bestehenden Methoden verglichen. Verschiedene Ansätze hinsichtlich der kartografischen Interaktionsgestaltung werden durch die Integration in ein bestehendes Geoportal getestet. Die Ergebnisse einer Nutzerstudie zeigen die grosse Bedeutung vielfältiger Zugänge zu Informationen auf und erlauben die Definition von Richtlinien zur Erkundung von Zweck und Inhalt der Funktionen. Des Weiteren zeigen Probanden eine Präferenz für dynamische Interaktion und die sofortige Darstellung der vorgenommenen Änderungen auf der Karte.

Da die vorliegende Arbeit nur Teile des weiten Spektrums webbasierter Kartografie durch Gelegenheitskartografen sowie öffentlich zugänglicher Kartografie berührt, wird das entwickelte System als frei verfügbare Bibliothek zur Verfügung gestellt. Es kann somit genutzt und ergänzt werden, um weitere kartografische Prinzipien mittels Funktionen zu vereinheitlichen, Neokartografie zu unterstützen und den *cartographic gap* zu überwinden.

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I INTRODUCTION

1. Motivation

Cartography has undergone tremendous changes in the last two decades thanks to technological progress. Geographic content has become gradually available on the Web, and distributing maps and geospatial data using the Internet has become an evidence in modern cartography. Moreover, we have transitioned from a situation of geospatial information scarcity to an era in which geospatial information is not only abundant but also easy to access via online mapping platforms and geoportals. These concurring trends participated in the democratization of cartography, which saw the emergence of a new generation of novice mapmakers, sometimes called neocartographers. Furthermore, the unrestricted use and reuse of geospatial tools and data have been supported by the open data and open source movements.

As a result, the general public has easy access to geospatial visualization applications and cartographic tools, allowing them to rapidly create custom cartographic visualizations with data from different sources. However, the resulting maps are often of poor quality, especially regarding symbolization, and fail to reach the standards that stem from well-accepted cartographic principles.

Maps are communication tools and thus map representations of low quality can distort or prevent the transmission process between the map and map reader: the legibility of the map and understanding of its content are impacted. Principles and rules that support the quality of classic paper maps are strongly anchored in cartography, however, as the map medium changes from paper to screen, some principles lose their relevance or require adjustments. An additional reason for the low quality of user maps in geoportals is that there are no cartographers involved in the map design process. Indeed, cartographic tools and geospatial data have made their transition to the fast-paced online world outside the traditional field, whereas cartographic principles and know-how that have been developed during the time of traditional paper maps have not been transferred to the Web as easily.

This discrepancy of availability is what we call the cartographic gap and is the catalyst for this thesis: there is a need for tools and functions to assist neocartographers in their online mapmaking activities. Such tools would be useful for creating maps that are neither professional nor for a quick lookup of information, but rather that consist of a combination of data and aimed at being used several times or shared. The time invested in using the functions should bring added value to the map user in terms of legibility and quality.

Beyond the creation of cartographic tools to be integrated into online mapping platforms and geoportals, there are also challenges regarding the opening up of cartographic knowledge and how to best transmit it to novice mapmakers through their online mapping activities. By providing a cartographic framework supporting the definition and formalization of functionalities and explanations about the map design process, we hope to contribute to reducing the cartographic gap. This task is an inspiring challenge to attempt to convey cartographic knowledge and expertise to the neophyte but enthusiast geoportal users. Cartography is a field with a long and rich tradition, which involves numerous principles, but few absolute truths. Thus, the formalization of cartographic knowledge requires the transposition of heuristics and general principles into rules and sensible default settings to be efficient and accessible to the larger public. Finally, because cartography is as much science as art, and because the map design process is considered as an ill-structured problem, communicating about map design requires a deep and precise understanding of the principles and decision-making processes involved.

2. Shortcomings and research questions

Cartographic technologies and workflows changed prodigiously in the last 60 years: first with the advances in computer technologies, and then with the ubiquity of the Internet and the emergence of Web 2.0. These changes enabled the democratization of cartography by simplifying the generation, distribution and publication of geospatial data outside the circle of traditional actors in cartography. Now, not only does a more important part of the population have access to a greater amount of data, but the procedures to acquire geospatial data are being facilitated. Indeed, datasets of many different kinds and sources are available through various online platforms and services. Furthermore, this trend is supported by the open data and open source movements. They contributed to, and keep on, promoting the visibility and reuse of available datasets, thanks to institutions such as the Open Data Foundation and the Open Knowledge Foundation (Open Data Foundation 2014, Open Knowledge 2014).

Under those circumstances, scholars started to articulate the concept of neogeography, which is defined as "people using and creating their own maps, on their own terms and by combining elements of an existing toolset" (Turner 2006). Soon after, the terms "neocartography" and "neocartographers" were coined to describe more precisely respectively the activities of making maps outside, or alongside, the traditional realm of cartography, and the mapmakers, who frequently use "open data and open source mapping tools", but might not "come from traditional mapping backgrounds" (ICA Commission on Neocartography 2011, Cartwright 2012).

Geoportals and online mapping platforms play a crucial role for neocartographers because they are ideal tools to disseminate and use geospatial datasets. This is demonstrated by the rapid development of commercial and open source infrastructure for geoportal solutions, the production of scientific content regarding geoportals (De Longueville 2010), and the crucial role played by geoportals in national and regional Spatial Data Infrastructures (SDI) (Mansourian et al. 2011).

The traditional field of cartography has to count now not only with a new medium for map production but also with a new category of diverse mapmakers and a decentralized mapmaking process. In this challenging context, this thesis will tackle issues of online cartographic symbolization for casual mapmakers, or neocartographers, and develop tools to address these issues. To begin with, the following shortcomings and associated research questions have been developed.

Low quality of user map symbolization in geoportals:
Public geoportals offer specific challenges to cartographic representation and symbolization because their geospatial datasets often come from different institutions and are thus very heterogeneous in content, scale and representation. The symbolization of the different datasets is mostly realized on a standalone basis, and there is rarely a coordinated symbolization strategy across a single geoportal. Additionally, the available datasets can be represented at any scale, even if they have been generated at a much larger one. The combination of datasets into a user map under these conditions can quickly lead to a less than optimal map representation, especially when the mapmaker has little or no cartographic knowledge and no tools at disposition. In this situation, the diversity and abundance of data in geoportals become a disadvantage for the mapmaker, cartographic principles get violated, and conflicts arise. Cartographic conflicts ensue from several reasons, such as scale reduction, poor visual variable choices and/or high density of information, however, this thesis focuses on cartographic conflict linked to principles about symbolization. In order to improve the symbolization of datasets in user maps in geoportals, cartographic conflicts linked to symbolization must be collected and then investigated through the lens of sound cartographic principles.

Research question 1 (RQ1): Which (and how) cartographic conflicts found in user maps on geoportals can be resolved with the help of cartographic principles about symbolization?

Lack of proper cartographic functionality to optimally symbolize user maps in geoportals:
Cartographic knowledge and principles have been integrated into online standalone applications or into desktop applications. The first ones usually provide general guidance on the map design process to novice and professional mapmakers alike, using simple geospatial data designed explicitly for this purpose, whereas the second ones usually require the users to provide their own data. The geoportal context is different because the platform provides a large and diverse amount of data from which one can create custom maps and then export them. However, as seen in the previous shortcoming, the results of such user map can be far from satisfactory. Thus there is a need to integrate cartographic functionality within online mapping platforms and to reconcile the provider and publisher roles of geoportals with the one of map creator.

Research question 2 (RQ2): How to formalize cartographic principles into actionable functionality for their integration within a geoportal?

Insufficient understanding regarding the design of user interactions with the purpose of opening up cartographic principles in the geoportals to the mapmakers:
So far the democratization of cartography has mostly reached the areas of data and tools accessibility, but opening up the cartographic knowledge that helps designing maps of high quality, both cartographically sound and legible, still requires further examination. Cartographic principles are complex and hardly absolute rules, which not only creates challenges when they must be formalized but also when they need to be explained. A geoportal is an appropriate setting to explore the integration of cartographic knowledge and functions, not only in a general sense but also in relation to the specificities of the maps created by the users (and mapmakers). The integration of cartographic functionality can inform and solve potential conflicts in the map. Furthermore, the design of user interactions that reflect subjectivity and uncertainty within the complex and ill-structured map design problem needs to be investigated.

Research question 3 (RQ3): How can interactions and interfaces be designed to support opening up cartographic knowledge in a geoportal?

3. Methodology and research objectives

Building on the above-presented shortcomings and research questions, the following research objectives (RO) are defined for this thesis:

- RO 1 Identification of common cartographic conflicts on geoportals and their potential solutions from cartographic principles and best practices.
- RO 2 Creation of cartographic functionality, that supports neocartographers' mapmaking activities and improves the quality of their map mashups on geoportals.
- RO 3 Evaluation of different interaction and interface designs to support opening up cartographic knowledge in a geoportal.

In order to achieve the research objectives and to answer the research questions, a methodology based on an empirical approach was followed. The overall methodology is built as follows. First, the literature and state of the art (SOTA) regarding cartographic principles, geovisualizations on geoportals, and user interaction and interface design was reviewed. This review is crucial because it allows the development of the next phases in conformity with the concepts and best practices of the field. Second, the shortcomings were defined in more detailed based on observations of existing cases. Third, solutions to the shortcomings were developed and formalized before being implemented into a prototype. The implementation into an existing geoportal allowed to test and calibrate the developed solutions in a setting close to real use. Finally, the results of the functions and their implementation were evaluated in terms of user experience and usability. The methodology is covered in the four scientific papers that constitute the core of this thesis. Figure 1 explains the methodology followed for each research objective and to which paper they correspond. In the following paragraphs, each paper is summarized.

Paper I – ***Smart cartographic functionality for improving data visualization in map mashups*** focuses first on identifying cartographic conflicts in geoportals that can be resolved by changes

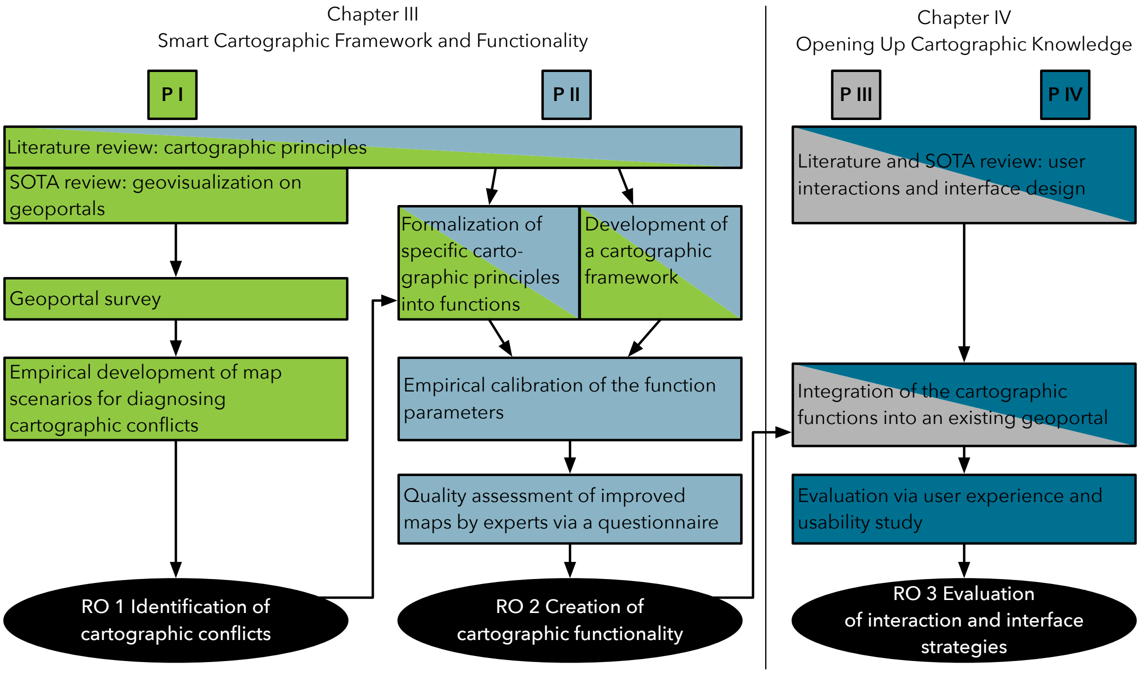

Figure 1. *Methodology overview: steps towards achieving the research objectives (RO) and to which papers (P) they correspond. SOTA = State of the art.*

in symbology (RQ1) and then moves on to describing a framework that can be used to formalize cartographic solutions to the conflicts (RQ2).

A review of the state of the art in cartographic visualization in previous works and a detailed analysis of the cartographic content in 21 existing national geoportals were essential to identify cartographic conflicts, especially the ones that can be resolved by changes in symbolization. The survey of these geoportals also allowed to assess the subject matters and cartographic capabilities of geoportals. We identified four functions that can be used for cartographic purposes: transparency settings, user map, layer order settings and print function. The knowledge about the most commonly available topics in national geoportals served as the foundation to develop three map scenarios in which cartographic conflicts were examined. Three main types of conflicts were observed across most geoportals: poor layer drawing order, lack of visual hierarchy and unaddressed scale problems.

The knowledge gained from the literature review and geoportal survey set the premises for defining a framework for the formalization of smart cartographic functions. The framework consists of a contextual map model, object catalogues and cartographic rules. The contextual map model describes the elements of the map and their relations, while the object catalogues support the semantic-based rules of the framework. Indeed, cartography is intrinsically linked to the meaning of the phenomena and data represented on the map, which explains the need for semantic information as well. The catalogues cover different map types, layer categories and themes. They enable the definition of rules about layer order and map content with regard to the map type.

Then, the framework was used to formalize a few cartographic principles and to implement them within an existing geoportal as proof of concept. This preliminary framework implementation successfully allowed to automatically reorder layers and to detect conflicts between the map content and map type. In conclusion, it confirmed the validity of the framework for defining cartographic functions and supported proceeding to the formalization of further cartographic functions for online mapping environments, such as geoportals.

Paper II – ***Smart cartographic background symbolization for map mashups in geoportals: a proof of concept by example of landuse representation*** addresses the lack of visual hierarchy in user maps in geoportals by investigating different strategies for background symbolization (RQ2).

Online on-demand maps often have a color-saturated base map and thus layers in the background need to be de-emphasized when combined with other layers, which are the main topic of the map. Thus, principles pertaining to visual hierarchy in maps and the role of colors were examined. Then, based on those examinations, different functions for background symbolizations that support an adequate visual hierarchy in maps were developed. To assist the integration and evaluation of the functions, it was necessary to define the persona of a casual online mapmaker (non-professional cartographer) who wants to compose a map.

Before applying the background transformation to layers in the maps, two preparatory steps were carried out to verify the content of the map and re-order the layers optimally. Both preparatory steps are based on semantic information pertaining to the layer and map type, as well as on cartographic principles. Additionally, a function assigns the different layers to the three visual planes of the map: background, middle ground and foreground. Creating different visual planes supports better visual hierarchy in the map and thus facilitates the understanding and reading of the map by users.

The three background functions transform the original style of a layer into a background style and are as follows: a traditional grayscale version of the original style, a linear desaturation and a smart function that analyzes the color scheme before applying luminance, chroma and lightness transformations. The effectiveness and suitability of the functions for background symbolization were evaluated based on four criteria: color information retainment, contrast within the color scheme, differentiation of the classes within the modified style and combination with a shaded relief. Furthermore, a survey among professional cartographers was realized to judge the final results of the functions with actual map examples from the geoportal. The outcomes from the survey supported the results of the analysis pointing to the promises of the smart method but indicated a need for a slight recalibration of the function parameters.

Paper III – ***Sharing cartographic knowledge with the crowd: on the complexity of cartographic rules*** discusses the complexity of cartographic principles and the repercussions it has on their formalization and integration in the user interface (link between RQ2 and RQ3).

Cartographic knowledge consists of principles, expertise, conventions and rules of thumbs, all of which renders its formalization difficult and far from straightforward. The map design process is furthermore considered to be an ill-structured problem due to the vastness and complexity of the field. While complexity can be understood as a large number of intricate information pieces that interact with one other, there is no unified theory. In cartography, it can come from the phenomena depicted or from the graphics used on the map. The different levels of complexity among cartographic principles should be considered for their integration in a Graphic User Interface (GUI). Thus, an evaluation of a cartographic function complexity can help to choose an optimal type of GUI design integration.

Estimating the complexity of cartographic functions was realized with three variables: the number of parameters in the function, their interactions, and the type of solution expected (well-defined vs. loosely defined). Two cartographic functions from the previous papers were used to exemplify the complexity estimations and further discuss the implications for their integration into the GUI. Questions such as the implementation of subjective aspects and heuristics were raised in the conclusion.

Paper IV – ***Integrating cartographic knowledge within a geoportal: interactions and feedback in the user interface*** explores and tests different possibilities to integrate cartographic functions within the GUI of geoportals (RQ3).

Important concepts pertaining to interface design and user interactions were reviewed to provide sound foundations for the integration of the cartographic functions within the geoportal. The philosophy of human-centered design (also called user-centered design) emphasizes the importance of putting the users' needs at the center of the design process, taking into account how people interact with technology and interface. Important principles of this approach are an early focus on users and tasks, consistency, and feedback information. Moreover, concepts such as usability and user diversity are also considered crucial for successful GUI and interaction designs.

The cartographic functions from Papers I and II were integrated within a wizard in the geoportal. The main characteristics of the wizard's GUI were shortly presented: the dual mode between "data browser" and "user map", the interaction levels, and the error and warning system. As the wizard was implemented in an existing geoportal's GUI, it was also an opportunity to review and adapt some aspects of the original GUI.

Then, a usability test was conducted with non-cartographer participants, who, however, use maps for their hobbies, research or navigation. A map creation scenario and a list of tasks were defined to evaluate the user experience and ease of use of the wizard implementation. A couple of existing evaluation methods were employed in that regard: the User Experience Questionnaire (UEQ) and the NASA Raw Task Load Index (RTLX). The results showed an overall positive experience and little frustration or failures in the application. Furthermore, the qualitative feedback provided a deeper understanding of which types of interactions were preferred.

The usability study enabled the generation of guidelines for the design of cartographic functions and the wizard aiming at opening up cartographic knowledge, such as the importance of clear action and output, providing help and explanations in different forms while letting users interact with the system and learn by hands-on experience with the functions. Finally, while it pointed to questions still open regarding knowledge integration within the GUI, the study showed that when cartographic functions for the creation of custom user maps lead to a positive experience, it can be a real added value for geoportals.

4. Structure of the thesis

This cumulative thesis is structured in six chapters. After this introductory Chapter I, in which we present the motivation, shortcomings and research questions and objectives that guide the thesis, Chapter II reviews the relevant scientific and technical background information in cartography, including a description of the technical infrastructure used for the proof of concept. The core of the thesis consists of the four scientific papers mentioned above and organized in two separate chapters. First, Chapter III *Smart cartographic framework and functionality* describes cartographic conflicts most commonly found in geoportals and presents the framework developed to resolve them, including specific functions to improve the symbolization of background layers (Paper I and Paper II). Then, Chapter IV *Opening up cartographic knowledge* discusses approaches and challenges to opening up cartographic knowledge. It details the implementation of cartographic functions in the graphic user interface of a geoportal as proof of concept and analyzes the results of a usability study conducted on it (Paper III and Paper IV). Then, Chapter V reviews the research questions in light of the work accomplished and summarizes the results. Finally, the concluding remarks in Chapter VI discuss the relevant aspects of the thesis for society and science and closes with thoughts about potential future research directions.

II BACKGROUND

1. State of cartography

This section starts with a short overview of the evolution of cartography in the past decades, especially concerning technology. It shows how the democratization of cartography brought major changes regarding actors, production processes and ways maps are used. It further explains why map legibility is important and what can hinder it. Then, it examines the challenges associated with the formalization of cartographic knowledge.

Technological innovations in areas related to computer science have had an important impact on cartography and mapmaking since the second half of the twentieth century (Tyner 2010). The first step was the digitalization of cartographic work with the beginning of computer-based cartography in the 1960s. Then, in the 1990s with the rapid and successful spread of the Internet, the Web became a new and highly effective form of delivery for maps and geospatial data (Peterson 2007). Web cartography allowed not only to distribute scanned versions of paper maps but also to develop dynamic maps distributed via client-server mechanisms. Moreover, technical equipment to capture geospatial data and process them (e.g. GPS or personal computer) became accessible and affordable to the general public.

The first decade of the twenty-first century saw an explosion in the amounts of data being collected and available, as well as the increase of personal mobile devices, allowing access to maps and data from anywhere and immediately. These phenomena participated in the democratization of cartography with the transition of a century-old tradition of centralized and controlled map production by national mapping organizations to a situation where anyone can create their own spatial visualization with accessible tools (Morrison 1997). This paradigm shift has many implications for the field of cartography: most significantly the distinction between mapmaker and map user is blurred as cartography enters the era of map mashups, overlays and user-generated maps; also, changes to a map can be applied on the fly and rather than one multi-purpose map, the public expects customizable multiple single-purpose maps (Morrison 1997); and finally, the map is no longer a fixed work as the data representation and symbolization can follow users' needs and wishes. Additionally, implications linked to the new medium also play an important role: because the map is not static anymore (flexible scale and extent, and interactive content), and as screen displays behave differently from paper, many cartographic principles pertaining to symbology and representation needs to be adapted or replaced adequately for this new digital medium; and as online maps and online map interface play a growing role in other industries, the general public is getting familiar with maps as they become ubiquitous online. With the paradigm shift, the term "neocartographers" (Turner 2006, Haklay, Singleton and Parker 2008, ICA Commission on Neocartography 2011, Cartwright 2012) was conceived to encompass new actors in the field of mapmaking, that use open source mapping tools and open data to create their own maps, while not having traditional cartographic training.

Democratization of cartography has been helped further by both the open source and open data movements (Open Data Foundation 2014, Open Knowledge 2014) formalized in the mid-90s, and then promoted and used in the first decade of the twenty-first century by governmental institutions as well. The Open Data Movement advertised the fact that voluminous amounts of geospatial data were now available (relatively) easily and for free, while the Open Source Movement promoted free and open tools for data processing and visualization. Open standards for the interoperability on the Internet were set by, among others, the Open Geospatial Consortium (OGC 2017) and the International Organization for Standardization (ISO 2017). These standards and specifications contributed to facilitating the opening of online mapping activities, by allowing the combination of distributed services and data sources seamlessly.

In this context of fast-paced technological changes, the field of cartography must now reconcile new actors (neocartographers), new map production processes (decentralized), and new applications (custom on-demand maps and map interfaces) with its long-standing tradition and body of knowledge.

1.1. Neocartography and the cartographic gap

As seen previously, these new circumstances allowed processing tools and geospatial data to be accessible and affordable or open to the general public. However, the focus so far has been mainly on the access to the data and tools, but not on opening up cartographic knowledge and principles that underlie well-designed and legible maps. As a consequence, the creations from these new mapmakers often violate or ignore vital cartographic principles, and the quality of their maps is low compared with what can be expected from cartographically sound maps (Bucher et al. 2007, Field, O'Brien and Cartwright 2011, Harrie, Mustière and Stigmar 2011). Indeed, cartographically sound maps, because they follow map design principles, are characterized by an absence of cartographic conflicts. Thus, the main reason for low-quality maps in the neocartography context lies in the absence or difficult access to cartographic principles and knowledge-based tools outside the realm of professional mapmaking. This difference in access to the data and tools on the one hand and to the knowledge of the trade, on the other hand, is what we define here as the cartographic gap (Figure 1). Access to all three pillars – data, tools, knowledge – is the prerequisite for sound and successful neocartography practice, which goes beyond the mere compilation of geospatial data visualized together, because cartographic knowledge and principles play a crucial role in guaranteeing the legibility of maps.

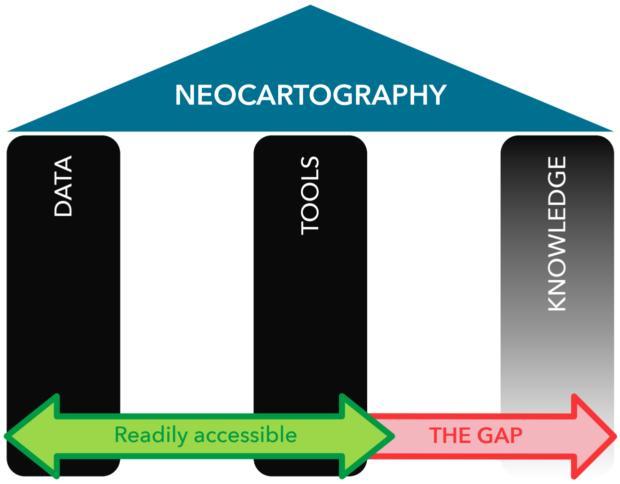

Figure 1. The 3 important pillars for a successful practice of neocartography. At the present, there is a gap in access to cartographic knowledge for mapmakers outside the realm of professional cartography.

A map is at the center of a complex process to communicate cartographic information, that involves both mapmakers and map users (Koláčný 1977). Cartographers observe and select the reality they wish to represent in the map, guided by their experience, their purpose and the mental model they hold of reality. By using map symbols and visual variables, cartographers encode cartographic information and renders it accessible to human perception (stages 1 to 4 of Koláčný). On the other side of the map, the map users also have an active role to play in constructing meaning and retrieving information from the map (MacEachren 1995). Map readers discern the map (perceptual process), comprehend its content, and build their own mental model of the cartographic information displayed on the map (cognitive process) and in turn, their knowledge and experience are augmented (stages 5 to 7 of Koláčný). This stage of comprehension is influenced by the abilities, previous experience and knowledge, and needs of map readers, but also by choices made by cartographers in the previous stages (Koláčný 1977). This is why cognition principles are crucial to cartography: they can explain why some maps or symbols are better at communicating cartographic information and spatial knowledge effectively (Slocum et al. 2009). Thus, the role of cartographic principles is to facilitate this construction of knowledge and to make maps less prone to misinterpretation (MacEachren 1995). When a map is legible, it means that it is easy to read and understand (Robinson et al. 1995) and that spatial phenomena are represented in a clear manner, allowing to efficiently interpret the map visually (Harrie, Mustière and Stigmar 2011). However, as explained above, neocartographers do not have easy access to cartographic knowledge and expertise, and tend to use representation choices that mislead or impede the legibility of maps. For this reason, opening up and facilitating the use of cartographic principles is crucial for a successful practice of neocartography.

1.2. Cartographic conflicts – barriers to map legibility

Poor choices of symbolization and representation can lead to cartographic conflicts of diverse types. The word conflict is used here in a broader sense and refers to any visualization issue or shortcoming. Common cartographic conflicts found in map mashups or maps created in the context of neocartography include unwanted feature overlaps, visual clutter, misuse of color schemes and color rules, and lack of contrast and visual hierarchy. A map consisting of parts (symbols and features) that form a whole, cartographic conflicts occurring at the part level lead to cartographically unsound maps, but they also impact the legibility of the map as a whole and its capability to communicate information effectively.

These conflicts are often linked to the use of geospatial data at a smaller scale than they were intended for and without applying any generalization methods. As a consequence, geometric features are too detailed for the specific scale, resulting in coalescence and congestion, and overall visual clutter. Additionally, it can cause unwanted feature overlaps, especially when polygon features are involved, leading to objects on the maps being occluded by other features. Maps that encounter these problems are often difficult to interpret or use because the objects on the maps cannot be easily distinguished from one another. This phenomenon can be worsened when the number of features on the map is too high for the space available.

The misuse of color, both in terms of conventions and expectations, as well as from the rules associated with color schemes, are also common in map mashups. In particular, map users expect certain color conventions, such as blue for hydrology features or green for forests. Symbolizing them in another color without explicit criteria grounded in cartography can lead to confusion or misinterpretation. Moreover, different types of color schemes carry different meanings about the data they represent, being either quantitative or qualitative differences, as well as sequential or diverging phenomena. Consequently, color issues arise either when the option to modify the symbolization is offered without any color functionality to support it, or when there is no possibility to change the symbolization, which leads to incompatibility between the different layer visualizations.

Finally, map legibility can be further lowered by the lack of visual hierarchy within the map. The concept of visual hierarchy, also called "figure-ground phenomenon" from the Gestalt theory (Ellis 1955), "levels of visual prominence", "visual or conceptual levels" (Robinson et al. 1995), or "visual planes" (MacEachren 1995), pertains to the "perceptual organization" of the map (Slocum et al. 2009). This concept helps the map reader to differentiate between the information that composes the foreground (figure) and the information in the background (ground). It greatly helps the map user to quickly grasp how the map is organized and what is the main topic or phenomenon represented on the map. Such issues are often found in map mashups where the untrained mapmaker had no possibility of changing the symbolization of the original layers, resulting in a situation where they all might look like foreground information.

A successful map should indeed not only be free from cartographic conflicts, but also be easily readable and understandable (i.e. legible) (Koláčný 1977, Robinson et al. 1995), be attractive, satisfy the users' needs, and produce an overall aesthetic and rational effect (Koláčný 1977), while supporting the comprehension and transfer of spatial knowledge effectively (MacEachren 1995, Dent 1999, Slocum et al. 2009). Resolving all conflicts at the part level does not guarantee the production of a "good map", but definitely removes numerous barriers to designing a successful map.

1.3. Formalization of cartographic knowledge

To facilitate the access to cartographic knowledge beyond traditional online courses, cartographic principles should also be formalized as integrated knowledge-based functions within online mapping applications. However, such task is not trivial because of the characteristics of the cartographic knowledge and the complexity of the map design problem. Indeed, the cartographic body of knowledge consists of many principles that are closer to general guidelines than absolute truths and the design process involves a significant amount of subjectivity. Additionally, expertise plays a significant role in the ability of a cartographer to adequately represent a spatial phenomenon on the map.

As a consequence, the formalization process must be able to deal with subjectivity, flexibility and uncertainty, while allowing one to satisfactorily model cartographic rules and points of decision within the map design process. These requirements render the formalization of cartographic knowledge complicated, even potentially unachievable without a precise and explicit definition and without a restriction of the scope of the cartographic problem at hand (Forrest 1999, Smith, Richard A. 2010) or without a segmentation of the map design process (Hutzler and Spiess 1993, Jan, Zdena and Jaromir 2009). Moreover, because cartographic representations are intrinsically linked to the meaning of visualized spatial data, any formalization process must support semantic content. Fulfilling this semantic requirement can range from a simple annotation system to more complex methods, of which the main ones are quickly reviewed below and summarized in Table 1.

Tagging systems, although flexible, are not ideal because they are not stable enough to build functions on top of them. Controlled vocabularies are similar to tagging but controlled, consistent and organized. In comparison, taxonomies are hierarchical and can have facets, allowing to represent different aspects of information. One step higher on the formalization ladder, one finds ontologies, which aim at enabling computers to talk with one other about a domain and support inferencing. An ontology is defined as an explicit and formal specification of the knowledge of a domain, consisting of the objects or terms belonging to the domain and the describable relations among them (Gruber 1993). Moreover, ontologies allow to differentiate the domain knowledge from the operational knowledge (Noy and McGuinness 2001). A domain ontology formalizes the existing knowledge of a specific domain and consists of established concepts that can be leveraged

Table 1. *Different methods to classify and organize fields of knowledge.*

	Characteristics	**Examples**
Tagging system	Flexible and simple Multiple tags for same object (Too) loose structure, no hierarchy and no relationship No explicit meaning	OpenStreetMap Folksonomy
Controlled vocabularies	Restricted lists of words or terms for some specialized purpose, usually for indexing, labeling or categorizing (Hedden 2010) Similar to tagging, but controlled, consistent and organized	Library of Congress Subject Headings
Taxonomies	Hierarchical: "kind of controlled vocabulary in which each term is connected to a designated broader term [...] and on or more narrower terms [...]" (Hedden 2010) Faceted taxonomies: multiple subsets, representing different aspects of information	Online clothes retail (type of clothes, size, color, material)
Ontologies	Explicit formal specifications of the terms and relations among them (Gruber 1993, Noy and McGuinness 2001) Support inferencing	Dublin Core (DC) ontology

by the task ontologies (Iosifescu Enescu and Hurni 2007). Task ontologies gather knowledge about solving specific problems at a conceptual level and represent the operational knowledge. In the context of cartography, the domain knowledge is a set of common concepts and vocabulary about the field (e.g. map type, layer content, etc.) and the operational knowledge cover the abstracted cartographic principles and rules that determine map design decisions (e.g. layer ordering, background from foreground differentiation (Iosifescu Enescu and Hurni 2007)).

Since the advent of computers, numerous attempts were carried out to propose cartographic models, frames, ontologies and standards with goals ranging from expert system applications (Hutzler and Spiess 1993, Su 1996, Forrest 1999, Jan, Zdena and Jaromir 2009, Smith 2010, Smith 2013, Penaz et al. 2014) to geoportal functionality (Mansourian et al. 2011, Toomanian, Harrie and Olsson 2012) and cartographic interoperability for the Web (Bucher et al. 2007, Iosifescu Enescu and Hurni 2007). However, due to the complexity of cartographic expertise and the fact that the cartographic process has been defined an "ill-structured problem" (Smith 2013), the attempts have been unable to provide a unified and structured approach to formalize the map design process, because of the vastness and complexity of the problem (Jan, Zdena and Jaromir 2009). Similarly, both Beconyte (2011) and Christophe (2012) pointed out the complexity of the definition of cartographic styles and the numerous parameters, sometimes subjective, that influence the final results.

In conclusion, the objective of this thesis regarding the development of a contextual map model to formalize cartographic rules and functions poses the following requirements for the model: allowing the formalization of cartographic knowledge into rules that can mimic the thoughts process of cartographers at decision point in the design process; enabling the definition of well-thought assumptions and sensible default parameters to deal with uncertainty, prioritization, and flexibility; and allowing the generation of feedback to the user regarding the chosen parameters and their suitability.

2. Geoportal technologies

In this second section, the state of the art in geoportals technologies and their role for online cartography are examined. Geoportals are defined as any "web site that presents an entry point to geographic content on the web or, more simply, a web site where geographic content can be discovered" (Tait 2005). More concretely, geoportals offer "capabilities for searching, mapping, publishing and administrating geographic information" (Tait 2005). Additionally, geoportals and similar online mapping platforms may offer to their users the possibility of combining the available layers of information into a single visualization (or map). The growing importance of interactive geoportals as the main access point for geospatial data is observed in the fast-paced development of commercial and open source infrastructures, the production of scientific content on the subject (De Longueville 2010) and in the pivotal role of geoportals in national and regional Spatial Data Infrastructures (SDI)) (Mansourian et al. 2011). Additionally, external factors such as the Infrastructure for Spatial Information in Europe (INSPIRE) directive (European Parliament and Council of the European Union 2007) and the open data movement further promoted the use of geoportals as gateways to public geospatial data.

2.1. Service-oriented architecture and Web services

Service-oriented architectures (SOA) are architectures that rely on loosely-coupled software components that provide services available over a distributed network (Iosifescu-Enescu 2011) and geoportals rely on the request-response mechanism of SOA and Web services to dynamically access and display geospatial data in the browser from remote resources through the HTTP protocol. Web services are applications that make functionality accessible to other applications over the Web and via an Internet-protocol. These services handle both direct and remote interactions from machine to machine, using a standards-based interface (Alonso et al. 2004). Thus, they enable the delivery of remotely available functionality from a service provider to a service consumer (Figure 2). In the field of Web cartography, Web services are used for a wide range of tasks including the display and retrieval of data, processing operations and search functions. In order for all these services to communicate with each other (i.e. to be interoperable), it is crucial that they operate using common standards (see below *Standards*).

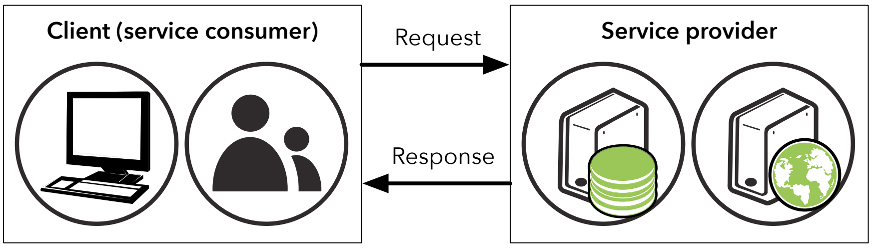

Figure 2. *Request-response mechanism.*

Furthermore, these services are stateless (i.e. each request is treated independently) and location transparent (i.e. the actual location of the server is irrelevant). These characteristics of Web services make them ideal and efficient at supporting online cartographic applications. Moreover, Web services allow to access, visualize and combine geospatial data that are owned and curated remotely. This is especially useful for national SDIs that combine geospatial data from lower administrative units.

The generic architecture for service-oriented Web mapping platforms is divided into three layers or tiers: a data tier, a logic tier and a presentation tier (Figure 3). The data tier hosts the data, usually in a database management system (DBMS) where they are organized in collections of tables. Thanks to spatial databases, geospatial data can be managed efficiently using geometry types, spatial indexes, and spatial functions, which increase performance, and they can be updated without disturbing the other tiers. Additionally, spatial DBMSs offer an independent solution to Geographic Information Systems (GIS) proprietary formats for the data tier. The logic tier contains the services and provides the link between the data tier and the presentation tier. The services perform the tasks required to send the data and/or their visualization to the client (presentation tier): for instance, processing, symbolizing and sending the map image to the presentation tier. Finally, the presentation tier, usually located on the client machine, enables the users to interact with the application, most of the time through a Graphic User Interface (GUI).

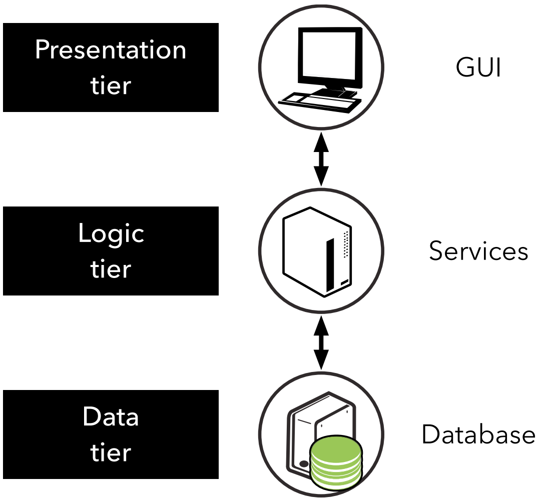

Figure 3. *Traditional three-tier architecture.*

2.2. Standards

The interoperability and sharing of geospatial resources over the Web have been made possible by the Open Geospatial Consortium (OGC). This organization gathers stakeholders in the area of geo-enabled Web, such as industries, government agencies, and universities, and develops publicly available interface standards through consensus building (Open Geospatial Consortium 2017). The following standards are the most relevant ones for Web cartography and geoportals.

- **WMS** (Web Map Service): An implementation of the WMS standard provides the client with spatially referenced 2D maps in the form of an image (JPG and PNG or SVG) dynamically from geographic information that can be displayed in a browser (Open Geospatial Consortium 2006a). It especially focuses on providing custom styled maps with the help of three standards: the Styled Layer Descriptor (**SLD**) (Open Geospatial Consortium 2007b), the Symbology Encoding (**SE**) (Open Geospatial Consortium 2006b) and the Filter Encoding (**FE**) (Open Geospatial Consortium 2010).

- **WMTS** (Web Map Tile Service): The WMTS standard is similar to the WMS in the sense that it renders maps as images too; but its focus is on static maps, where the extent and the scale have been constrained to discrete tiles. Consequently, the service returns only the existing files and allows the use of the browsers cache capability (Open Geospatial Consortium 2010).

- **WFS** (Web Feature Service): The WFS standard allows to share geospatial vector data by letting clients retrieve only the geospatial data they are seeking and not a whole file. In comparison with a WMS, where the client receives the visualization for the data, this service delivers the actual data (Open Geospatial Consortium 2014).

- **WPS** (Web Processing Service): The WPS standard defines an interface that should facilitate the publication of geospatial processes, their discovery and their use by clients. Some examples of processing capabilities that can be offered by a WPS are reprojection algorithms, clip and mosaic functions, or more complicated tasks such as predictive models calculations (Open Geospatial Consortium 2007a)

- **WCS** (Web Coverage Service): A WCS provides access to coverage data (raster data), representing space- or time-varying phenomena, which can either be used as inputs for other tasks or that can be directly delivered to the client (Open Geospatial Consortium 2012).

These standards define the implementation specifications for the services and further specify request parameters, such as spatial extent or layer name, which can be used to discover available geospatial content or request geospatial visualization (e.g. WMS) or data (e.g. WFS and WCS) from the server. For instance, by sending a valid request to a WMS, the client can dynamically receive a map as an image that portrays the specific geospatial content requested, whereas WFS and WCS return the actual geospatial data to the client. Additionally, the standards SLD, FE and SE allow to specify what and how the portrayed map returned by the WMS should look like, meaning how the geospatial data within the maps should be symbolized.

The actual stand of geoportal technologies enables geoportals to offer powerful capabilities, such as choosing and visualizing many types of geospatial data, adapting and combining the rendering or style of the data, adding users' own data, and to customize data representations. Furthermore, geoportals are in constant evolution, following the development of underlying technologies and users' needs, such as a growing access via tablets and cell phones.

3. Technical infrastructure

The technical infrastructure of the geoportal presented below are the foundations for the implementation of the proof of concept for this thesis. The infrastructure enables the integration and the testing of solutions in an existing geoportal. Assembling the underlying geoportal technologies and gathering the geospatial data for the geoportal infrastructure was made possible by the Geoidea.ro project. This project was instrumental in achieving the research objectives related to the integration of advanced cartographic features within a geoportal to support neocartographers' activities and to the opening up of cartographic knowledge.

3.1. Geoidea.ro project

The GEodata Openness Initiative for Development and Economic Advancement in Romania (Geoidea.ro) was a joint project of the Institute of Cartography and Geoinformation, at ETH Zurich in Switzerland and of the Groundwater Engineering Research Center, at the Technical University of Civil Engineering of Bucharest in Romania. The main goals of the project were to improve the scientific basis for the adoption of an open geospatial data model in Romanian; to analyze and support the open data initiative in Romania; and to develop innovative technologies and tools for geospatial data publishing and retrieval through a geoportal. It had roots in the belief that publishing public and governmental geospatial data over the Internet, under an open license and in a reusable format can strengthen citizen engagement and yield new innovative business, bringing substantial social and economic gains. Additionally, the project was firmly grounded in the open source technologies and open data movement.

The research activities carried out in the course of the project and used for thesis were the development of a geoportal and tools for publishing open geospatial data and encouraging their reuse, as well as the gathering and processing of data for publication. The project provided an adequate setting, i.e. a public geoportal with data from multiple sources, to answer the research questions of the thesis and to apply potential solutions within a proof of concept. Valuable open geospatial data were available, but the absence of tools to properly combine and visualize them for reuse causes the geoportal and the data to lose some of their added value. Furthermore, it provided an opportunity to open cartographic knowledge within the context of open source and open data geoportals.

The project was co-financed by a grant from Switzerland through the Swiss Contribution to the enlarged European Union and ran from 2013 to 2015.

3.2. Geoportal architecture

The geoportal developed for Geoidea.ro is built upon a classical three-tier architecture and leverages the advantages of a service-oriented architecture. The part of this section is based on a report written for the project and entitled "Architectural and Interface Design Document" (Panchaud and Iosifescu Enescu 2013). The architecture relies on modular and scalable components that are interoperable not only with one other but also with external systems. Moreover, as the project is inscribed in an open framework and aims at publishing governmental open geospatial data, the architecture is based on open source solutions. Additionally, it is compliant with most international standards, such as OGC and W3C, at the service and client levels. The Web-based user interface is built upon the Scalable Vector Graphics (SVG) standard and thus is supported by all the major browsers.

Figure 4 shows the components of the architecture that supports the generation and then display of maps for the browser. Geospatial data are stored in databases or file repositories which are used by Web services to deliver the data representations to the Graphic User Interface (GUI, i.e. client). The framework developed for this thesis, CartoWiz, is added on the client side (see Paper I for more information about the architecture and components of the framework).

Each section below details the three tiers as implemented for the geoportal of the Geoidea.ro project.

Data tier and data sources

The geospatial datasets used for this thesis are treated in the original context of the Geoidea.ro geoportal, meaning in the way they had been processed, organized and symbolized for the general public. They consist of OpenStreetMap data expressly processed for the project, as well as thematic and administrative data from the Romanian open data platform, and data from some other open source datasets, such Natural Earth. Moreover, to be able to check replicability of the cartographic functionalities developed for this thesis, a parallel geoportal with equivalent datasets for Switzerland and France has been assembled.

Data have been gathered from the above-mentioned sources and processed to be uploaded to several spatial databases. Before the upload, several steps of processing were required, such as the

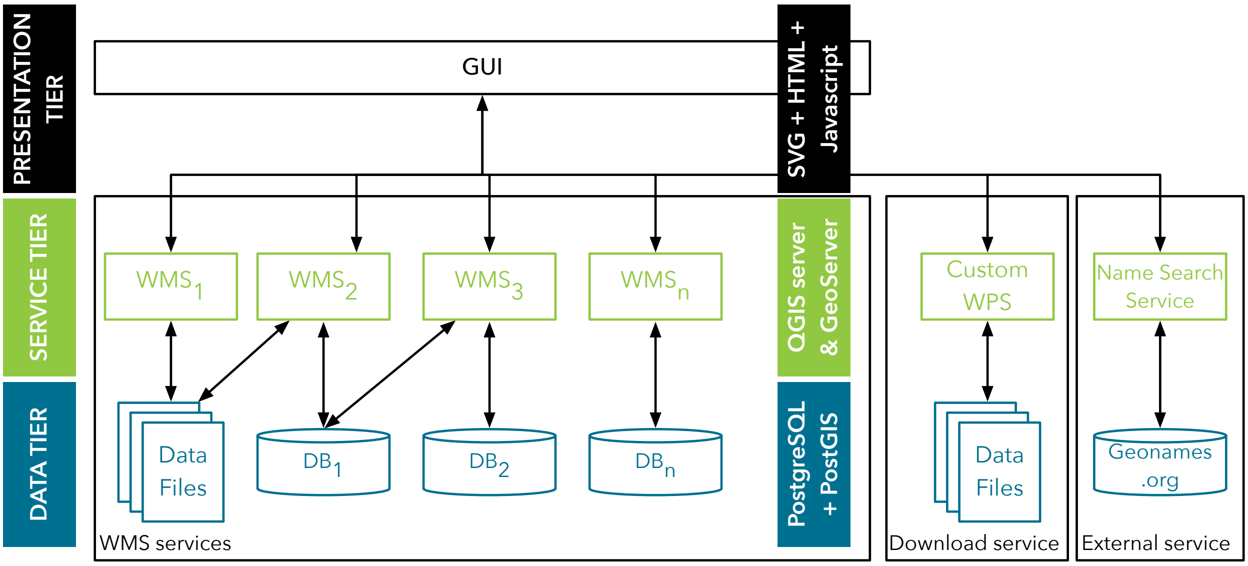

Figure 4. Architecture of the Geoidea.ro *geoportal. The core of the architecture are the WMS services and they are the foundations for the proof of concept.*

selection, generalization, and harmonization of the data. Furthermore, the process demanded an uniformization of the data organization, naming scheme and encoding.

Spatial databases are convenient to store and manage geospatial data efficiently thanks to the spatial functions and indexes that improve their retrieval and processing. Additionally, such databases allow to maintain the data available to the logic tier for processing or visualization purposes. As the system is modular and the services can deal with different data sources, the different datasets are not required to be in a centralized database. The data tier in this architecture is managed using a PostgreSQL (9.1.1) database and its spatial extension PostGIS (2.0.1) because they are mature and reliable open source solutions. This database management system supports importing from and exporting to all the major spatial formats, such as Shapefile, GeoTiff, GeoJSON and Well-Know-Text, and thus could handle imports form all the geospatial data sources mentioned above.

Logic tier and cartographic Web services

The logic tier is not only in charge of for aggregating the geospatial data from the different sources and for sending them together to the client (browser), but it also represents the core of the platforms, where the different functionalities are being executed.

Once the data are in a database and associated with a symbolization file, Web Map Services (WMS) have been parametrized and set up on the dedicated server. Additionally, Web Feature Services (WFS) have also been enabled for vector datasets. Both WMS and WFS for the datasets within the project are accessible via HTTP requests to anyone and not just via the geoportal interface. While a QGIS server (2.2) instance was used exclusively for the Geoidea.ro project, for the research part a GeoServer (2.6.2) instance was also used. Both comply with the OGC standards and support WMS and WFS. When the client (presentation tier) sends an HTTP request to the WMS specifying the extent, projection system, layers and styles, and format of the desired map, the WMS gathers the different data from the databases, symbolizes them and send the image back to the browser.

A custom download service relying on the open GDAL/OGR library for the input and output formats has been arranged for an easier access to the data. This guarantees that the download service is compatible with the other standard-based parts of the architecture. Furthermore, a third party service, Geonames.org, is used to search location names and their actual location in the form of coordinates.

Presentation tier and graphic user interface

The geoportal offers a GUI for the public to visualize, select, combine and download the available data in a user-friendly manner. The GUI acts as the presentation tier. As an interface it enables users to interact and use the available geospatial data and services. It allows users to enter inputs and to send requests to the Web services and to visualize the results of their requests in the browser. Concretely, the GUI translates the parameters from the GUI state (extent, scale, layers selected, etc.) into a WMS request, sends that request, and then seamlessly displays the map image returned from the WMS. In the same way, it parametrizes any download request to the geoprocessing download service and offers the resulting data file to the user through the GUI.

The GUI is built with a SVG-based framework and the interactivity is handled with JavaScript. The framework uses a modified version of the Carto.net (Neumann and Winter 2011) and subsequent GeoVITe (Iosifescu et al. 2011) frameworks. At first, the GUI has been adapted to the requirements of the Geoidea.ro project (Figure 5). and then, it has been heavily extended in the form of a cartographic wizard to support the cartographic functionalities developed in this thesis. The interface is a crucial part of the geoportal because it enables the users to interact with the general functionalities of the geoportal, and most importantly with the smart cartographic functions developed in the thesis. Thus, the existing GUI plays a significant role as a foundation for the development of the wizard and for the integration of the smart cartographic functions within a geoportal as proof of concept.

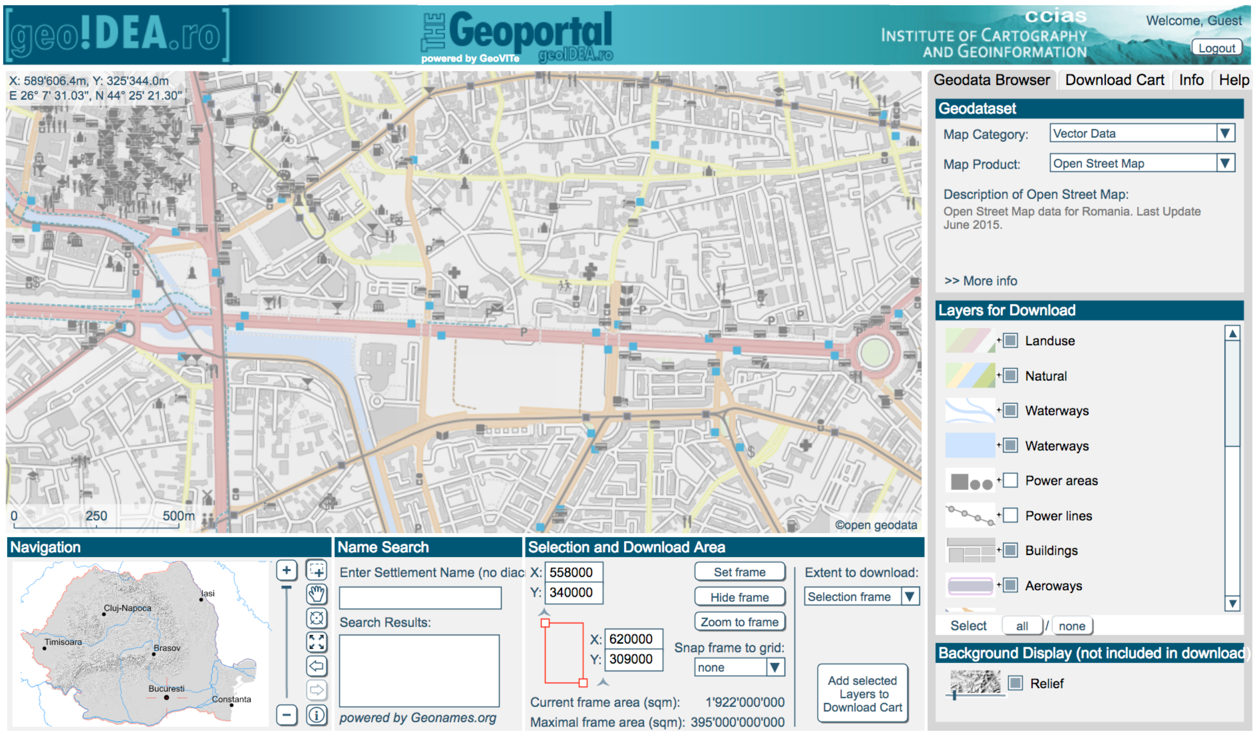

Figure 5. *Graphic user interface of the GEOIDEA.RO geoportal.*

III Smart cartographic framework and functionality

Smart cartographic functionality for improving data visualization in map mashups

Nadia H. Panchaud, Ionuț Iosifescu Enescu and Lorenz Hurni

Paper I

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Abstract

Thanks to the growth of geoportal products and online cartographic platforms, access to spatial data has never been so easy for so many people. However, access to cartographic knowledge for laypersons using such data is lagging behind. Platforms that allow users to create map mashups from diverse data sources can lead to unsatisfactory cartographic visualization, which reduces the map's legibility and the usefulness of such functions. This article's focus is on creating a framework that supports smart cartographic functions to improve the quality of map mashup. First, we assess the state of cartographic conflicts due to map mashup, using examples from existing geoportals. Afterwards, we describe a framework that allows us to define cartographic functions, focusing on symbology changes and based on a client-side approach. We do not aim to fully model the complex decision-making process of a professional cartographer; but rather to provide a set of smart functions that use appropriate assumptions and constraints based on cartographic principles and semantic information. As proof of concept, the framework and functions are then integrated within a geoportal.

Keywords: cartographic functionality, symbology, geoportal, mashup, Web mapping, map design

1. Introduction

Cartography is changing: there is a new trend in which laypersons and professionals alike have easier and broader access to geospatial datasets and mapping technologies. This trend is supported by the advent of the Web 2.0, more recently the Semantic Web, Neocartography (ICA Commission on Neocartography 2011), and advances in computer technologies for the masses. Numerous geospatial datasets from multiple sources, of various kinds and topics are available worldwide through online cartographic platforms and services.

Geospatial services and data are often published online on geoportals; this is especially true of public data. Interactive geoportals are powerful tools, well suited for disseminating geospatial datasets. This is shown by the fast-paced development of commercial and open source infrastructure, the production of scientific content on the subject (De Longueville 2010), and by the geoportal's pivotal role national and regional Spatial Data Infrastructures (SDI) (Mansourian et al. 2011). Beyond the publication of geospatial data, geoportals offer "capabilities for searching, mapping, publishing and administrating geographic information" (Tait 2005). Furthermore, geoportals and other online mapping platforms often allow users to create map mashups by combining available datasets. However, the visualization of geospatial data on these platforms often fails to reach the high-quality standards that stem from well-accepted cartographic principles. Possible cartographic visualization mistakes can be found in the following cases: dataset visualization at a smaller scale than the original without changes in symbolization or the combination of datasets with incompatible scales, leading to coalescence and congestion. Additionally, the datasets are often symbolized on a standalone basis, leading to serious symbolization conflicts and poor cartographic harmony once the datasets are combined.

Public geoportals and similar platforms are mostly focused on their role as geospatial data access platforms. They put little emphasis on adequate visualization of geospatial data for either visualization or exploration purposes, even though cartographic visualization capabilities bring added value to the search and evaluation process (Tait 2005). Knowledge about cartographic visualization methods is available in the formal and professional realm of cartography, but has not yet been transferred or integrated within informal mapping platforms such as public geoportals. This difference between the state of knowledge in formal cartography and what is available to informal mapmakers on online platforms is what we call the "cartographic gap". These informal mapmakers, or neocartographers (Cartwright 2012), have easy access to spatial data and tools, but not to cartographic principles and knowledge.

The motivation behind this work is to develop a framework that allows the definition of smart cartographic functions and their integration within a geoportal. These functionalities shall support users in their map-making activities. We aim to identify where cartographic functions are needed to fill the cartographic gap and more specifically focusing on cartographic conflicts that can be resolved by changes in symbolization. The word conflict here is not meant in the strictest cartographic sense, but rather in a broader sense, to refer to a visualization issue or shortcoming.

This paper is structured as follows. First we review the state-of-the-art in cartographic visualization on geoportals as reported in the literature. Second, we survey existing geoportals regarding their content, functionalities, and potential cartographic conflicts from mashups. Then we develop a framework to support smart cartographic functions for improving map mashups by means of symbology changes, after which, we show the potential of the framework by implementing it in an existing geoportal. Finally, we discuss the strengths and weaknesses of the approach and conclude with future works.

2. State of the art in cartographic visualization on geoportals

As seen in the introduction, the geoportal approach is widely used as an access interface to geo-spatial data and services. However, the mapping and publishing capabilities realized with viewing services often offer cartographic visualization of poor quality (Iosifescu Enescu and Hurni 2007, Harrie, Mustière and Stigmar 2011). Quality here is understood as explained by Harrie, Mustière and Stigmar (2011) as "the degree to which the user can efficiently interpret the map visually". The absence of adequate cartographic visualization or its non-optimization can confuse the users (Jenny et al. 2010), prevent the optimal use of geoportal functionality (He, Persson and Östman 2012) and decrease map legibility (Huang and Gartner 2012).

Most conflicts in map mashups originate from the main characteristics of the platforms on which they are created. For exploratory purposes, they usually allow the user to see the different datasets at all possible scales, even when some are not appropriate. This leads to potentially poor combinations of data from different sources and levels of detail.

When data are visualized at a smaller scale than originally intended or when there is a mismatch between levels of detail, it can cause congestion and coalescence. Moreover, most layers are symbolized on a standalone basis and when the layers are combined, the resulting overall symbology can be of low cartographic quality. Both aspects can render a map illegible.

Several studies of cartographic conflicts and their possible solutions in geoportals have already been completed (Table 1 summarizes the conflicts and solutions), and many of these issues apply to other types of online cartographic platforms as well. Harrie, Mustière and Stigmar (2011) mention several interconnected issues that might arise in cartographic visualizations, namely semantic and geometric heterogeneity, label and symbol inefficiency, and diversity of levels of detail. Toomanian, Harrie and Olsson (2012) concur regarding the inefficiency of symbols by mentioning the lack of visual hierarchy (Slocum et al. 2009), which can also be understood as visual levels or planes within the map (MacEachren 1995). Furthermore Toomanian, Harrie and Olsson (2012) and Kiik (2015) elaborate on polygon overlaps and how to resolve the issue. Iosifescu Enescu et al. (2015) mention further specific issues such as coalescence and congestion occurring in cases of scale reduction or scale mismatch. Several studies deal with visual clutter in point data, including how to filter relevant points of interest (Huang and Gartner 2012) and reviewing the different generalization operators (Korpi and Ahonen-Rainio 2013).

Aspects related to color schemes, such as the lack of color constraints and poor color contrast, have been the focus of several studies. Buard and Ruas (2007) analyzed the perception of contrast (in opposition to the mathematical contrast) between colors, attempting to define how changes in hue and value impact the perceived contrast. The chromatic circle used in their study was later used to improve color contrast for on-demand risk maps (Chesneau 2011). These authors furthermore combined it with semantic information regarding the relationship type (association, difference, or other). Bucher et al. (2012) leverage the legend to analyze the relationship and color contrasts on the map. To do so, they assign contrast scores to pairs of themes on the map and try to detect inconsistencies, so that they can suggest alternative colors to improve the overall map contrast.

Many of the above-mentioned approaches aim at an automated solution to a specific map design problem on field-specific platforms. They are often complex; typically, they require a specific data model and custom Web services and lead to a high computational load. They are often not implemented in public geoportals because they require much more processing time than an ordinary user is willing to wait for on a geoportal. For instance, the method employed by Toomanian, Harrie and Olsson (2012) needs 39 seconds to deal with three layers and up to 90 seconds for five layers. Chesneau (2011) mentions that her process requires just under a minute. To ensure a fluid experience for the user and maintain the flow of thought, a "reasonable" response time of less than 8-10 seconds is required. This limit is linked to human perceptual abilities and was determined by Nielsen (1993), confirmed in his later studies (Nielsen 1997, 2010), and by Zona Research (1999). To actually maintain an uninterrupted flow of thought on the Web page, a response time of less than one second would be needed (Nielsen 1993 , 1997, 2010), though a three-second rule as a threshold has also been suggested (Iosifescu Enescu et al. 2015).

Additionally, some conflicts should be resolved using cartographic generalization techniques such as: selection, simplification, smoothing, aggregation, merging, and collapse operations. Automation of these techniques is still a major research topic. Another important issue is the optimization of label placement. These issues are, despite their importance, beyond the scope of this work regarding

Table 1. Summary of cartographic conflicts and corresponding solutions.

<table>
<tr><th>Conflicts</th><th>Within or between layers</th><th>Solutions in the literature for geoportals and similar applications</th></tr>
<tr><td>Scale problems</td><td>both</td><td>Filtering, placement, aggregation (Huang and Gartner 2012)
Selection, refinement, displacement, aggregation, typification, simplified symbolization, spatial distortion (definitions in Shea and McMaster (1989); applied to the context of geoportals in Korpi and Ahonen-Rainio 2013)</td></tr>
<tr><td>Too detailed geometries</td><td>within</td><td>Generalization (Harrie et al. 2009, Harrie, Mustière and Stigmar 2011, Iosifescu Enescu et al. 2015)</td></tr>
<tr><td>Coalescence, congestion</td><td>within</td><td>Thinning, line smoothing, color change (Iosifescu et al. 2015)</td></tr>
<tr><td>Lack of visual hierarchy</td><td>between</td><td rowspan="2">Hue, lightness, or saturation contrast (Chesneau 2011)
Contrasts as perceived, not as calculated (Buard and Ruas 2007)</td></tr>
<tr><td>Lack of color contrast</td><td>both</td></tr>
<tr><td>Lack of color support</td><td>both</td><td>Predefined color circle (Chesneau 2011)
Semantic constraints, preservation constraints, graphic constraints and cartographic constraints (Harrie et al. 2009, Harrie, Mustière and Stigmar 2011)</td></tr>
<tr><td>Polygon overlaps</td><td>between</td><td>Icon pattern (Toomanian, Harrie and Olsson 2012)
Border and hatches, icon pattern (Kiik 2015)</td></tr>
</table>

smart cartographic functionality. However, the proof of concept integrates solutions to deal with scale problems in the background.

3. Geoportals survey

After reviewing the state-of-the-art solutions for cartographic conflicts from the scientific literature, we look into the cartographic capabilities and content of existing geoportals. The analysis of concrete geoportals that are used by the public (as opposed to by professionals or scientists) is useful in several ways.

The analysis results give a frame to the type of cartographic visualizations that can be expected from map mashups originating from national geoportals, thus clarifying the scope of the smart functionalities that we want to develop. They also enable the definition of three scenarios of layer combinations that an ordinary user could make. This gives us the foundation for our analysis of cartographic conflicts in geoportals in the next section.

3.1. Geoportal content and capabilities

For the analysis of the geoportals, we compiled a list of 21 national geoportals that are supported by governmental or public institutions and that offer a map interfaces to visualize the data. A selection of 21 functional and stable geoportals worldwide following these criteria was made (see the section *Detailed survey data* for the complete list). The analysis was conducted during the summer 2015.

The topics of the geospatial data available on the geoportals were surveyed and categorized. As seen in Table 2, the most readily available data on geoportals are administrative boundaries, transport infrastructure, hydrography, satellite imagery and orthophotos, base maps, land use and land cover, and geology. The 12 geoportals that also have mashup capabilities offer these topics as well (except geology).

The following functions have been surveyed because they are part of the map mashup workflow on geoportals: layer mashups, layer order controls, layer transparency, and print options (Table 3). A small majority (12 out of 21) of the geoportals offer an intuitive and easy way to combine layers in a mashup. Very limited possibilities of mashup are available on 3 other geoportals (only a few layers for mashup or complex workarounds needed). For the analysis of conflicts on geoportals, we only kept the 12 geoportals with true mashup capabilities.

Next, options that allow for changing how a map looks were considered, namely control over layer order and transparency: there are 12 geoportals that provide an option for layer order and 18 that provide for transparency. Layer order controls allow the user to reorder the layers and correct unfavorable overlaps and unwanted occlusions as long as the issues are between layers and not within a single layer. The transparency parameters can help solve overlaps and visual prominence conflicts. Both functions seem straightforward to use, but can still lead to suboptimal choices by uninformed users.

The print function is offered by 15 out of 21 geoportals and it ranges from a basic screenshot of the map interface to more complex sets of tools allowing users to add a title, legend, or metadata.

Table 2. Topic categories available on the geoportals.

Topic Categories	Geoportals (n=21)	Geoportals with layer mashup (n=12)
Administrative boundaries	21	12
Transport infrastructure	19	12
Hydrography	19	12
Satellite imagery/Orthophotos	19	12
Base maps	18	12
Land use/Land cover	16	12
Geology	16	11
Biodiversity	15	9
Cadastre	11	6
Relief (shaded or colored)	11	7
Population/Society	11	7
Ready maps	11	8
Climate	9	6
Energy	8	5
Elevation	8	4
History	5	4

Table 3. Functions supporting cartographic tasks on the geoportals.

Functions	Geoportals (n=21)
Layer transparency	18
Print options	15
Layer mashup	12 (+3*)
Layer order control	12

* Geoportals with very limited mashup capabilities (only a few layers available or complex workarounds required).

3.2. Cartographic conflicts in the surveyed geoportals

Map mashups from the three scenarios defined below are the basis for our analysis of specific cartographic conflicts found on geoportals. These conflicts are detailed in the next sections and consist of the drawing order of layers, unaddressed scale problems, and the lack of visual hierarchy.

Based on the topics that are available across the 12 geoportals with the layer mashup function, we define three scenarios (Table 2 for topic categories available on the 21 geoportals). We define in such a way as to make it possible to compare similar topics of geospatial information represented in different ways, at various scales, and containing different types of geometries.

The first scenario involves the creation of an overview map with a satellite image as background and with some topographic and man-made features, such as hydrography information, transport networks and administrative boundaries at the country scale and at a state or province scale. In the second scenario, the same topics as in the first scenario are used, but the satellite image is replaced by land use or land cover information. This scenario is generated at the country, state and metropolitan scales. The third scenario combines bike routes with a base map offered by the geoportals at medium scales.

Drawing order

Geoportals have different strategies for handling the order in which the layers are drawn in a mashup. The majority of geoportals draw the layers in the order in which the user adds them to the map: that is, the first layer added to the mashup is "below" the others. In 9 of the 12 geoportals, the user can then rearrange the layers within the layer stack (see the section *Detailed survey data*).

One geoportal (#2) does not offer layer reordering and sorts the layers according to their geometries. Two other geoportals (#10 and #11) lack this functionality as well and draw the layers according to the order in which the user adds them.

Except when a layer clearly visually obstructs another one on the map (in Figure 1 and Figure 2, rivers are drawn on top of the lakes because rivers are usually prolonged through the lakes due to data modeling reasons), it is often difficult to notice at first glance potential overlapping conflicts between layers, especially with an increasing number of layers. For instance, how should rivers, lake, roads and administrative boundaries be ordered to ensure optimal legibility on both water bodies and land use background?

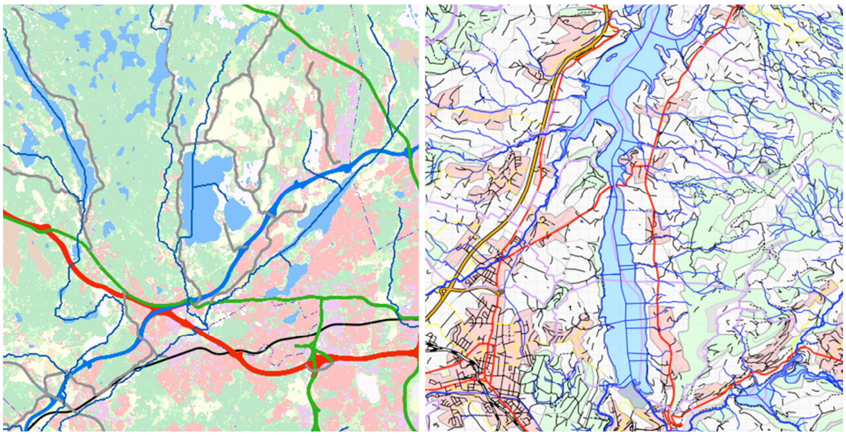

Figure 1. *Centerlines of rivers visible on top of the lakes: #4 Paikkatietoikkuna (left); #1 Geo Admin (right). Sources: Finnish Transport Agency CC BY 4.0 and Finnish Environment Institute SKYE CC BY 4.0 (left); Bundesamt für Landestopografie (right).*

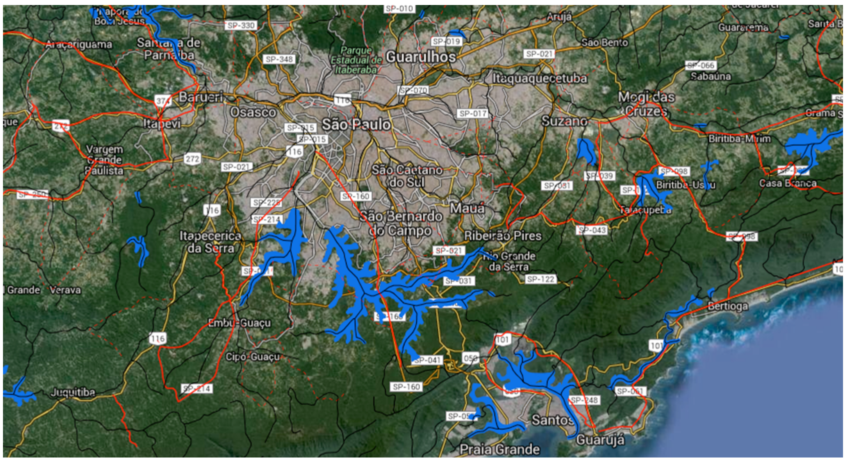

Figure 2. *Centerlines of rivers are visible on top of the lakes, while rivers and roads cover the labels (#9 INDE). Sources: Map data from INDE Viewer (via CC BY-SA 3.0), imagery and map data © 2015 Google.*

Unaddressed scale problems

One characteristic that geoportals share with other online mapping environments is the possibility of exploring any datasets at any scale. This leads to congestion, coalescence, and imperceptibility when geospatial data meant for a larger scale are displayed at smaller scale or when the levels of detail of the different data sets are too disparate. These types of conflicts can be found particularly in scenarios 1 and 2 at small scale, for which the geoportals do not offer simplified road networks (Figure 3).

A few geoportals integrate solutions to scale problems into the application background. One approach involves scale-dependent symbolization within map products, often by applying visibility thresholds for specific feature categories and adapting the thickness of lines (Figure 4). This must be carefully defined and designed by the responsible cartographer. The downside to this approach lies in the fact that it might create artificial and abrupt changes in how a map looks as well as in its content. Furthermore, it is automatically applied when the zoom level of the map changes so the user has no control over it. Additionally, it requires more preparation work from the cartographer, this explains why half of the geoportals analyzed do not offer such symbolization.

The French (#3) and Luxembourgian (#5) geoportals offer some scale-dependent symbology, but map legibility at intermediate scales is still insufficient (Figure 5).

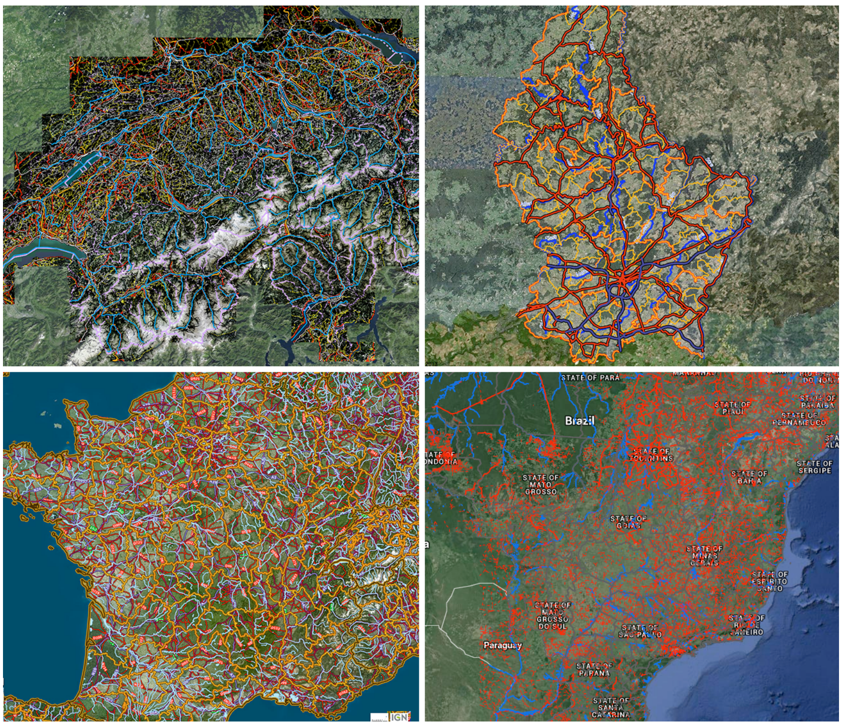

Figure 3. *Congestion and coalescence of roads and hydrological networks at small scales: from left to right, top to bottom, #1 Geo Admin; #5 National Geoportal; #3 Géoportail IGN; #9 INDE.*
Sources: Bundesamt für Landestopografie (top left); Géoportail officiel du Luxembourg, ACT (top right); © GEOPORTAIL (bottom left); Map data from INDE Viewer (via CC BY-SA 3.0) and imagery and map data © 2015 Google (bottom right).

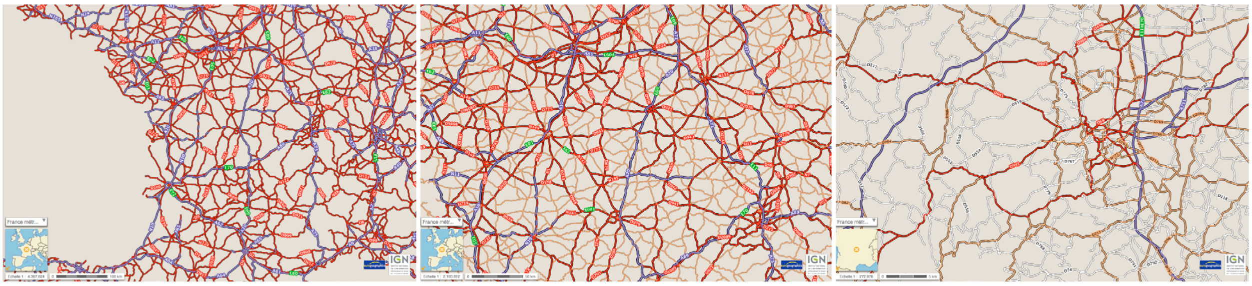

Figure 4. With scale-dependent symbolization, the selection of visible features and labeling are varying with scale, from small to large scale (#3 Géoportail IGN).
Source: © GEOPORTAIL.

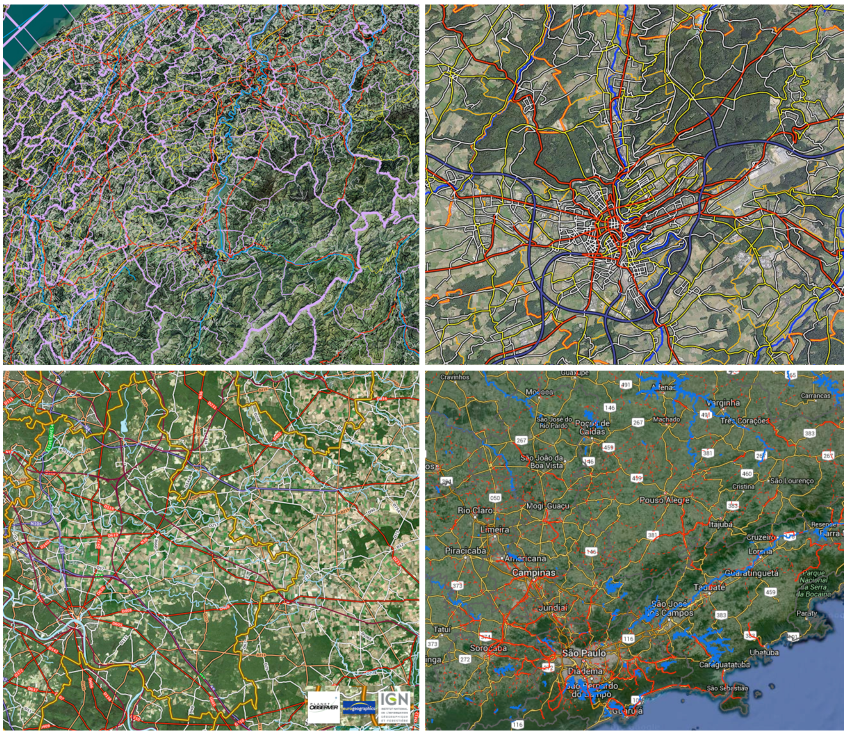

Figure 5. Cluttering of roads and hydrological networks at medium scales: from left to right, top to bottom, #1 Geo Admin; #5 National Geoportal; #3 Géoportail IGN; #9 INDE.
Sources: Bundesamt für Landestopografie (top left); Géoportail officiel du Luxembourg, ACT (top right); © GEOPORTAIL (bottom left); map data from INDE Viewer (via CC BY-SA 3.0) and imagery and map data © 2015 Google (bottom right).

Visual hierarchy

The visual hierarchy in a map relates to the visual importance of the different layers of data. Information in the foreground should have a more prominent symbolization, while the supporting background information should not stand out.

Satellite imagery and orthophotography are widely used as background information, especially for smaller scale (Hoarau 2012). Both have darker, more saturated colors, which offer poor contrast with the road networks, that is also represented using saturated colors (Figure 3 and Figure 5).

With the numerous European geoportals, a specific issue related to visual hierarchy comes from the land cover data derived from the CORINE datasets. The default symbology uses strongly saturated colors that are prone to be interpreted as foreground information and often provide poor contrast to other information in a map (Figure 6).

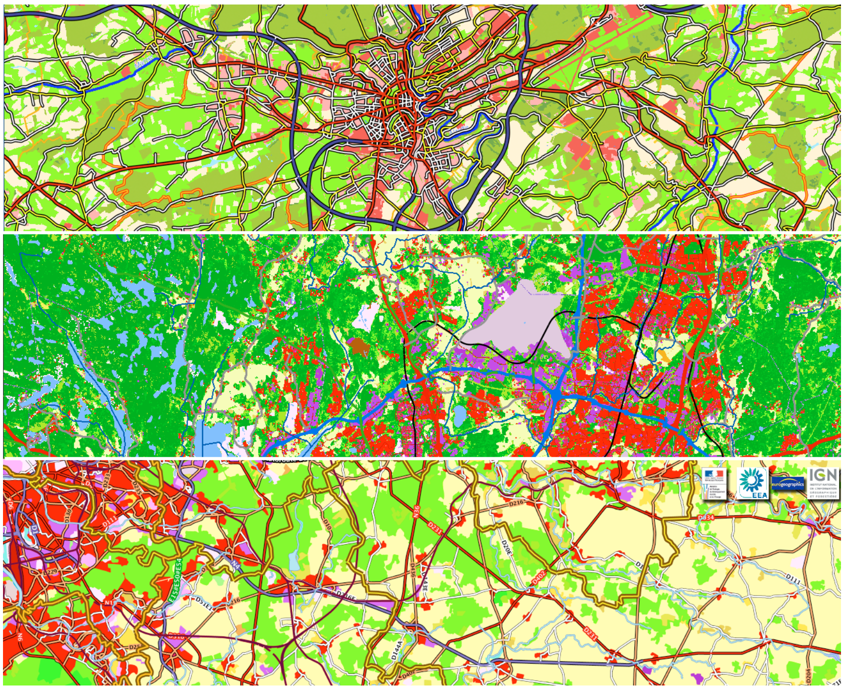

Figure 6. CORINE land cover default symbolization from the French and Finnish geoportals and equivalent data from the Luxembourgian geoportal with road network, from top to bottom: #5 National Geoportal; #4 Paikkatietoikkuna; #3 Géoportail IGN.
Sources: Géoportail officiel du Luxembourg, ACT (top); Finnish Transport Agency (CC BY 4.0) and Finnish Environment Institute SKYE (CC BY 4.0) (middle); © GEOPORTAIL (bottom).

Many geoportals allow the user to change layer transparency. This is useful with overlapping polygons and to reduce the visual importance of a complex background map, such as satellite imagery or land cover data. One geoportal (#3) provides the user with an additional functionality that can turn every single layer into its grayscale representation (Figure 7). Reducing saturation, which is the equivalent of moving toward a grayscale, is a known strategy for rendering a layer visually less prominent.

Figure 7. Original symbolization of the roads layer (left) and its grayscale version (right): #3 Géoportail IGN.
Source: © GEOPORTAIL.

4. Closing the gap

The previous section showed the existence of basic functions on geoportals, such as layer reordering and transparency settings, which can solve cartographic conflicts in map mashups. These functions are straightforward, but the map design problem onto which they are applied is not. In comparison, the literature presents complex functions that aim for more or less automated solutions (see the section *State of the art in cartographic visualization on geoportals*). They are, however, difficult to implement in national geoportals or on other online cartographic platforms. Thus the risk of cartographic conflicts in user mashups is still high on geoportals.

In this section, we present a framework for smart cartographic functionality on geoportals and similar online map mashup platforms. This framework consists of a knowledge base, that includes a contextual map model, formalized cartographic principles, judicious assumptions, and semantic information. The framework supports a white box approach to smart cartographic functions, which can be seen as a stepping-stone to a more comprehensive approach to closing the cartographic gap. The smart cartographic functions are envisioned as semi-automated tools for preventing major cartographic faux pas and improving the cartographic quality of a mashup.

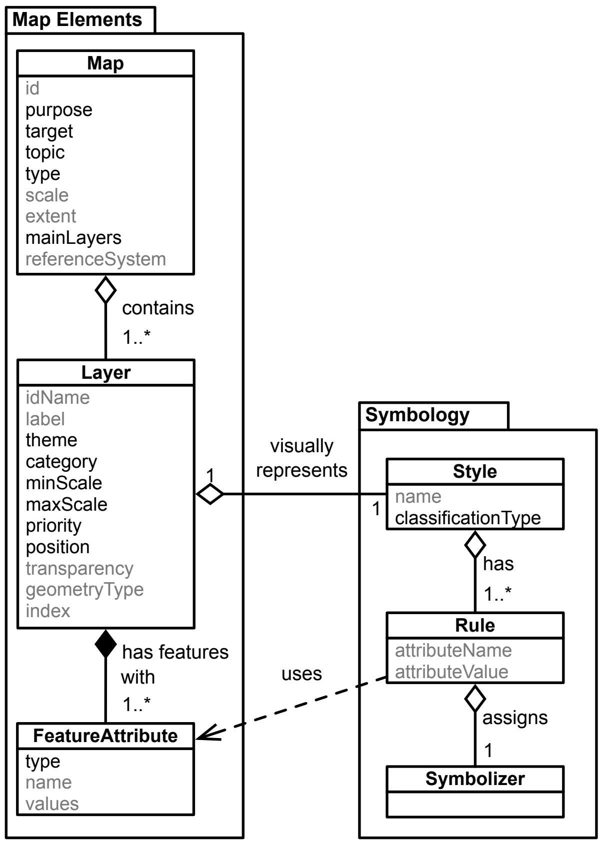

Figure 8. *Elements overview of the contextual map model. Attributes in black are semantic content.*

4.1. Contextual map model

A contextual map model describes the elements of a map and their relations as they are needed for the framework. We base the contextual map model on previous studies that dealt with cartographic models, semantics and ontologies (Iosifescu Enescu and Hurni 2007, Smith 2010, Stevens, Smith and Bianchetti 2012, Penaz et al. 2014) and as well as on the requirements for smart cartographic functionality.

The *Map* elements define the map and its content, whereas the *Symbology* elements describe the styling options of the map content (Figure 8).The *Map* object is the container for the other cartographic objects. In the context of Web maps, layers are the organizational units for the map content. *Layer* objects hold features that are homogeneous in terms of theme, geometry type and attribute sets. Because we presuppose no access to the geometries (often the case on such platforms), we can simplify the model and link the feature attributes directly to the layer.

A *Style* object associates rules and symbolizers to visually represent the geospatial data of a layer. At any moment in time, only one style can be associated to one layer. The attributeName and the attributeValue are necessary to build and assign the rules. The contextual map model holds technical information, which can be derived from the platform environment, and semantic information, which requires the work of a cartographer (attributes in black in Figure 8). For instance, the theme and category of the layer are semantic information. Equally, the layer priority describes whether the layer is one of the main layer of the map, and the position describes in which visual ground the layer is.

4.2. Objects catalogues

Because cartography is intrinsically linked to the semantics of the phenomenon represented on the map, the cartographer relies on the meaning of the data in making design decisions. In this process, principles, conventions, and heuristics support the cartographers. This implies that smart cartographic functions will require semantic information that is useful and usable.

We define here two object catalogues to support the semantics-based rules of the framework: one for the map object and one for the layer object of the contextual map model. These catalogues are based on the analysis of the geoportals and their content.

The semantic catalogue for the layer object is organized in a two-level hierarchy. Layer categories allow broad differentiation between the layers (Figure 9). Map images represent pre-generated

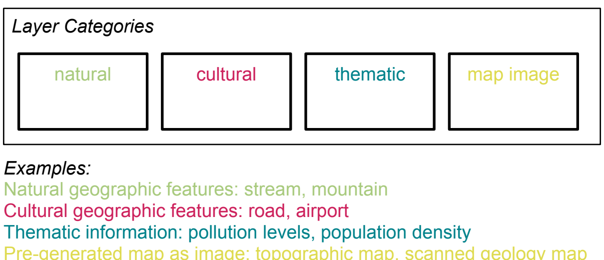

Figure 9. *Layer categories.*

complete maps that geoportals offer as one layer (e.g. scanned geology map or national topographic map) and are usually originally in raster format. A distinction is made between geographic features, which are concrete objects in the real world (one could go to the location shown on the map and see the geographical features), and thematic information (e.g. population density or pollution levels), which are often attached to administrative units or points of measurement. The geographical features are actually represented by two categories: natural (e.g. a stream or a mountain) and cultural (e.g. a road or an airport) features.

But this is not enough information about the content of layers to apply cartographic principles in a meaningful way. Thus, we add a second level for more detailed differentiation of the layer content. For example, knowledge is required for assigning correct color conventions or layer order. The semantic information for the layer themes is defined after close inspection of the data available on

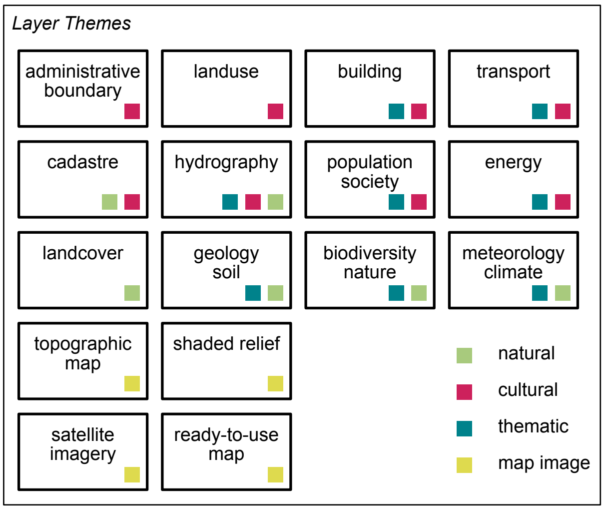

Figure 10. Layer themes. Color-coded layer categories are shown for each layer theme that appear in the category as observed in the sample of the 21 geoportals.

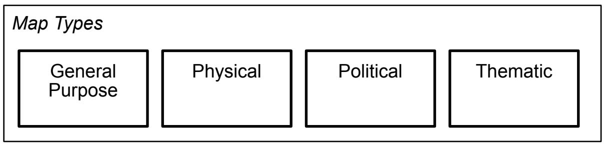

Figure 11. Selected map type taxonomy.

the surveyed geoportals, especially regarding the recurring themes and their distinctions within the geoportals. The following layer themes (Figure 10) cover 90% of the content of the geoportals surveyed. Furthermore, thy allow fine-tuning the restriction of layers to certain map types.

The map type catalogue is much simpler, but no less important. Indeed, the cartographer applies different rules and restrictions depending on the type of map. A general-purpose map is not designed the same way as a physical map, or a thematic map. This taxonomy allows differentiating exclusion rules and symbolization based on the map type. It can be expanded for more specific map types and associated rules if the need arises in the future, but for now it defines four map types (Figure 11) that can easily be realized, based on the content of the average geoportal.

These semantic catalogues are important because cartographic principles are based on the meaning of the geospatial data, not just on their geometry. Knowledge about the semantic content of the geospatial data allows us to make assumptions as to how the data should be represented. Moreover, it informs the cartographer about the possible type of symbolization for the layer and its role in the map. It also enables the framework to restrict layers to a specific map type based on their category: layer categories and themes can be "a must", "allowed", or "forbidden" in the different map types.

4.3. Exclusion rules and assumptions

Mashups are combinations of layers into a single map. All possible combinations cannot be foreseen or recommended from a cartographic point of view. Thus, we develop exclusion rules for combinations when we can assume that they would produce visualizations transgressing major cartographic principles. In addition, we use inclusion rules as a constraint, such as forcing the presence of thematic layers when the map type chosen is a thematic map. For each map and layer parameter, we can assign constraints and then test for combinations that disregard the constraints. There are two major types of incompatibility: at the content level (e.g. a general map that does not require a thematic layer) or at the geometry level (e.g. the level of detail of a layer is incompatible with the scale map). Figure 12 shows some content constraints.

Other constraints deal with the drawing order of layers. These are built on well-reasoned assumptions, which are derived from design choices in recognized best-practice paper and digital map products. They are organized with different priority levels; when rules contradict each other the rule with the higher priority is applied (Figure 13). The priority is linked to the level of specificity of the rules regarding the layer content: geometry-based rules do so not take into account the content of the layers; category-based rules do in a general way; and rules based on themes take the layer content more specifically into account.

∀ mapType(general),	¬layerCategory(thematic)
∀ mapType(physical),	¬layerCategory(thematic) ∃ layerTheme(hydrography) ¬ (layerCategory(cultural) && ¬layerTheme(administrative)) ∃ (layerCategory(natural) && ¬layerTheme(hydrography))
∀ mapType(political),	¬layerCategory(thematic) ¬ (layerCategory(natural) && ¬layerTheme(hydrography)) ∃ layerTheme(administrative)
∀ mapType(thematic),	∃ layerCategory(thematic) ¬ (layerCategory(thematic) <5)

Legend

∀ parameter(*value*)	parameter(*value*)

∀: *for all* ∃: *there exists at least one*

&&: *and* ¬: *not (negation)*

Figure 12. *Constraints examples on the content of the different map types.*

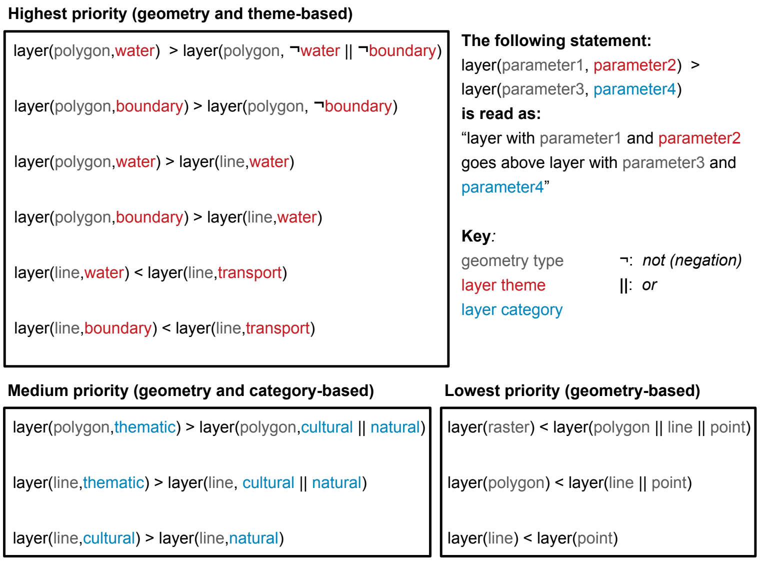

Figure 13. *Constraints examples on the drawing order of the layers.*

Rules regarding the compatibility of the map scale and the scale range of the data are also defined. They aim at making users aware that some datasets are not optimal for certain scales. This is especially the case when the data are visualized at a smaller scale than they are intended for, and which leads to congestion and coalescence.

5. Implementation

In this section, we present the integration of the framework into a geoportal to show its potential. We do this using a wizard. The contextual map model and the different object catalogues (as semantic annotations) are important linking elements between the framework, the wizard, and the mashup. They enable the use of formalized cartographic rules and principles with the data available in the geoportal. The following smart cartographic functions have been integrated and tested: layer reordering, compatibility of layers within a map type, and generation of a new style.

The proof-of-concept implements the framework within a geoportal that uses Web Map Service (WMS) compatible with the Styled Layer Descriptor (SLD) and accompanying standards. This geoportal uses scale-dependent symbolization on the server side. The choice of a WMS-based geoportal was made because the technology is widely used and documented. However, the framework could also be implemented in a platform using different technologies, such as vector tiles, because the framework definition and its specific implementation within the geoportal are separated.

As the framework focuses on conflicts that can be solved by changing the symbology, the approach for the implementation does not require access to the geometries themselves, nor perform complex operations on geometries and thus requires fewer computational resources. Furthermore, it leverages common, existing functionalities of geoportals (e.g. interactive layer stack and transparency).

In the next section, we briefly explain the architecture of the system. Then, we describe the workflow of the user on the geoportal when using the wizard and the smart cartographic functions. Finally, we discuss the performance test and mashup result.

5.1. Architecture

The geoportal used for the proof of concept is based on a classical three-tier architecture with WMS for the delivery of the map to the Graphic User Interface (GUI). We implement the framework on the client side to reduce the back-and-forth communication with the server. The GUI does not request the new map from the server until the new symbology has been fully defined on the client side.

The knowledge base comprises the object catalogues, including the object definitions, and the rule library as explained in the previous section. A contextual map model for the specific map mashup on the geoportal is created from the object catalogue and information derived from the geoportal state. Then the wizard uses the rule library to assess the contextual map model. The contextual map model also uses information from the SLD library, which holds the file describing the default styles of each layer on the geoportal (Figure 14).

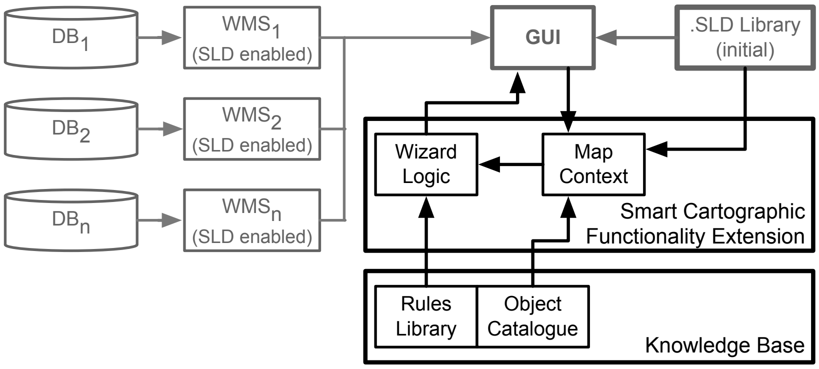

Figure 14. Schematic view of the system architecture for the proof-of-concept.

Once the wizard starts, it parses the contextual map model to verify it and to suggest improvements to the map symbology. The new symbology is requested from the WMS with the parameter SLD_BODY in a GetMap request. It is then generated in the contextual map model and the wizard translates it into a request that WMS can understand. Therefore, we assume it would be possible to develop another parser that would generate a style request.

5.2. Workflow

We analyzed the workflow for creating mashups on the existing geoportals. Based on our analysis, we defined the following workflow, which integrates smart cartographic functions (Figure 15). In step 1, the user explores the geoportal thematically and spatially. One can then incrementally add layers to the mashup while exploring. Then one can choose to start the wizard or not. In step 2, the wizard opens and the user is asked to define additional parameters for the map explicitly, such as its type or the main layers of the map. Other information is read directly from the geoportal, such as the selected layers, and the map extent and scale. The third step is a critical point for the wizard, because it must be able to assess the map definition and content. At this point it also verifies whether the user is making any major cartographic "faux pas" regarding the type of map, its content, or its scale. If some parameters are not compatible, the wizard provides the necessary corrections in the

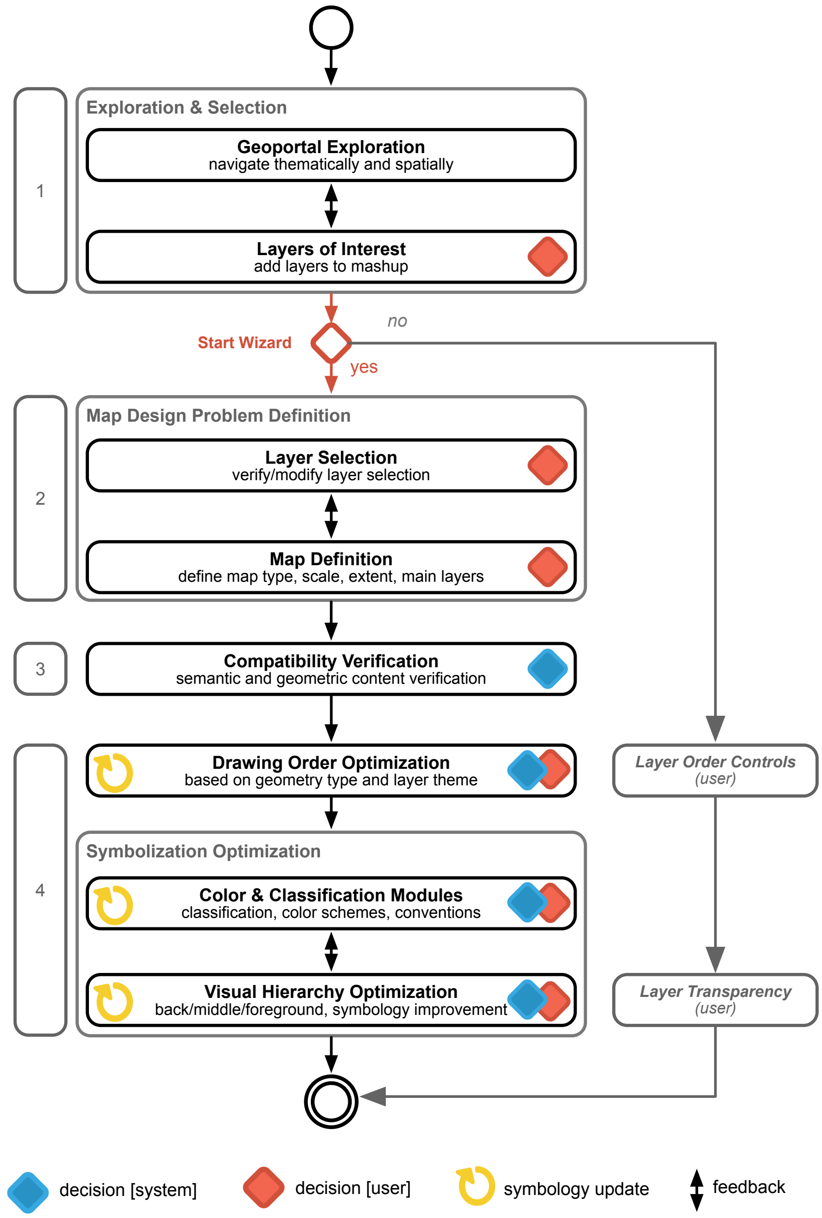

Figure 15. Simplified view of the workflow. In gray on the right, the workflow without the wizard.

form of automatic changes, hints, or requests for additional input, for example regarding choices of layers, scales or map types.

Once step 3 is completed, the wizard moves on to optimizing the drawing order of the layer as well as the visual hierarchy of the map. Step 4 consists of several subtasks and feedback loops, at which the wizard makes suggestions to improve the appearance of the map. The user, however, has the last word and can overwrite any non-critical aspects.

5.3. *GUI integration*

The above-mentioned workflow is integrated into the existing geoportal GUI. The user must explicitly start the wizard. Once started, the wizard presents the user with the state of one's selection and additional choices of parameters. The principal concept for the design of the wizard GUI is that the user can always overwrite the wizard's decision. For instance, after layer reordering has taken place,

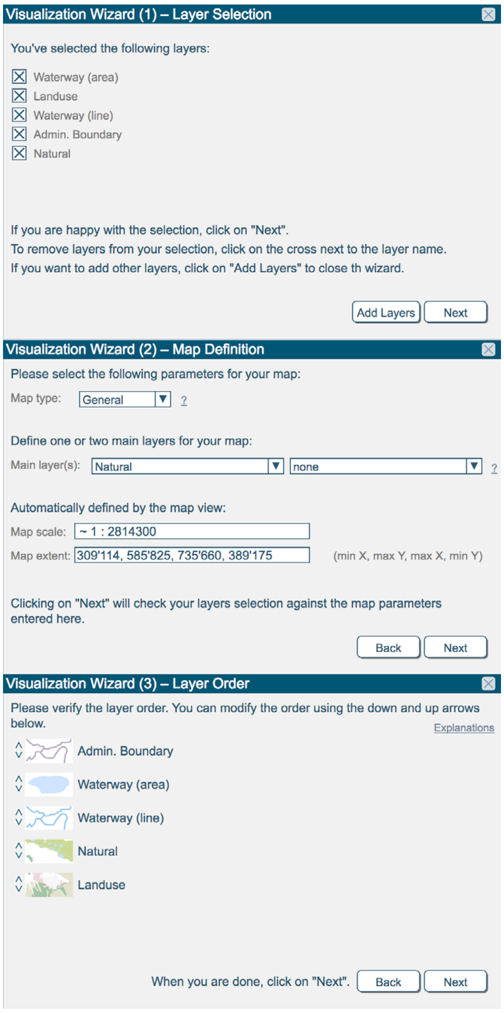

Figure 16. Windows 1, 2, and 3 of the visualization wizard.

the user can verify and adapt the wizard's suggestions (Figure 16, window 3). We plan to provide a wizard mode with sensible defaults and assumptions that does not need user input and can run at once.

5.4. Performance

This implementation within the geoportal allows the layers to be reordered automatically, as well as assigned to the background based on the map type and layer themes. In a further step, the wizard applies a function to render the background information visually less prominent.

The wizard deals with the contextual map model and not directly with the data. Thus, it can quickly process the state of the map and any required improvements. But improvements in the map are limited to symbolization changes.

To further show the potential of this architecture, we tested the time required for reordering layers with this proof-of-concept architecture (i.e. the architecture is, from a performance point of view, not optimized). The more changes required within the order, the more time the functions need. For eight layers, the wizard needs less than 1ms, and for 11 layers it needs 25ms to reorder the layers. We then tested the time needed for generating a new set of styles for 5 layers. It requires 8ms to build the request and then 4.5s for the requests to be treated and sent back as images from the server; the bottleneck here is on the server side.

5.5. *Improvement of map mashups*

The functions implemented so far are a first step toward cartographic support for map mashup. Below we show the automatic reordering of the layers as performed by the wizard using the knowledge base developed in this work (Figure 17). The reordering is optimized to avoid hiding features of one layer below the features of another layer. Additionally, it uses semantic information about the layers to meaningfully re-arrange the layers in the mashups. This helps avoid overlaps, such as lakes above boundaries and land above roads. Moreover, it provides a layer structure that places natural elements on the map first, then man-made ones and finally thematic layers if no other restrictions apply.

The function that checks whether layers and map parameters are compatible only influences the data visualization indirectly by setting restrictions upstream of the design process. This function also sets non-binding restrictions on the use of data at unfavorable scales.

The map and layer parameters combined with the smart functions help detect issues that can negatively impact the readability of the map. For instance, these issues can appear when polygonal layers representing land use and thematic data are combined, leading to overlaps or when the map scale is outside of the scale range of the layer. Other issues detected pertain to the content of the map. The absence of a thematic layer in a thematic map is an example, as is river layer without a layer representing lakes.

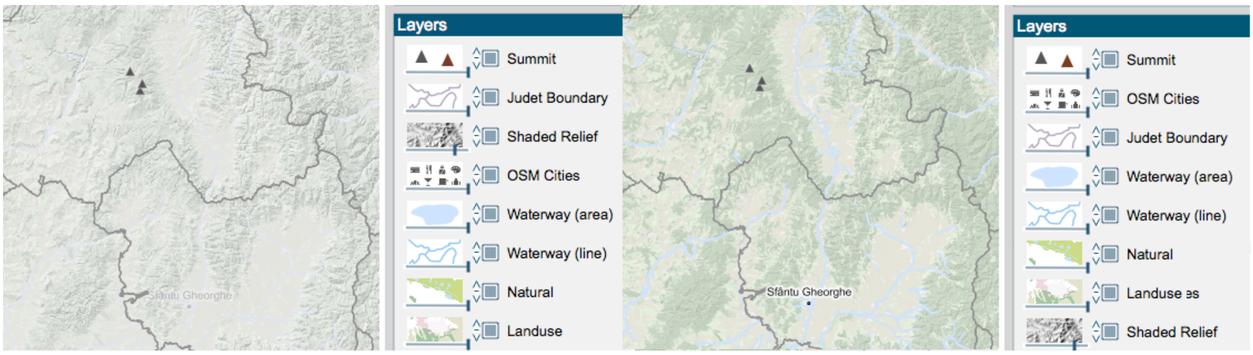

Figure 17. *Reordering of the layers in the mashup (left: before, right: after). Some transparency is added to the shaded relief on the left to show the underlying data on the illustration, originally the relief hid the layers below. Sources: Map data © OpenStreetMap contributors and from Natural Earth and USGS (2008).*

6. Conclusions and outlook

The goal of this work was to develop a framework that can be used to create smart cartographic functions to solve issues in online map mashup. The survey of 21 geoportals, especially the analysis of their content, their cartographic capabilities, and the cartographic conflicts found in their mashups, helped define a framework consisting of a contextual map model, object catalogues, and rules. We then evaluated the framework by implementing it in an existing geoportal and testing the following functions: layer reordering, content compatibility, and new style generation.

The framework definition was successful because it enabled us to formalize cartographic principles and integrate them into a wizard. Moreover, the contextual map model was effective in storing and providing information about the map design problem of specific layer combinations, so that smart cartographic functions could be used to improve the quality of the data visualization. These functions help avoid conflicts due to overlaps between layers and incompatibility of content and scales. Furthermore, we showed how existing functionalities on geoportals could be combined with the framework to create smart cartographic functionalities supporting the users in their map mashup activities.

The smart cartographic functions have been integrated within a workflow that is similar to what the users follow when creating mashups in the geoportal. But additional knowledge and functions have been included from a cartographer's point of view. This compromise should reduce the cognitive workload of the users while supporting the transfer of cartographic knowledge. To determine whether the workflow and knowledge transfer are truly effective, available functions must be extended and a usability study conducted.

Using the implemented functions, we were able demonstrate that a client-side, symbology-based approach to solving cartographic conflicts was not only possible but also quick. However, with increasing complexity of the map design problem speed might become an issue. Because not all functionalities run at the same time and that the user needs time to enter information into the model, optimization is possible. Implementation using different platforms and technologies could lead to variation in performance results.

The separation of the knowledge base from the implementation makes it possible to transfer the framework to other platform environments. For instance, a vector-tiles-based platform would work well with the framework, as it would offer the possibility of styling and re-styling the data on the client-side directly.

Further steps for this research include the optimization and further testing of the constraints; the rules must also be adjusted to guarantee that the logic is robust enough. In addition, the framework should be tested with datasets from another geoportal and the functions pertaining to visual hierarchy and color schemes, that have been defined in the framework, need to be tested thoroughly on the implementation side, especially in regards to the improvement of the map mashups symbolization.

Future areas of research include the optimal integration of the system within the GUI of the geoportal and the evaluation of the optimal approach for transmitting cartographic knowledge. Indeed, even though the framework is open and the implementation outputs the reasoning for each task performed, many open questions still exist regarding the amount and means of communication about each task and result.

Additional work will cover topics such as the required amount of control the user needs, and the potential need for different user profiles. Whether and how user profiles could be added to the contextual map model and be part of the system still requires more investigation.

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8. Detailed survey data

A – Surveyed geoportals

	Name	Country	URL
1	Geo Admin	Switzerland	https://map.geo.admin.ch
2	Portail de Wallonie	Belgium	http://carto1.wallonie.be/cigale/viewer.htm
3	Géoportail	France	http://www.geoportail.gouv.fr
4	Paikkatietoikkuna	Finland	http://www.paikkatietoikkuna.fi
5	The National Geoportal of the Grand-Duchy of Luxembourg	Luxembourg	https://www.geoportail.lu
6	GeoVITe	Switzerland	http://geodata4edu.ethz.ch
7	Spatial Information Portal of Lithuania	Lithuania	http://www.geoportal.lt/map/
8	Geoportal.de	Germany	http://www.geoportal.de/DE/Geoportal/geoportal.html
9	INDE	Brazil	http://www.visualizador.inde.gov.br
10	Bhuvan 2D	India	http://bhuvan.nrsc.gov.in/map/bhuvannew/bhuvan2d.php
11	Andhra Pradesh Geoportal	India	http://bhuvan.nrsc.gov.in/state/AP
12	Geonorge	Norway	http://www.norgeskart.no/geoportal
13	Geodata Sverige bit för bit	Sweden	https://www.geodata.se/
14	Open Geography Portal	United Kingdom	https://geoportal.statistics.gov.uk
15	Geoportal de Chile	Chile	http://www.geoportal.cl/geoportal/
16	Land Information New Zealand (LINZ) Data Service	New Zealand	https://data.linz.govt.nz/
17	Geoportale Nazionale	Italy	http://www.pcn.minambiente.it/viewer/
18	Publieke Dienstverlening op de Kaart	Netherlands	http://pdokviewer.pdok.nl/
19	USGS Geoportal	USA	http://www1.usgs.gov/csas/geoportal/
20	Data.gov	USA	http://catalog.data.gov
21	Geoidea.ro Geoportal	Romania	http://geoidea.ro

B – Cartographic capabilities of surveyed geoportals

	Layer transparency	Print options	Layer mashup	Layer order control	Direct download
1	yes	yes	yes	yes	*no*[a]
2	*no*	yes	yes	*no*[b]	*no*
3	yes	yes	yes[c]	yes	*no*
4	yes	yes	yes[c]	yes	*no*
5	yes	yes	yes[c]	yes	yes[d]
6	yes	*no*	yes	yes	yes[e]
7	yes	yes	yes	yes	*no*
8	yes	yes	yes	yes	yes[f]
9	yes	yes	yes	yes	yes[f]
10	*no*	*no*	yes	*no*[g]	yes[f]
11	*no*	yes	yes	*no*[g]	*no*
12	yes	yes[h]	*almost*[i]	yes	yes[f]
13	yes	yes	*almost*[j]	yes	yes[f]
14	yes	yes[h]	*almost*[k]	yes	yes
15	yes	yes[h]	*no*	*no*	*no*[l]
16	yes	*no*	*no*	*no*	yes
17	yes	yes[h]	*no*	*no*	*no*
18	yes	*no*	*no*	*no*	*no*
19	yes	yes[h]	*no*	*no*	*no*[l]
20	yes	*no*	*no*	*no*	yes[f]
21	yes	*no*	yes	yes	yes
Total	**18**	**15**	**12**	**12**	**11**

[a] Separate portal
[b] Order according to geometries
[c] With login
[d] With login and payment
[e] If authorized
[f] Partially
[g] Order according to the selection order
[h] Minimalistic
[i] Copy–paste WMS links into the interface
[j] Only WMS layers
[k] Limited choices of layers
[l] But REST API available

Smart cartographic background symbolization for map mashups in geoportals: a proof of concept by example of landuse representation

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Paper II

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Abstract

Geospatial data are now widely available to the general public thanks to geoportals and online mapping platforms. However, creating a map involves more than just combining data layers. Thus we develop cartographic functions for geoportals to support better visual hierarchy in user map mashups. This includes a couple of preparatory steps followed by a smart cartographic background symbolization derived from the original layer style. We evaluate different approaches to background symbolization: grayscale, desaturation and smart background. The different background symbolization methods are analyzed with two concrete map examples and evaluated with a survey. The smart background symbolization developed in this work improves the visual hierarchy of the map mashup by reducing the visual importance of the background layers.

Keywords: geoportal, Web cartography, smart symbolization, user map, map mashup, map design

1. Introduction

Thanks to geoportals and online mapping platforms, geospatial data of various kinds and sources are now widely available to the general public. However, creating a map involves more than just combining data layers. For instance, issues can arise when a large quantity of information is displayed on the map or when the content is not appropriately symbolized and organized. Proper symbolization of spatial data on maps is paramount to a successful communication, and thus to the understanding of the spatial phenomenon displayed on the map. The cartographic quality of user-created maps on geoportals and online mapping platform is often low because no trained cartographer is involved in the process (Harrie, Mustière and Stigmar 2011). Therefore, these platforms lack tools that can provide improvements to the map symbology. A major challenge lies in integrating methods and functions that can replicate the work and expertise of a cartographer within these platforms architectures. Geoportals and similar platforms propose pre-defined styles for the standalone layers, but often offer no possibility to adapt the styles once several layers are combined in a user map mashup. Additionally, the users often wish to combine not only data from different sources within the platform but also with their own data, which results in suboptimal data visualization because there is no possibility to change the background symbolization.

Even though methods to solve cartographic conflicts on geoportals have been developed in the past, they offer solutions difficult to implement in other platforms. The reasons that restrict their transfer comprise their specialization, complexity, and requirement for high processing capabilities. The motivation behind this work consists in providing tools that improve the legibility of user maps on geoportals and online mapping platforms. Creating these tools involves developing strategies and methods that solve cartographic conflicts often found in geoportals. This work focuses on conflicts arising from the lack of visual hierarchy in user-generated map mashups and that can be solved by changes in symbology. The tools developed should be general enough to be transferable to other platforms and detailed enough to bring an added-value to the user maps.

First, we review common issues that are linked to the visual hierarchy in map mashups and their potential solutions. Then, we explain the preparatory steps and the background symbolization functions we developed to improve the cartographic quality of map mashups. We show how the functions work with concrete examples from existing geoportal data. Afterwards, we evaluate the results based on an analysis and an online survey. We conclude with reflections on future improvements to the tools and their integration within online platforms.

2. Methodology

To improve the visual hierarchy, we develop a set of rules and assumptions to be implemented within a geoportal. We build on an earlier work that defined a contextual map model and a hierarchical object catalogue for spatial data most found on generic national geoportals. It provides the frame and parameters on which the rules and assumptions can be defined.

First, we collect principles regarding the lack of visual hierarchy and the role of colors in maps. Rules, well-thought assumptions and sensible default values are defined from the collected principles to construct smart cartographic functions. Good default values are essential for users with no or little training in geovisualization (Cartwright et al. 2001). This process is seconded by an in-depth review of best practices and previous work in corresponding topics.

Second, we integrate the different aspects of the rules and assumptions within the geoportal. To mimic the work and reasoning of a cartographer as closely as possible, we introduce a prioritization of the rules, which allow to show the balancing of different, and occasionally contradicting, cartographic principles during the map design process.

To support the evaluation and integration of the functions, we define the persona of a casual online mapmaker (non-professional cartographer), who wants to compose a map, and the corresponding use cases (Figure 1). More specifically, this mapmaker needs a general map for orientation purpose with transportation means as the main theme and at medium scale. The mapmaker wishes to use an alternative solution to the traditional topographic maps or the major online map platforms, which offer too many details (i.e. a large quantity of labels, icons and roads). Thus, the mapmaker decides to use an online geoportal that allows combining individual layers into a map.

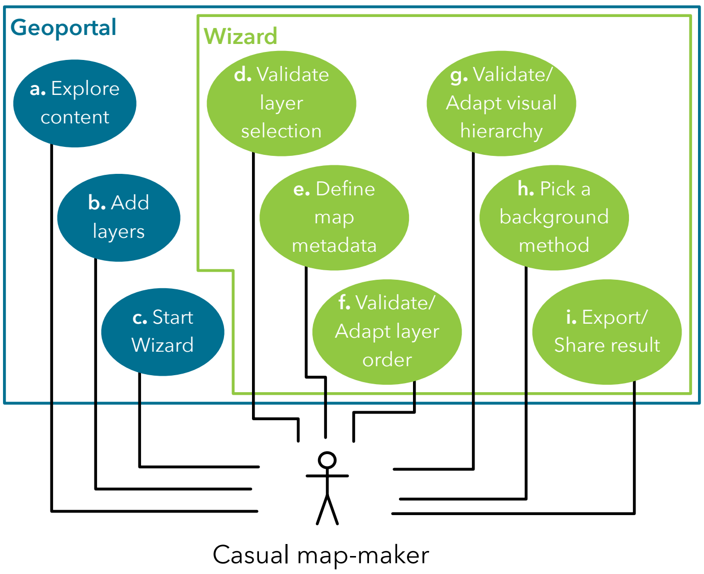

Figure 1. *Casual mapmaker persona and use cases (a.-i.). The main scope is the "geoportal" with a sub-scope "wizard". The geoportal is the main interface for data exploration and selection, whereas the wizard applies the smart cartographic functions (see the section Smart cartographic functions and symbology).*

The developed functions are integrated within the Graphic User Interface (GUI) of the actual geoportal and wizard for testing. We evaluate the resulting map mashups in two ways: (1) a close analysis based on four criteria and (2) an online qualitative survey.

The analysis is based on the ability of each modified color scheme to retain color information, to show contrast within itself, to allow differentiating color classes, and to be combined with a shaded relief.

The online qualitative survey focuses on two characteristics of the modified colors schemes, namely to retain color information and to help differentiate the foreground information from the background. The survey was built using two map examples with similar content but for different geographic locations and different scales. The first task of the respondents was to rank the three different background symbolizations as applied to each map example. Then, they were asked to assess each background symbolization separately in regards to the two characteristics mentioned above. The 21 respondents (4 women and 17 men) are trained cartographers, GIS specialists, and/or working with maps on a regular basis. One-third of respondents designs or makes maps themselves 'very often'; one-third 'often'; and one-third 'sometimes'. Most of them are in between 25 and 44 years old (17); one is younger and three are between 45 and 64 years old.

3. Related work

For a cartographer, providing legible maps represents an essential part of one's work. A legible map shows the spatial phenomenon in a clear manner, meaning that "the user can efficiently interpret the map visually" (Harrie, Mustière and Stigmar 2011). Among other aspects, it involves attributing different levels of visual importance to the map elements to structure the map and help the map reader understand the information. But, map legibility can be reduced when the density of information displayed on the map is too high or when not appropriately symbolized. Removing unnecessary information and keeping only what support the message of the map improve its legibility by eliminating distractions and background noise (Spiess 1970). Similarly, using appropriate symbology supports a clear visual hierarchy within the map.

Providing adequate symbolization of data on geoportals can be challenging because users can combine data however they wish in map mashups, but with little control on symbolization. However, geoportals' capabilities and functionalities have progress in the recent years and offer more complex visualization methods than before and thus should allow to support optimal symbolization for legible map mashups. For instance, standards such as the Styled Layer Descriptor (SLD) have been extended to support diagrams representation and thematic cartography; 3D cartography can also be realized with service-driven approaches; and additional interactive functions supporting customization are now available (Iosifescu et al. 2013). Original work on solving issue regarding the combination of satellite imagery and vector maps on geoportals has been conducted with overlay and blending techniques and relies on an extended SLD standard as well (Hoarau and Christophe 2015).

Many advances on geoportals regarding symbolization are found in the area of expanded customization options and tools to help non-informed users make appropriate choices: for instance, picking a new color scheme can be supported by existing color palettes suggested to the users or map samples (Lafay et al. 2015). Often, these tools are associated with constraints, such as cartographic conventions, contrast constraints and color pattern, that prevent suboptimal options. Finally, semantic metadata and linked data start being used and integrated in geoportals (Hu et al. 2015, Panchaud, Iosifescu Enescu and Hurni 2017) and thus allow the definition of complex cartographic functions relying on the meaning of the data behind the map.

3.1. Visual hierarchy

The concept of visual hierarchy, also called "figure-ground phenomenon" from the Gestalt theory (Ellis 1955), "levels of visual prominence", "visual or conceptual levels" (Robinson et al. 1995), or "visual planes" (MacEachren 1995) pertains to the "perceptual organization" of the map (Slocum et al. 2009). It enables the map reader to perceive a difference between the information that compose the foreground (figure) and the information in the background (ground).

Contrast is crucial to differentiate the base map from the main topic of the map (Spiess 1970). Creating a clear visual hierarchy includes the use of marked brightness contrasts and contrasts at the edges between figures and grounds (Spiess 1970, Dent 1972). A minimal number of two levels should be present in any well-designed map, one for the main topic and one for background information (Spiess 1970). Then, a cartographer can interpose supplementary levels for a finer visual differentiation (Robinson et al. 1995).

For points and lines in the role of figure, making the features darker than the surrounding information is one option. However, for areas, it was shown that using dark and light features was not a sure way to indicate figure or ground (MacEachren and Mistrick 1992, MacEachren 1995). Conventional principles state that background layers should be symbolized in toned-down and lighter colors (Spiess 1970), but Hoarau (2011) showed that a darker background is possible as long as contrast to the other themes is well marked.

As a general rule, large contrasts in brightness and thick lines against thin line are good practices. Dent (1972) mentioned additional ways to provide contrast: contrast of hue, contrast of cold and warm colors, complementary contrast, simultaneous contrast, contrast of saturation and contrast of extension. Simultaneous contrast should be avoided in cartography; whereas saturation contrast helps with the formation of figure and background (Bláha and Štěrba 2014).

An empirical study shows that hue and value impact the perceived contrast between two colors compared to the mathematical contrast (Buard and Ruas 2007). Using a chromatic circle, cartographic experts were asked to evaluate differences in hue and value. For instance, between a red and a pink of the same value, the red appear darker. It was found that neighboring colors on the chromatic circle are not perceived as being separated by equal steps of hue or value. The results of the study allow to recalibrate color contrasts calculation to take into account the perceived contrast between colors.

The literature provides a large body of knowledge to improve map legibility with the help of contrast and line thickness. However, for online on-demand maps, the cartographer is only marginally part of the mapmaking process. Consequently, the quality and legibility of the map created by the users can be much lower (Bucher et al. 2007, Field, O'Brien and Cartwright 2011, Harrie, Mustière and Stigmar 2011). This inference leads to the development of tools to improve the symbolization of online user maps. Color Brewer (Brewer and Harrower 2013) is a well-known example of a standalone tool to help informal, and professional alike, mapmakers improve their color schemes. Other "Brewers" have been then developed to help mapmakers produce better maps, such as the

Type Brewer (Sheesley 2006), the Map Symbol Brewer (Schnabel 2007), the Projection Wizard (Šavrič, Jenny and Jenny 2016), and the OCAD ThematicMapper (Tsorlini et al. 2015).

3.2. Background symbology

Online on-demand maps often have a color-saturated base map and thus they need to be deemphasized when combined with other layers in the foreground. Toomanian, Harrie and Olsson (2012) suggest an approach based on color saturation which involves converting the color from RGB to HSV to decrease the saturation according to pre-defined ranges before reconverting the color to RGB. This approach is combined with a more complex method to solve conflicts of polygon overlapping the base map: transformation of a polygon's fill into a symbol pattern. Strong and saturated colors are chosen to differentiate clearly the polygon from the base map (background). Additionally, polygon borders and the symbols are of the same color to guarantee they are associated with each other. The symbols are kept simple but mimetic, as argued by Robinson et al. (1995) and MacEachren (1995). A further study (Kiik 2015) tested the approach of Toomanian, Harrie and Olsson (2012) against the representation of polygons only with boundaries, with a transparent fill, or with hatches. This eye-tracking study shows that the preferred map design is the transparency solution, which is also the most efficient method for polygon identification (followed closely by symbols and hatches).

When the different aspects of cartographic design mentioned above are not taken into account, this leads to lower map quality and legibility. The most impactful types of errors are "incorrect usage of cartographic representation method […], visual and/or dynamic variables […], semantic and pragmatic error" (Bielecka and Dukaczewski 2009). Other studies show that poor cartographic visualizations can confuse the users (i.e. map reader) (Jenny et al. 2010), prevent the optimal use of geoportal or similar online cartographic environment (He, Persson and Östman 2012), and decrease map legibility (Huang and Gartner 2012).

For all the above-mentioned reasons, providing symbolization tools improving map legibility for online mapping platforms support a broader purpose than just appropriate symbology; it also facilitates a more efficient map communication process and use of the online platform.

4. Preparatory steps

This section explains the preparatory steps that are performed before applying a method to improve the background symbolization of the map mashups.

Data in geoportals are often organized in different map products or topics. In the geoportal used to test the functions, the user can select and combine any layers from different map products and add them to a "user map" (see use cases a. and b. – all use cases refer to Figure 1). Then, the mapmaker must start the wizard (use case c.) to benefit from the cartographic functions. Once the wizard has started, the mapmaker validates the layer selection (use case d.), enters metadata about the map via drop-down menus (use case e.). At this point the wizard applies the first preparatory step, namely the content constraints. Then, the second preparatory step of the wizard re-orders the layer appropriately. Finally, the mapmaker validates or adapts the layer order, if the specific layer combination is not ordered optimally to the mapmaker's opinion (use case f.). These preparatory steps are based on a framework defined in a previous work and rely on semantic annotations attached to each layer (for details, see Panchaud, Iosifescu Enescu and Hurni 2017).

4.1. Content constraints

Geoportals and other map mashup platforms often allow the users, i.e. the mapmakers, to combine any data layer with any other ones. Although this gives users a greater freedom of exploration, it can lead to awkward cartographic visualization as a combined map. Thus, in the first preparatory step, a function analyses the layer selection with the map parameters and informs the users of poor or unadvised combinations. It is based on a careful evaluation of the data topics available on public and state geoportals and of the relation of the map content to the map types.

Layer list

Layer combinations that are highly improbable raise warnings based on the layers' respective categories and themes. For instance, the selection of rivers without the presence of lakes will raise a warning. The layer categories and themes give semantic information about each layer content. Layer categories provide a broad distinction, such as natural or man-made elements, whereas the layer's themes are more detailed, e.g. indicating whether a layer contains transportation information or hydrological features.

Map types

So far, the framework offers four map types: general-purpose map, physical map, political map and thematic map. We differentiate four relations between a layer and a map type: for a certain map type, the layer can be "a must", "allowed", "not allowed", or "allowed but with warning" regarding its potential inappropriateness. The matrix found in Figure 2 details these four relations based on the map types and layer categories, with additional conditions pertaining to the layer themes and categories. For instance, on a physical map, there must be at least one layer of category "natural" and theme "water", as well as at least one natural layer with a theme different than water; a cultural

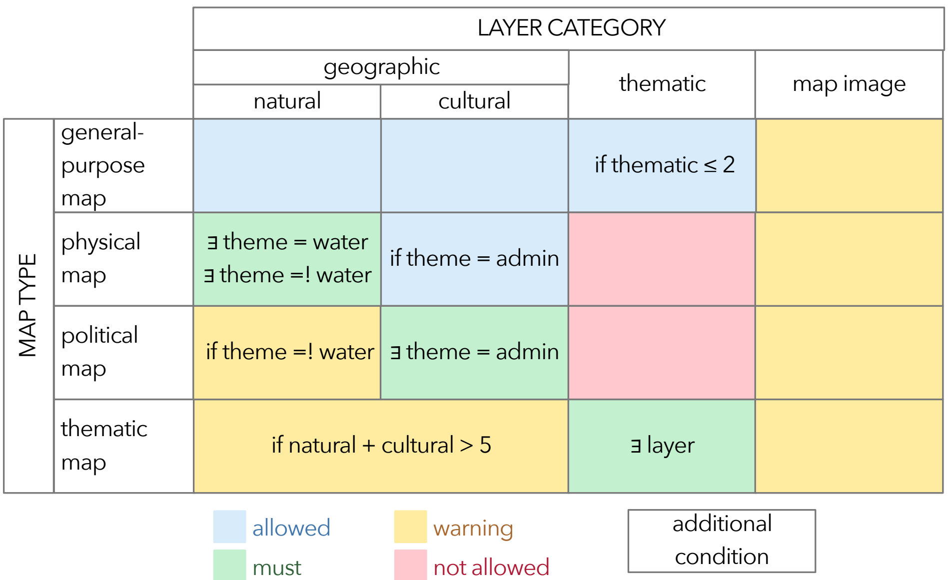

Figure 2. *Compatibility of layers with different map types, according to layer categories and themes.*

layer is allowed if the theme is administration; and thematic layers are not allowed. A layer that is already a map in itself (e.g. scanned topographic map) is difficult to combine with other layers and thus raises a warning.

4.2. Layer order

The second preparatory step deals with the re-ordering of the layers from the user-random order to an optimal one. The rules are simple, but they show interesting aspects of the reasoning process behind cartographic principles.

A cartographer balances the general cartographic principles with the specificity of each map. However, formalizing this flexible reasoning process within a function is complex. Thus, when implementing the function, this balancing translates into rule prioritization.

In the case of the drawing order of layers, the general rule requires to draw first polygon geometries on the map, then line geometries, and finally point geometries on top to ensure that all can be displayed properly. Additionally, more specific rules depending on the type of maps and layer content can be derived from the body of cartographic knowledge; for example, to deal with the drawing order of layers with the same geometry type. There also exists exceptions and special cases. A typical example is the issue of rivers drawn as centerline through the lakes (for modeling reasons) as seen in Figure 3. As long as both are represented with the same color and the lakes do not have a stroke for their contour (a), the order does not matter much. But as soon as a more complex symbolization is used (b), issues of unwanted overlaps appear. It can be corrected by setting the rivers below the lakes (c) and thus contradicting the general rule.

The function is split into two different pipelines based on whether two layers have the same geometry type or not (Figure 4). In pipeline 1 (different geometry types), the high-priority rules regarding the layer themes check whether exceptions exist to the general geometry rules, which have a lower priority.

In pipeline 2 (same geometry type), high-priority rules determine which layer should be above which based on layer themes. If the combination matches none of the high-priority rules, medium

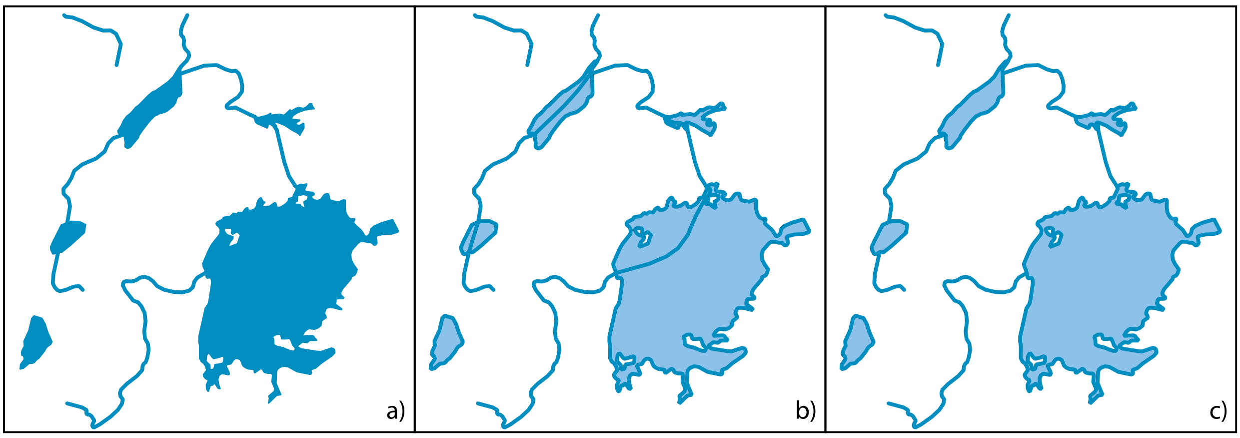

Figure 3. *Rivers, lake centerlines, and lakes, a question of layer order: a) same stroke and fill color = no conflict, b) and c) different stroke and fill colors = the layer order matters.*
Source: Made with Natural Earth data.

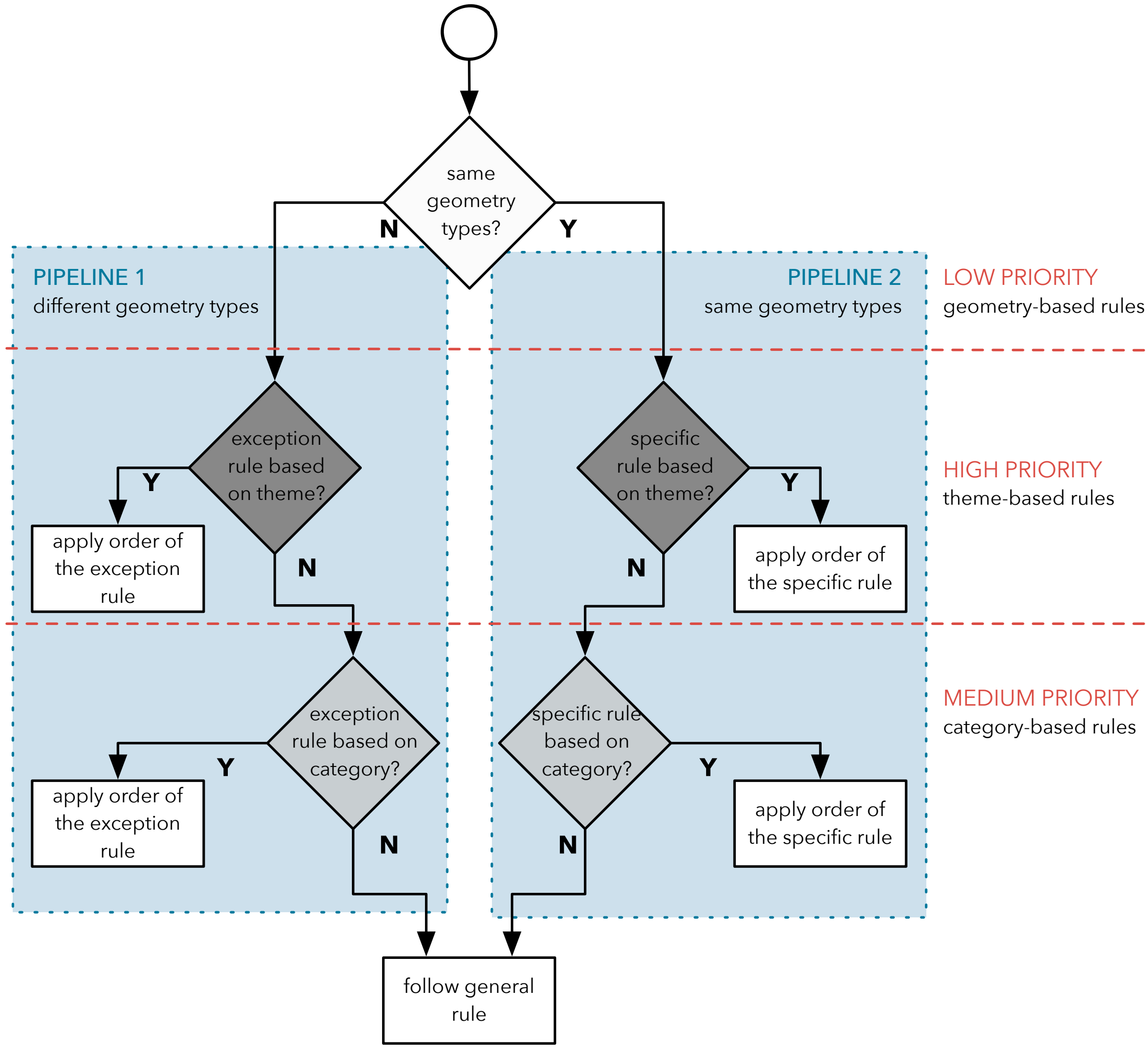

Figure 4. Pipelines for the drawing order of the layers.

priority rules based on the layer categories are applied. And if none of those can resolve the layer order, the initial order stays. With this structure, specific cases are verified first and are not run through lower priority rules. The priority of the rules depends on the specificity of the rule. The more specific semantic content the rule has, the higher its priority (Figure 5).

Figure 6 and Figure 7 present two examples of layer reordering as implemented in the geoportal. At this point, the mapmaker can validate or adapt the layer order (use case f. in Figure 1) The first one deals with a topographic-like map mashup. Layers containing landcover and forest are moved

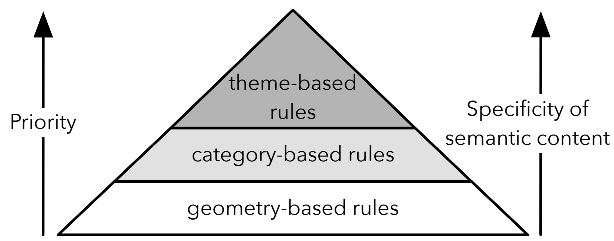

Figure 5. The more specific semantic content is present in the rule, the higher is the rule priority.

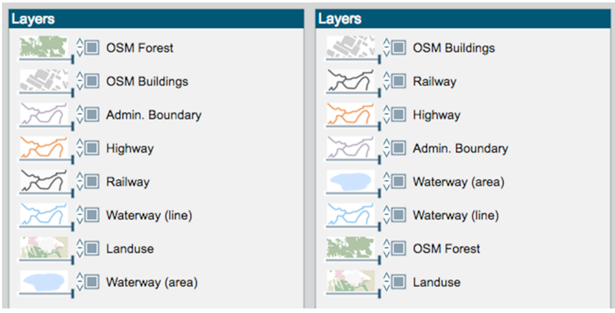

Figure 6. *Before (left) and after (right) reordering. The administrative borders are above the rivers, but below the other line layers; the water polygon layer (lakes) is above the rivers.*

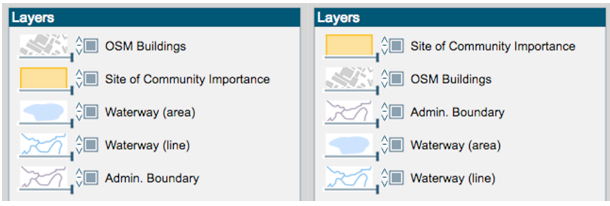

Figure 7. *Before (left) and after (right) reordering. The thematic layer is on top.*

to the bottom; the administrative borders are above the rivers, but below other line elements; the water polygon layer (lakes) is above the rivers. The second example has a thematic layer "Site of Community Importance" supported by other layers for spatial context (Figure 7). The thematic, and main layer of the map, is on top, while the supportive layers are ordered optimally.

5. Smart cartographic functions and symbology

Once the preparatory steps have been accomplished, the original symbology can be adapted. The cartographic body of knowledge consists of principles, which are not strict rules, and of subjective aspects, which are left to the cartographers. Thus replicating the decision-making process of a cartographer with a set of functions requires not only a precise and accurate understanding of the map design process but also well-reasoned assumptions and sensible default values. Only so, the functionality can efficiently support the casual mapmaker. The function described below works in a two-step manner. First, the layers are assigned to different visual levels within the map; then, the symbolization of the background layers is adapted to improve contrast with the foreground.

5.1. Visual hierarchy

The visual level of each layer is determined using information provided by the user and by the geoportal regarding the map and the layers. Three different visual levels are used: background, middle ground, and foreground. It allows a finer differentiation than using only background and foreground but does not render the function unnecessarily complex. Information taken into account to assign layers to a visual level are the layer geometry types, the layer themes and categories, the map type and the main layers of the map.

In a first round, a set of general rules assigns the main layers of the map to the foreground. Then, based on assumptions, they assign the layers that have a high probability of being in the background, such as satellite imagery or shaded reliefs. The rest of the layers are temporarily assigned

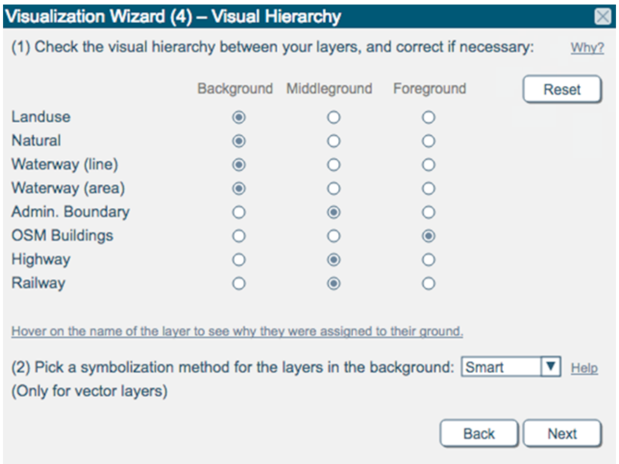

Figure 8. *In step (1), the mapmaker can adapt the visual hierarchy (use case g. from Figure 1); in step (2), the mapmaker can pick a symbolization method for the background (use case h. from Figure 1).*

to the middle ground. In the second round, specific rules fine-tune the position of the layers in the different visual levels. For instance, all thematic layers in a thematic map or the administrative boundaries in a political map are set in the foreground.

Because the function is built to assume the most probable solutions, it cannot anticipate all possible solutions and thus, once all the layers have been assigned, the user still has the possibility to correct the visual level assignment (use case g. in Figure 1). Figure 8 shows in step (1) the integration of the use case in the wizard GUI.

5.2. Background symbolization

This section presents the three methods for background symbolization that are later analyzed and assessed in the survey to evaluate their suitability for background symbolization.

Grayscale

Geoportals, e.g. Géoportail[1] and Map GeoAdmin[2], and map platforms, e.g. MapBox[3] and Google[4], sometimes offer a grayscale version of the default symbolization. Even though this is a rudimentary approach, it does visually lessen the importance of the layers. The Red-Green-Blue (RGB) color space model, which is used by screens, is used for this transformation. Using the luminance channel for color-to-grayscale transformations produces satisfactory results for most cases in a fast and efficient manner (Zemko and Sikudova 2016). Several similar coefficients (ITU-R 2011, 2015, World Wide Web Consortium W3C 2016) can be used to calculate the luminance from RGB depending on the original color space and the presence of gamma correction (Bradley 2014). Because we are not encoding images and video for transmission and the differences are negligible in our case, the simplest version (Equation 1) was used in this work in order to speed up the processing. Alternative methods could be the average or the full desaturation of the RGB values (Equations 2 and 3). From the R, G, and B values we calculate a new g value which is then used in the RGB triplet in order to create a gray tone using RGB(g,g,g).

1 Géoportail France from IGN. http://www.geoportail.gouv.fr accessed on 28.07.2016
2 Map GeoAdmin from swisstopo. https://map.geo.admin.ch accessed on 28.07.2016
3 MapBox and its Mapbox Light style. https://www.mapbox.com/maps/light-dark/ accessed on 28.07.2016
4 Google Map style from Snazzy Maps. https://snazzymaps.com/style/15/subtle-greyscale accessed on 28.07.2016

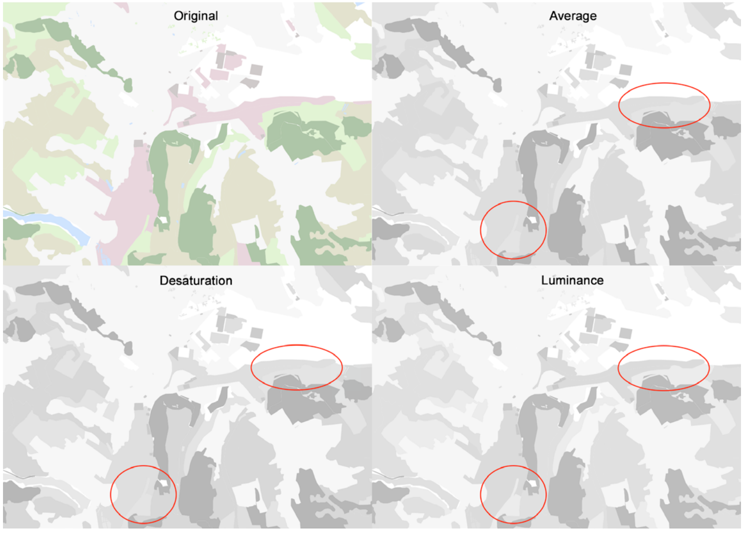

Figure 9. Comparison between the different grayscale methods. Red circles point to differences. Source: Data © OpenStreetMap contributors.

The method "Luminance" gives a slightly better result for background because the contrast between the different colors is softer than with the full desaturation method while better preserving distinction between the original colors. Nevertheless, the three methods result in visually very similar images (see the red circles in Figure 9 for some differences).

"Luminance" $$g=Y=R\cdot 0.3+G\cdot 0.59+B\cdot 0.11 \quad (1)$$

"Average" $$g = ((R+G+B))/3 \quad (2)$$

"Full Desaturation" $$g = (Max(R,G,B) + Min(R,G,B))/2 \quad (3)$$

With R= red value; G = green value; B = blue value; Max(n) = maximal value among n; Min(n) = minimal value among n; g= value for gray tone.

Desaturation and smart background

As background style transformation, we test also another approach based on the suggestion of Dent (1999) regarding greater contrast between figure and ground information: because most standalone layers are styled as figure by default, they require to be modified into a visually more subtle style to work as background. By increasing the saturation contrast between layers, the figure-ground relation is better rendered (Bláha and Štěrba 2014). To decrease the saturation, the original RGB color must be translated into another color space, e.g. the Hue-Saturation-Value (HSV) or the Hue-Saturation-Lightness (HSL). We use the HSL model because a change in saturation in this model keeps the lightness constant, whereas it is not the case for the HSV model. Then, the S value can be reduced accordingly, here of a 0.4 factor (Equation 4).

"Desaturation" $$S' = S\cdot 0.4 \quad (4)$$

However, only decreasing the saturation as done by Toomanian, Harrie and Olsson (2012) is not enough. Increasing luminance differences is another mean to differentiate foreground from background information (Stauffer et al. 2015). Relative luminance, often only called luminance in the context of color spaces, is defined as the photometric luminance values normalized to 1, or 100, for a reference white (ITU-R 2015).

To modify the colors, we use the Lightness Chroma Hue (LCH) color space so as to use the chroma and not the saturation parameter. The LCH color space is derived from the CIE Lab one. Even though often used interchangeably, the terms saturation and chroma are slightly, but crucially different in their definition. Saturation is the "colorfulness of an area judged in proportion to its brightness" (Commission Internationale de L'Eclairage (CIE) 2011) , whereas chroma is the "colorfulness of an area judged as a proportion of the brightness of a similarly illuminated area that appears white or highly transmitting" (Commission Internationale de L'Eclairage (CIE) 2011). The (relative) luminance of vivid colors from the RGB, HSV and HSL spaces are highly discontinuous: a pure red or a pure green (saturation 100%) is not perceived with the same lightness. This means that linear changes in saturation are not perceived as linear changes by the human eye; whereas the HCL color space is based on how the human perception works and change in chroma is perceived linearly by the human eye in terms of lightness (Stauffer et al. 2015). Additionally, LCH is device independent (Cruse 2016).

The more chroma we remove, the more the colors tend toward a grayscale. We can use other parameters such as the luminance and lightness to further de-emphasize a color scheme without removing too much chroma.

The function to reduce the visual prominence of layers in the background operates in three steps. First, the luminance values of the different colors of the layers are reduced to a smaller range toward higher value (= toward white). This reduces the relative differences in brightness overall and thus there is less contrast within the layer itself (Equation 5). Second, the color lightness is increased to prevent colors from turning too much toward a grayscale and from producing darker colors (Equation 6). Third, the chroma values are slightly reduced to avoid too saturated colors that would attract too much attention (Equation 7).

The two first steps aim at keeping the relative difference between colors, while reducing the absolute value differences. The chroma reduction uses a power function, which can change according to other parameters of the map and layer combinations, such as a transparency requirement. Moreover, a generally more saturated color scheme is altered more prominently.

Step 1: $$Lum' = max_{Lum} - [p_{Lum} \cdot (max_{Lum} - Lum)] \tag{5}$$

Step 2: $$L' = z \cdot (max_L - [p_L \cdot (max_L - L)]) \tag{6}$$

Step 3: $$C' = y \cdot (C^{P_C}) \tag{7}$$

With $p_{Lum} = 0.6$; $p_L = 0.6$; $p_C = 0.7$, *which are the calibrating parameters;*
Lum', L', and C' are the value for luminance, lightness, and chroma for the new color;
Lum, L, and C are the value for luminance, lightness, and chroma or the original color;
max_{Lum}, max_L, max_C *are the maximal luminance, lightness, and chroma of the original color scheme; y and z are adjustment coefficient in case of transparency.*

The parameters result from a calibration process testing a range of values with two different color schemes, one being already close to satisfying background conditions and another one consisting of saturated colors. The goal of the calibration is to avoid gray colors (except for initial gray), to keep a large enough range of chroma or saturation so that color of similar hues can still be differentiated,

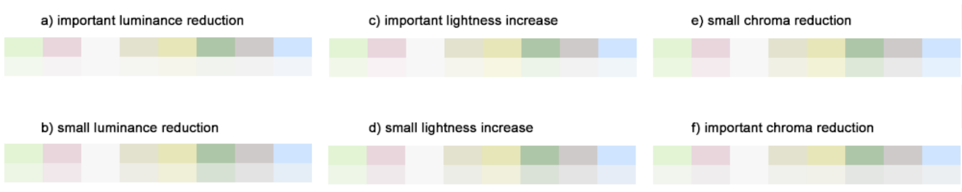

Figure 10. Variation based on the different parameters for a color scheme belonging to a land use layer. For each pair of color scheme lines, the top line of colors is the original color scheme and the bottom line is the modified one.

and to prevent a feeling of grayish color scheme. First, we tested the function with color scheme "lines" (Figure 10) and then moved to actual map examples (Figure 11 and Figure 12).

For map examples, we use landuse or landcover background with hydrological features and roads. Depending on the layer combination, an opacity parameter is integrated to the function; e.g. when there is a shaded relief combined with a landuse layer or more generally when polygon layers and raster data are used together in a map. Because adding transparency reduces the fullness of the color, the reduction of chroma and lightness are dependent on a coefficient (y and z in the Equations 6 and 7). When the layer opacity is full, the coefficient is 1; when the layer needs some transparency, the coefficient is reduced, leading to smaller variations from the original color.

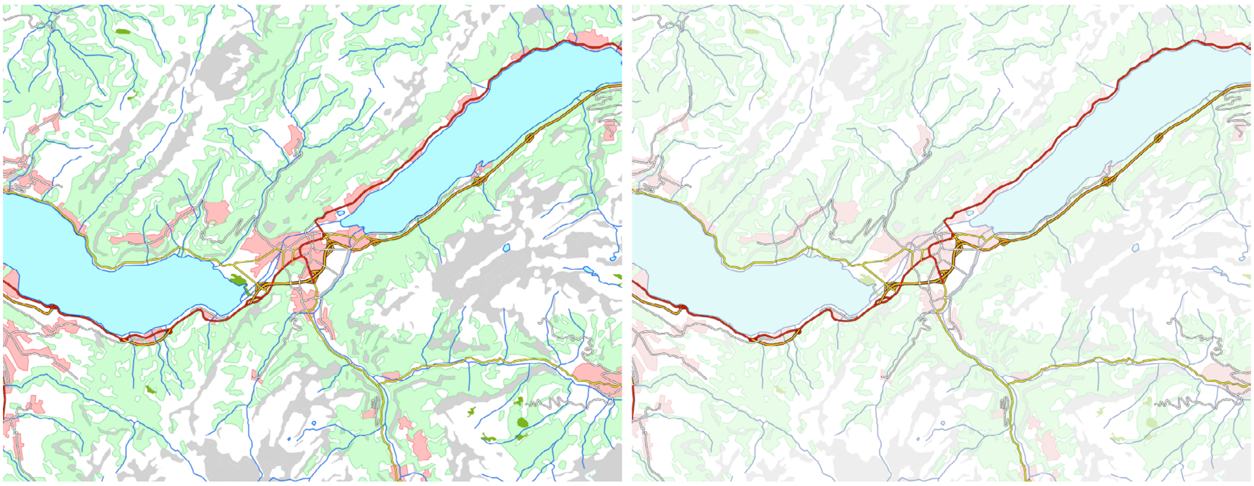

Figure 11. Original (left) and modified (right) map background.
Source: Data © 2016 swisstopo (JD100042).

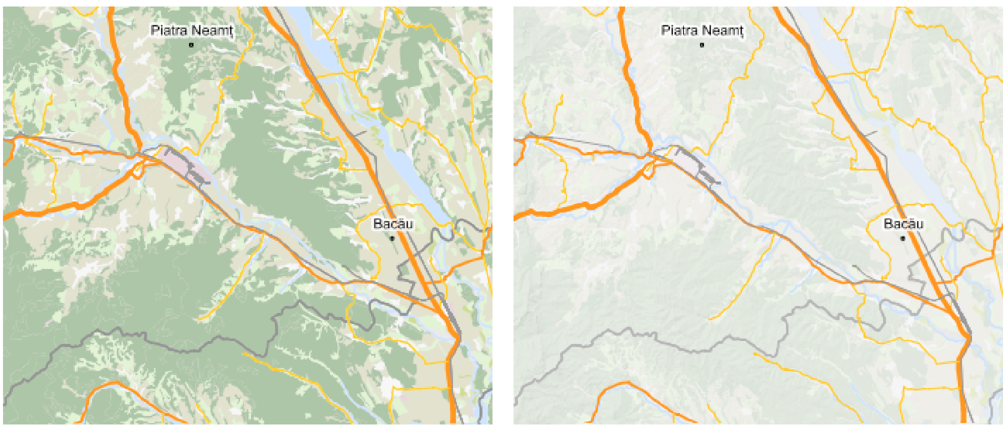

Figure 12. Original (left) and modified (right) map background.
Source: Data © OpenStreetMap contributors.

6. Results and discussion

We compare the grayscale, the desaturation and the smart background methods with the original maps and with each other in two map examples. To this end, we not only analyze in detail the resulting map visualizations, but we also conduct the survey described in the *Methodology* section. The illustrations used for the analysis and the survey can be found in Figure 13 and Figure 14.

6.1. Analysis

Grayscale

The grayscale method renders the symbolization less prominent and it is practical because simple to implement, but it has drawbacks. If there are too many colors (starting at 7 or 8) in the original scheme, it becomes difficult to differentiate them on a grayscale. When the original color scheme consists of light colors already, it can render the differentiation between the resulting shades of gray even more difficult. Furthermore, the same linear transformation is applied, no matter of the characteristics of the original color schemes: there is no subtlety in this method. Two original colors differing in perceived brightness can be transformed into the same gray with this method, which is problematic for differentiation. True grayscale maps are specifically designed and not a mere

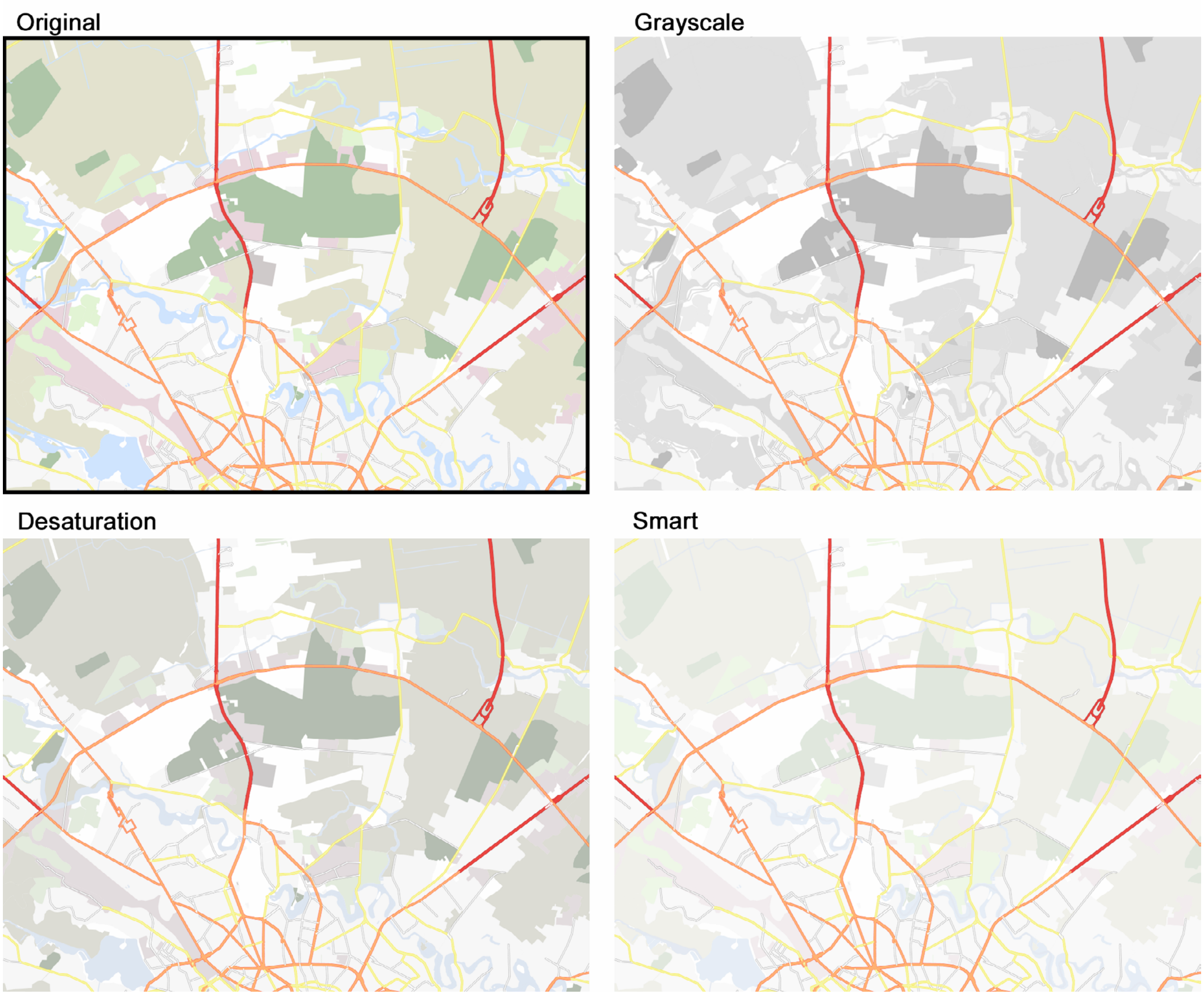

Figure 13. *Map example 1.*
Source: Data © OpenStreetMap contributors.

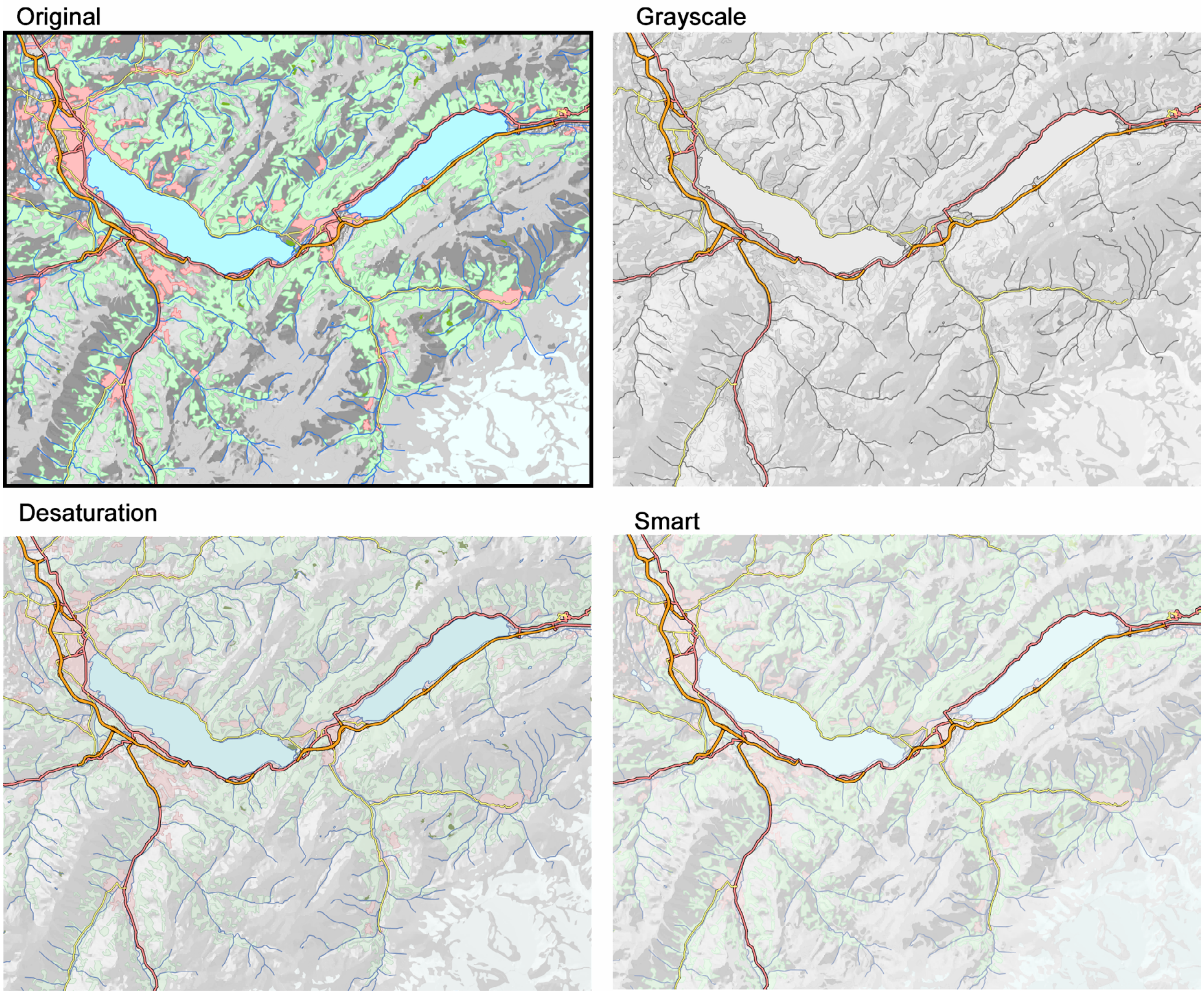

Figure 14. Map example 2.
Source: Data © 2016 swisstopo (JD100042).

transformation of a colored counterpart. Additionally, this method is not appropriate to combine with a relief because the grayscale of the background layer cannot be distinguished from the shaded grays of the relief.

Even with numerous drawbacks, the grayscale method can be better than the original symbolization for certain map purpose because it lessens the visual importance of the background layer and thus improves the figure-ground relation.

Desaturation

The desaturation method is simple in the sense that it reduces the saturation value in the HSL color space. Depending on the value of this coefficient, the final result comes closer to the grayscale or to the original color scheme. The coefficient chosen is 0.4 and gives satisfactory results with original bright color schemes. The results with lighter original schemes (e.g. Map 1) are satisfactory as well if it originally had contrast within its color schemes. For both map examples, it is still possible to clearly differentiate the classes of the initial color schemes and it provides a better contrast with the foreground than original symbology. However, combining the desaturation method with a relief background yields a grayish and darker map background.

Smart background

The smart background method we develop here shows more promises. We tested and calibrated the method with color schemes showing different characteristics: from already pastel tones to much darker and saturated color schemes. Compared to the grayscale alternative or a simple reduction of saturation (or chroma), the smart background method as presented here shows several advantages.

First, the function keeps the color information of the original schemes, although modified: there is a smaller loss of information from the initial scheme. Second, the function uses different parameters that take into account the overall scheme and not each color separately. The function reduces the contrast within the layer itself while tuning down the intensity (i.e. chroma) of the color scheme. Because of changes in luminance, the resulting color schemes is not as grayish as the one with the desaturation method and works better with a shaded relief in the background.

However, the method, as implemented so far, cannot anticipate strong simultaneous contrast resulting from the transformation. Additionally, if a darker color is present in the original scheme, it might still offer significant contrast to the rest of the scheme. Finally, color-blindness was not taken into account while developing this approach.

One common aspect to these three methods is that the symbology changes are based on the color scheme of the layer it is applied to and not yet in relation to the color schemes of other layers within the map mashup.

6.2. Survey results

The first part of the survey asks to rank the three background styles according to how supportive the 21 participants find them for a specific scenario. The scenario is as follows:

> Imagine you want to create a map for orientation purposes with the main topic being the roads. Imagine you wish to provide this map to your friends for your birthday party (the location is not on the map examples, since it is not important for this survey). As you are sending online invitations, you went to a geoportal to create this custom map.
>
> Now the geoportal offers three methods to transform the background information of the maps, so that the roads are better highlighted.
>
> Please tell us which one you would choose. You need to evaluate whether the background style helps render the map more legible. For your purpose, this means that the new style helps better differentiate the roads from the background, while still retaining information about the landscape.

For both Map 1 and Map 2, the method “Smart background” is preferred, although the preference is stronger for Map 2 (Figure 15). Issues mentioned in the comments concern the lack of contrast for this method in Map 1 and the original style in Map 1 being already “easy to interpret”. The original style of Map 1 has light tones and thus is already rather suitable for the background. Regarding Map 2, the “Smart” method is never ranked third, the two other methods being ranked similarly. The original color scheme of the background is more saturated than in Map 1 and it is combined with a relief, which might explain why the end result is better ranked in the survey.

In the second part, two statements comparing the original maps with one method at a time are evaluated. The first one asks whether the modified style retains information about the landscape in the background and the second one whether the modified style helps better differentiate the roads from the background. Figure 16 shows the results per statement and map, whereas Figure 17 aggregates the results per method.

In both Map 1 and Map 2 with the method "Grayscale", the respondents disagree with the statement regarding landscape information retainment: 57% , resp. 58% of negative opinion for Map 1 and

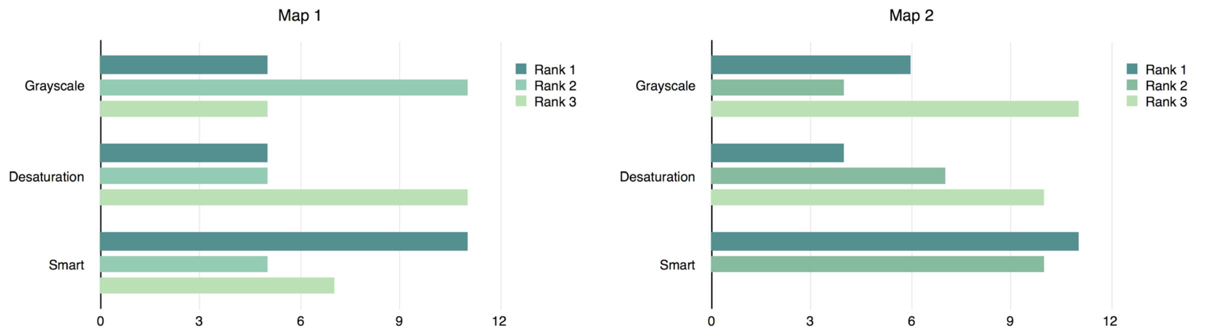

Figure 15. *Rank the three background styles according to how supportive you find them for the scenario (1 = most supportive, 3 = least supportive). Number of respondents for each ranking and method (n=21).*

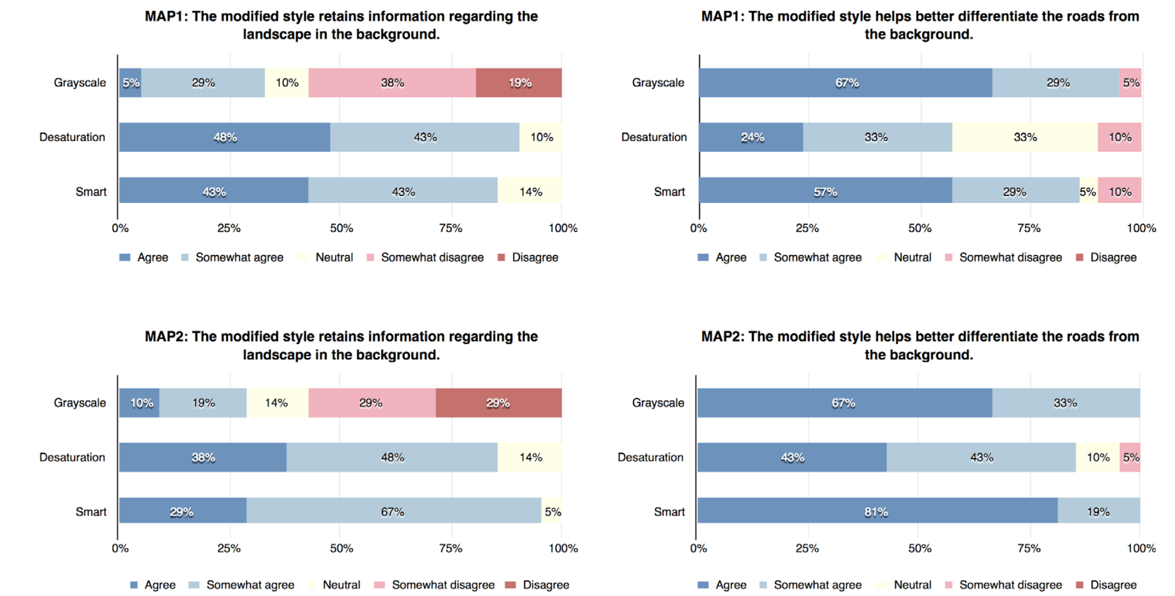

Figure 16. *Results for each map, per statement (in percentage of the respondents).*

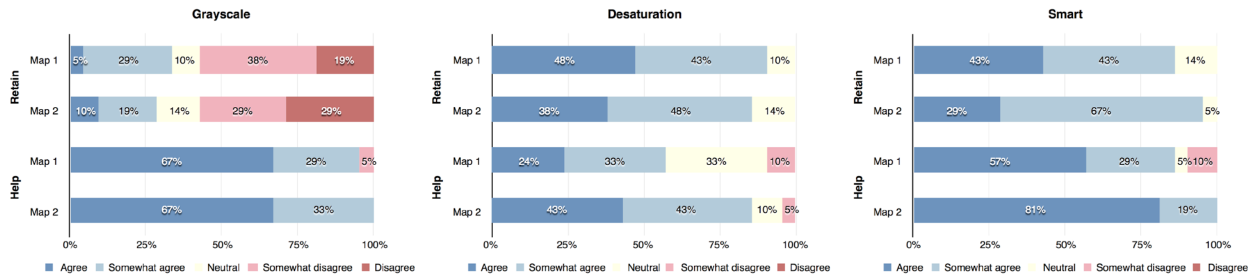

Figure 17. *Results for each method per aspect and map (in percentage of the respondents).*

Map 2 (Figure 17). However, they agree that this method helps differentiate the roads from the background (96% for Map 1 and 100% for Map 2). Comments include the fact that if it is only for the road network, it is acceptable, but if the map user care about the location as well, then too much information is lost.

For the method “Desaturation”, the respondents find that the modified style of Map 1 and Map 2 retain the landscape information in the background (91% and 86% of combined agree and somewhat agree). They are diverging opinion whether it helps with the roads differentiation in comparison to the previous method. Even though the numbers are slightly positive, this method scores less than the grayscale method on the same question. Some respondents mention the “unconventional” or “disorienting” colors that still interfere with the roads layer, whereas some state that they like having colors in the background while still providing better contrast.

Finally, regarding the method “Smart” developed in this work, both aspects of the modified styles receive positive answers from the respondents. They agree that the modified color schemes retain information at 86% in Map 1 and 96% in Map 2. Moreover, they agree that it helps distinguish the roads at 86% in Map 1 and 100% in Map 2. A couple of respondents disagree with the roads differentiation aspect for Map 1: one reason stated is that roads without outlines are more difficult to differentiate from the background. In the comments, there are six mentions of the roads being clearly visible or that this method is the best for the roads differentiation. A couple of respondents mention that it is their favorite style. However, three comments mention that the style looks “washed out”, “dim”, and “weak”. Color perception and personal preferences can vary among the end users, which might explain diverging opinion. Another respondent suggests that a style in between the “Desaturation” and “Smart” would be best. The respondent did not know the name of the style or how they were generated. This would indicate that the chroma parameter has been reduced too much in the “Smart” method. Thus we tested the parameters of the smart function a second time to generate a style that looks less washed out with pastel color schemes while still reducing strongly saturated color schemes to a background style. We modified the pL and pC parameters to 0.8 and respectively 0.6 instead of 0.6 and respectively 0.7 as originally planned. The Map examples 1 and 2 have been re-generated with the new parameter values (see the resulting maps in Figure 18).

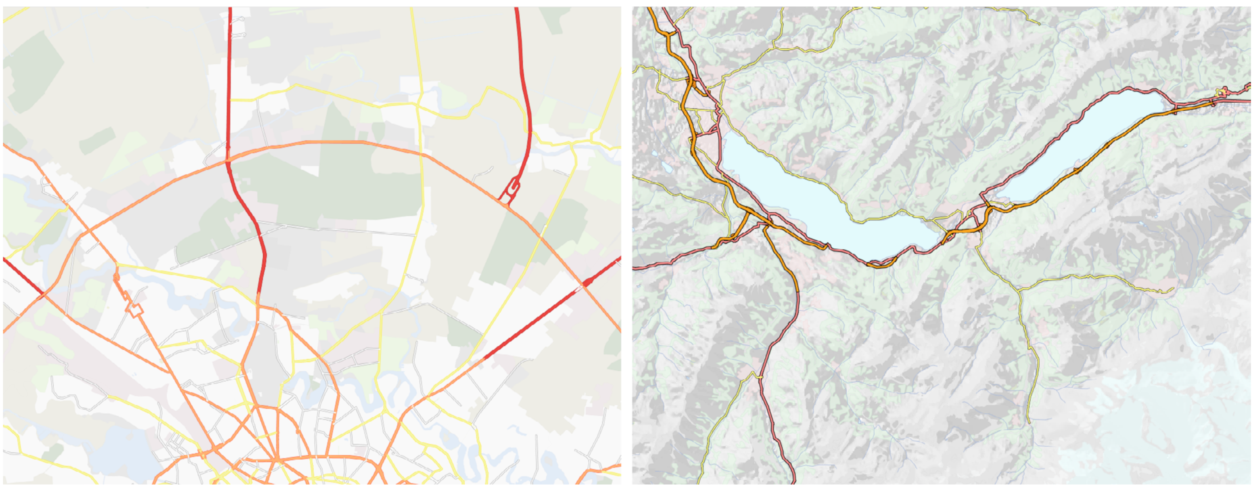

Figure 18. *Post-survey map examples, Map example 1 (left) and Map example 2 (right).*
Source: Data © OpenStreetMap contributors (left) and data © 2016 swisstopo (JD100042) (right).

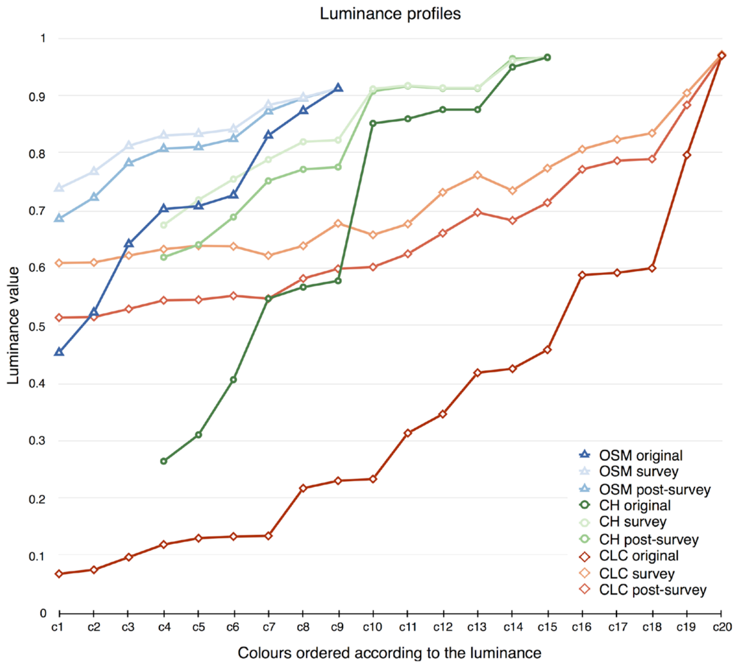

Figure 19. Luminance changes from original, to survey version, to post-survey correction.

Figure 19 shows the luminance curve of three color schemes: Map example 1 (=OSM), Map example 2 (=CH) and a color scheme similar to the CLC Urban Atlas standard colors. The luminance of each color schemes has been calculated for the original scale, for the formula used in the survey and for the modified post-survey formula. We can see that the new parameters lead to a less drastic change in luminance.

In all three methods, the respondent noted that the yellow roads were not well distinguishable from the background. The roads styles were designed to mimic the existing roads color schemes of the original data, but from the survey it becomes clear that yellow roads with no clear outline is are less than an optimal design choice.

7. Conclusions and outlook

This study proposes a new approach that integrates cartographic principles to improve the symbolization of background layers in map mashups in geoportals. We present a couple of preparatory steps and several methods (two existing and one novel) to modify the symbolization of background layers. The symbolization changes are preceded by preparatory steps that optimize the drawing order of the layers and constraints the map content. Then, we analyze the strengths and weaknesses of each method. The analysis is supported by an online survey realized among professional or trained cartographers. The analysis and the survey show that it is possible to improve background style in order to better support the main theme of a map mashup.

The new method developed in this work improves the map mashup in comparison with the original styles, even though it works better for some combinations of layers than others. This functionality can be useful for geoportals where diverse actors publish large amounts of spatial data without a central overview regarding color scheme and data combinations. Different institutions can have different standards for color schemes and the smart background method helps combining data from different sources in legible map mashups.

Professional cartographers and the production of high-quality maps are not the target of this functionality and they will keep relying on complex decision-making processes, experience and more intricate tools: it does not mean that there should not also be simpler but nonetheless usable and useful tool for the casual cartographer.

There are still areas of improvement and possible evolution for the smart background method. With original styles in light tones, the method seems to produce a background style that is too light or washed out. A new calibration parameter for light tones has been provided after the survey. However, one could also test whether to offer users the option to tweak the parameter themselves in a restricted range, for instance via sliders so that they can compare themselves how the smart background style changes with the parameters. Quite popular are also dark base maps and thus a future development of the functionality could be to propose a similar transformation of original styles. Additionally, so far the styles modification function only takes into consideration the color scheme of the background layer itself. In the future, statistics about the lightness, saturation, and general hue of the main layers of the map could be integrated as parameters in the transformation. This would allow to estimate the interplay between fore- and background layers and eventually calibrate the function parameters.

Generally, providing cartographic functions and symbolization improvements, that are based on cartographic principles, for map mashups on geoportals encourages and supports the re-use of the data available. Indeed, additional functions that allow for proper cartographic visualization (and not just a simple combination of layers) can serve to attract users and can be used to promote geoportals among the general public as more than an online storage for spatial data.

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IV Opening up cartographic knowledge

Sharing cartographic knowledge with the crowd: on the complexity of cartographic rules

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Paper III

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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 mapmaking 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 mapmaking process opened up to a wider audience, which thus is often referred as neogeographers. As explained by Haklay et al. (2008), the mapmaking 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). 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 mapmaking. 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 geoportals 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 require 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 1960s (Jan et al. 2009). Models for the formalization of cartographic knowledge abound-ed and their comprehensive integration in expert systems has been attempted (Hutzler and Spiess 1993, Forrest 1999, Jan et al. 2009, Xiao and 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 achieved, 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 and its siblings MapSymbolBrewer and TypeBrewer) for the production of 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 and Hurni 2007, Xiao and Armstrong 2012, Smith 2013, Penaz et al. 2014). The different models suggested in the above-mentioned papers focus on explicitly declaring cartographic concepts on a semantic level, defining their relationship and imposing restrictions on those relationships (Lemmens 2008), 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), or
- 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 thus be optimized so that features in 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 requisites 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 (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 steps 4 and 5).

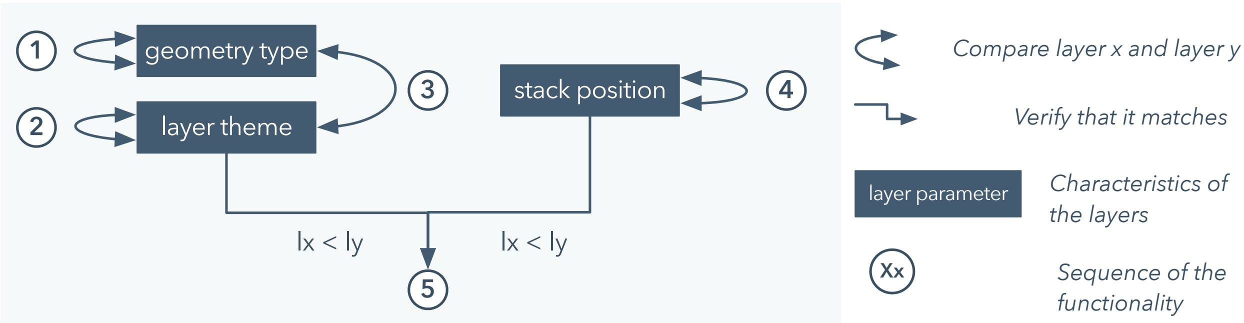

Figure 1. *Drawing order: conceptual implementation of the functionality.*

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; 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 and 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 works. First, certain layers hold parameters that exclude them from potential background (see 1a and 1b), then the layers are further analyzed 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).

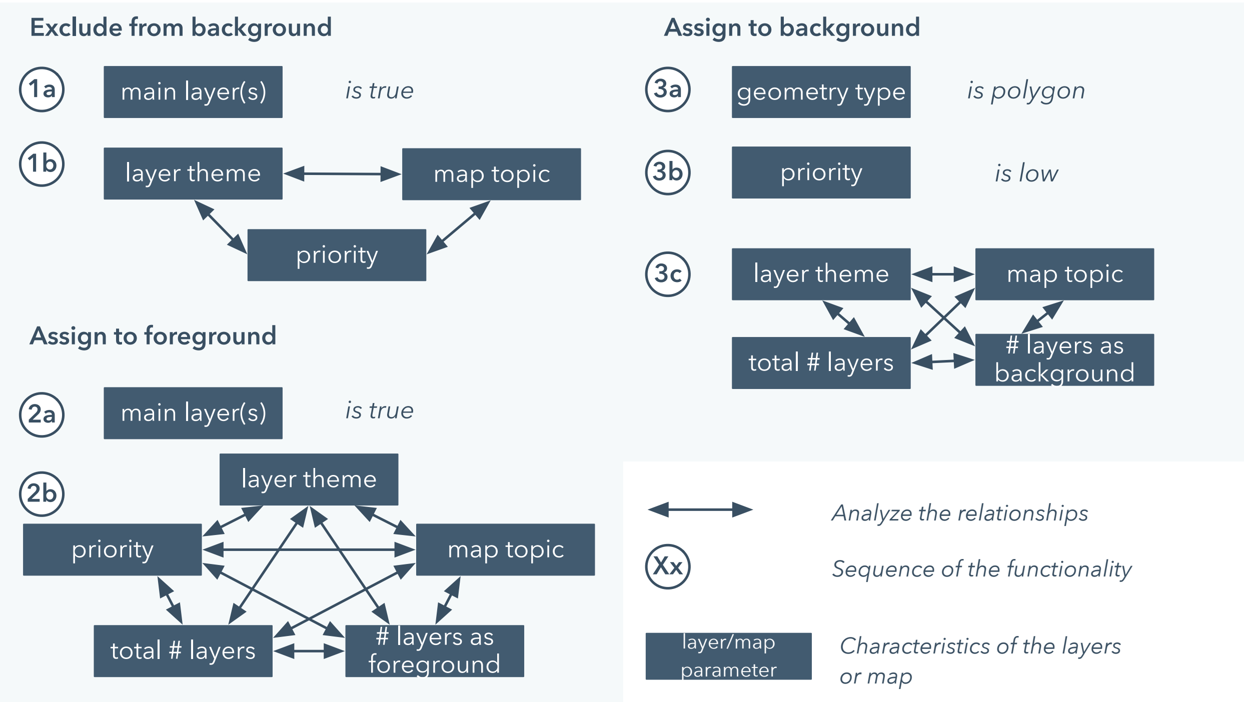

Figure 2. *Visual hierarchy: conceptual implementation of the functionality.*

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.

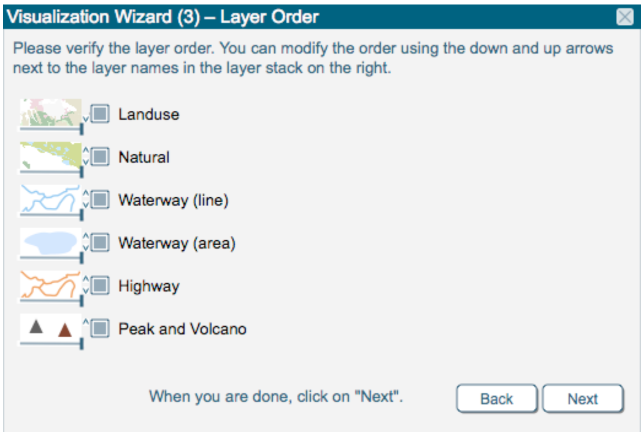

Figure 3. *The user can override the drawing order suggestion made by the wizard. The geoportal uses the painter's model, thus the layer on top of the list is the first drawn on the map.*

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 third step allows the user to validate and modify the drawing order as suggested by the wizard (Figure 3).

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) (Figure 4). Conflicting combinations are defined generally and when a specific case follows a general conflicting combination rule, an alert is issued.

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 a simple input-run-output pipeline is adequate.

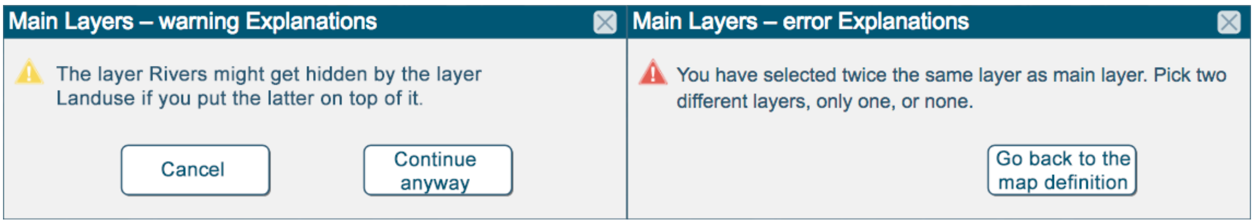

Figure 4. *Warning (left) and error (right) message examples.*

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, 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, users can have access to more detailed input parameters (Figure 5).

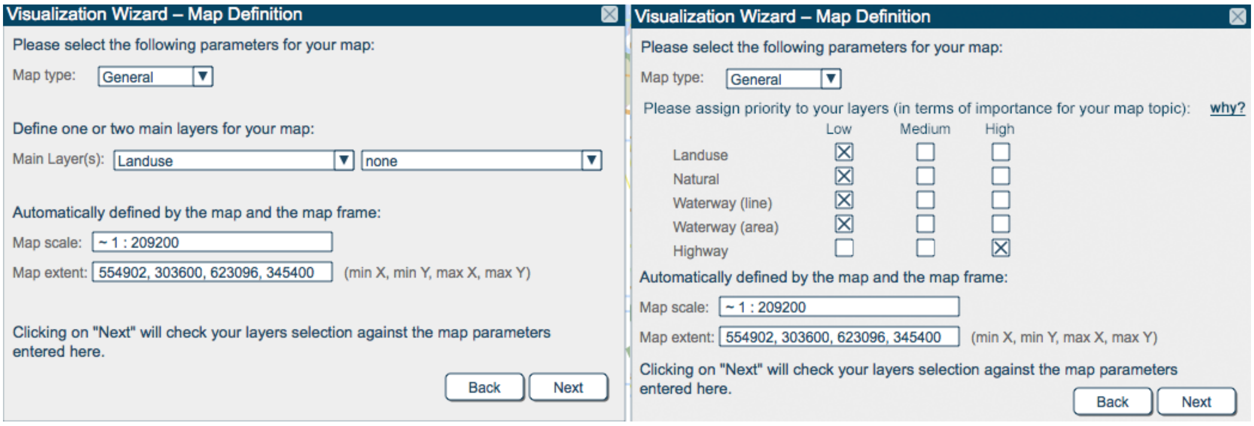

Figure 5. Two possible modes for the integration of the input parameters needed for the visual hierarchy functionality: simple (left) versus detailed (right).

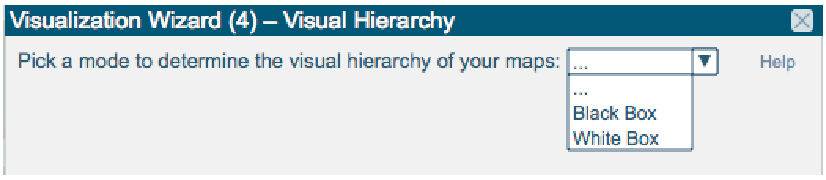

Figure 6. Pick the method to analyze the visual hierarchy.

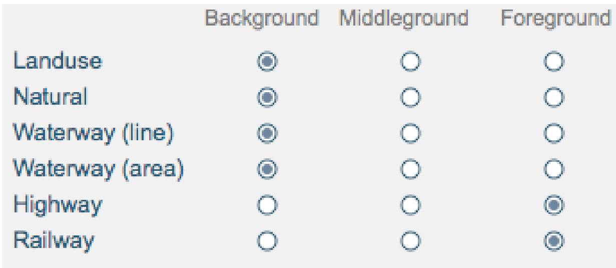

Figure 7. Result of the visual hierarchy analysis, with overwriting capabilities for the user before going to the next step.

Furthermore, the user can choose between a "black-box" method that does not ask for more input and a "white-box" (Figure 6) that allows a more interactive influence on the functionality, especially in the second part, when changes in symbolization are generated.

The "white-box" method enables the user to fine-tune the intermediate results of the functionality (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.

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 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 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 time 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. Conclusions 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 (Figure 8).

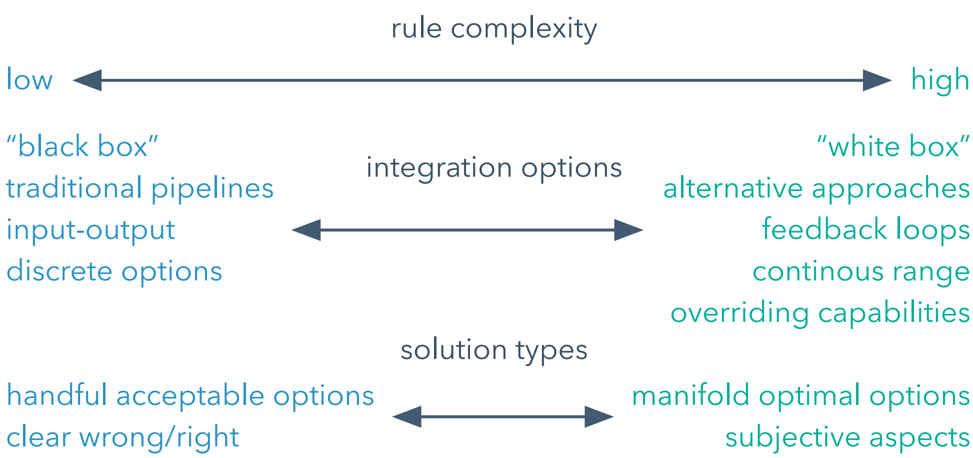

Figure 8. Ranges of rule complexity and solution types in comparison with integration options.

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 and 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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Integrating cartographic knowledge within a geoportal: interactions and feedback in the user interface

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Paper IV

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Abstract

Custom user maps, also called map mashups, made on geoportals by novice users often lead to poor cartographic results, because cartographic expertise is not part of the process. In order to integrate and open cartographic functionality within a geoportal, several strategies and design choices are explored. These design strategies aim at integrating explanations about cartographic rules and functions within the mapmaking process on the geoportal. They are defined and implemented based on a review of human-centered design, usability best practices and previous works on cartographic applications. Cartographic rules and functions are part of a cartographic wizard, which is evaluated with the help of a usability study. The study results show that the overall user experience with the cartographic functions and the wizard workflow is positive, although implementing functionalities for a diverse target audience proved challenging. Additionally, the results show that offering different ways to access information is welcomed and that explanations pertaining directly to the specific user map is found helpful and preferred. Finally, the results provide guidelines for user interaction design for cartographic functionality on geoportals and other online mapping platforms.

Keyword: geoportal, Web cartography, usability evaluation, user interaction, interface design, interactive cartography

1. Introduction

Geospatial datasets are abundantly available nowadays thanks to technological advances in data capturing, storage, processing, and distribution, as well as to the democratization of (online) cartography. Geoportals and online mapping platforms offer an appropriate means and environment for publishing, displaying, and distributing geospatial data. However, the datasets are often uploaded raw or with minimal symbolization onto those platforms. The map mashups created on those platforms by novice users tend to produce results of low cartographic quality because no cartographic knowledge or professional cartographers are included in the process (Harrie, Mustière, and Stigmar 2011) and because the different datasets have been symbolized on an individual basis and thus are not optimal for combination.

Cartographic principles have been gradually formalized and integrated within mostly standalone tools (e.g. Color Brewer for color schemes (Brewer and Harrower 2013) and the subsequent similar "brewers", e.g. for map symbols (Schnabel 2007) and type (Sheesley 2006)) and sometimes in small proportions within geoportals aimed at the larger public. Yet, most of the cartographic knowledge is often not easily accessible or not well integrated within online platforms on which the public create custom user maps.

The motivation behind this work is to explore and evaluate possible interaction design for functions based on cartographic principles within online mapping platforms, such as geoportals, for the casual mapmaker in order to support them in making better user-generated maps. Concretely, the aim is to design and evaluate an interface and related interactions for cartographic functions. These functions rely on cartographic concepts, such as figure-ground and color contrast, to improve the overall visual hierarchy and legibility of the map mashups.

Due to the nature of cartographic knowledge and the target audience of geoportals, there are specific challenges. First, a lay audience might hold a very different conceptual model of how a map and its content are organized than the one held by trained cartographers. Moreover, individual conceptual models among the lay audience are much more variable. Second, cartographic knowledge is made of principles, guidelines, and a certain amount of subjectivity, and thus there is a necessity to be able to communicate about the flexibility of cartographic knowledge. Furthermore, it is unclear what types of interaction best support the opening of cartographic knowledge in combination with specific maps created by the users. Questions regarding how to design interactions to support sharing cartographic knowledge via cartographic functions and its discovery by the casual mapmaker are still open. Concepts of usability and human-centered design can help these questionings, but there is a need to test concrete design implementations to gain a deeper understanding in the context of cartographic applications.

The first objective is to explore relevant design principles to support the integration of cartography-related user interactions and to implement them in an existing geoportal. Second, we investigate and evaluate the different types of user interactions that were implemented in regards of their usability and appropriateness for cartographic functions and knowledge. Finally, interaction design guidelines are to be derived from these evaluations.

For the usability test, an existing geoportal and a framework offering smart cartographic functions are used. The geoportal allows to create map mashups from the available data and the cartographic functions help improving the quality of the mashups by checking for appropriate content based on map types, by optimizing the drawing order of the layers and by improving the visual hierarchy (Panchaud, Iosifescu Enescu, and Hurni 2017). The functions also explain the choices and modifications done and these explanations should not stay hidden, but should be open to the user, and capitalized on by integrating them within the wizard GUI and workflow.

The article is structured as follows: Section 2 provides a review of the literature regarding the design process and choices in the development of mapping platforms. Section 3 presents the choices made for integrating the cartographic functionalities and for designing the interactions between the users and the platform. Then, Section 4 describes the usability study setups for evaluating the design choices and its results regarding the integration and use of the cartographic functionalities within the geoportal. The results are discussed in Section 5. Finally, this work concludes in Section 6 with considerations about the achievements and insights gained about interaction design for online mapping platforms.

2. Fundamental concept and related work

The section offers a review of fundamental concepts that inform the integration of cartographic functions and knowledge within the GUIs of geospatial applications. It also discusses best practices and advices from previous works related to designing GUIs for geospatial applications.

2.1. Human-centered design and user diversity

Previous works and best practices overwhelmingly show that the comprehension of the users' needs and expectations is crucial (Roth and Harrower 2008). It relies on the concept of "human-centered design" (HCD), also known as "user-centered design" (UCD), popularized by Norman (2013) in 1988 already and defined as an "approach that puts human needs, capabilities, and behavior first". The HCD approach has led to significant advantages such as improved usability, fewer errors during use and faster learning time (Norman 2005).

With the emergence of the HCD/UCD doctrine, several sets of principles were developed to support its implementation. We present here the core ideas of HCD with the eight golden rules of Shneiderman (1987) and the seven principles of Norman (1990). Norman (2013) updated the list in a revised edition of his book, which is also reviewed here. Overlaps and differences among the principles lists can be seen in Figure 1.

Common to all, constraints are described as a tool to help guide the user through the possible interactions and prevent the use of functions that are not available at certain points. Additionally, actions should be easily reversible, so that the users can undo potential mistakes and feel free to explore the interface without fear of making an error. Feedback about the user actions and the state of the system is also cited as crucial for a positive user experience.

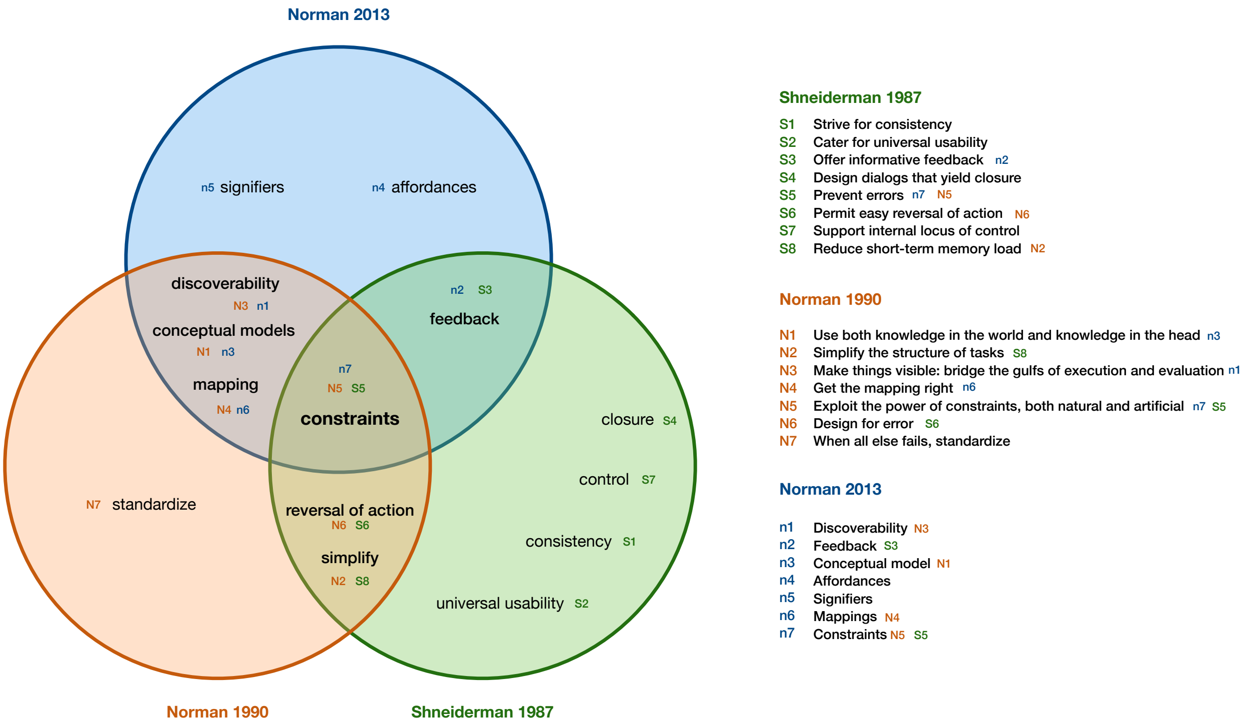

Figure 1. *Overlaps and differences between the different lists of principles for human-centered design.*

Important concepts from the Norman's principles are affordances and signifiers (Norman 2013). Affordances are the relationship between object appearances and the capabilities of the users: they help the users determine the possible interaction with the object. Some affordances are perceivable and act as a signal. When they are not perceivable, additional signifiers are needed; they are clues that convey how to use the objects (Norman 2013). They aim at reducing the amount of settings and icons that need to be learned before using the system by making them intuitive, easy to remember, and logical (linked to mapping N4) and they help reducing the short-term memory (STM) load (S8). Consistency (design aspects; but also sequences of actions terminology across the system) also supports the reduction of STM and lets the users focus on the content of the application and problem solving instead of on interface comprehension (Shneiderman and Plaisant 2005).

In the context of interfaces for geospatial data and visualization, it means that the interactions built into the GUI must make sense and be intuitive: for instance, users should not spend time deciphering the icons and buttons (Timoney 2013) (see S8 in Figure 1). Additionally, understanding the user context and providing direct controls to the user are critical steps to preventing errors (Haklay and Nivala 2010) (see S7).

While the above-mentioned list give a valuable insight into HCD, the framework of Gould and Lewis (1985) offers a more comprehensive approach and was the most widely adopted (Haklay and Nivala 2010) The three core principles are: (1) an early focus on the users and tasks, (2) the use of empirical measurements to evaluate the design, and (3) an iterative process. The first point deals with the importance of the users' goals and tasks as the drivers for the design. Moreover, it implies that characteristics, behavior, context of use, work and environment should be considered as well. Then, only through empirical measurements (e.g. user's reaction and performance) can one evaluate whether there are improvements from the prototype to the final version. Finally, the design process should go through several iteration cycles from design, test, measure, re-design, etc., as often as necessary (Gould and Lewis 1985).

As seen above, the HCD approach is supported by a large body of work demonstrating the importance of considering carefully the target audience, its needs, capabilities and preferences in designing interactions. In the context of map mashups, as opposed to traditional cartography, the map user is also often the mapmaker (Roth 2013) and thus the user has a double profile of needs and expectations which have to be taken into account.

Often online mapping environment regards their users as a homogeneous group, but there exist group and individual differences. For instance, (Slocum et al. 2001) mention expertise, culture, and age among several other characteristics, while (Fairbairn et al. 2001) also refer to the users' expectations, experience, competences, and preferences. These various users' facets lead to multiple user perspectives and thus treating them as a monolithic group is inadequate (Haklay 2003) and it is considered best practice to acknowledge different user skills and knowledge, especially between experts and casual users (Fairbairn et al. 2001, Jenny et al. 2010), and among laypeople themselves (Meng and Jacek 2009, Shneiderman and Plaisant 2005).

Consequently, there is no "one size fits all" interface (van Elzakker and Wealands 2007), but even so aiming at catering to universal usability can help (Shneiderman and Plaisant 2005)(see S2 in Figure 1). Suggestions from previous works are to design methods of interactions that can be adapted in terms of complexity to the end user (Slocum et al. 2001, Fiedukowicz et al. 2012, Jenny et al. 2010) and to provide flexibility in unfamiliar situations (MacEachren and Kraak 1997). Increasing the interface complexity or its degree of freedom can render the tasks more difficult for users and thus to alienate them (Slocum et al. 2001, Jones et al. 2009, Andrienko and Andrienko 2006).

2.2. Usability and best practices

The success of the interface depends also on how well it supports the user interactions with the application. The concept of usability is central to such success and is defined in the ISO 9241-11 standard as the "extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (ISO 9241-11 in (Resch and Zimmer 2013, He, Persson, and Östman 2012). (van Elzakker and Wealands 2007) explains effectiveness as achieving goals with accuracy and completeness, efficiency as minimal resource expenditure, and satisfaction as a comfort of use and a positive attitude. Additionally, (Nielsen 1993) defines usability with the help of five attributes: learnability (the system is easy to learn), efficiency (a high level of productivity should be possible, once the system is learned), memorability (easy to remember), errors (low error rate and easy recovery), and satisfaction (pleasant to use).

The cascading information-to-interface ratio is another approach to fulfill different users' profiles (novice or new users vs. advanced or regular users) by providing increasing levels of complexity in the interface (Roth and Harrower 2008). This consists of a multi-layered interface and can help fill the divide between novice and advanced users (Roth 2013). By showing only the most important parameters at first and only the more complex ones on demand, one can offer a simple interface at first sight for the novice user, while allowing the advanced user to access the complexity of the system as well. It is similar to "progressive disclosure" that hides parameters till they are actually needed (Wardlaw 2010).

Even though complex interfaces allow to realize cartographic actions in different orders, which provide flexibility, the productivity paradox has led to constraining the interface by reducing the number of cartographic functions or the degree of flexibility in order to increase productivity (Roth 2013). Other works pertinent to cartography support the idea of constraining the interface for improved user experience (Dou et al. 2010, Keehner et al. 2008, Jones et al. 2009).

Previous works also offer concrete key insights about interface characteristics that support improved usability. The interface should be consistent and systematic (Roth 2012); offer a small visual footprint (Roth and Harrower 2008); make important components visible; offer smart and adaptive functions (MacEachren and Kraak 2001); use appropriate metaphor as well as provide sensible default values depending on the context of use (Cartwright et al. 2001); use interface controls that feel most natural or intuitive (Harrower and Sheesley 2005); and avoid irrelevant interactivity and inconsistencies in information feedback (Jones et al. 2009). Additionally, windows should be reused and their number limited, while the same information should not be displayed in different places (Lauese and Harning in Jenny et al. (2010)). Also, pop-up windows should be avoided because users do not like them for several reasons (interruption, occlusion of the screen, require action to go back to the main window) and tend to close them right away without looking at the content (Resch and Zimmer 2013). To prevent further user frustration, interfaces should display warning messages and block unsupported actions early as well as allow to save the state of the system or its results (Jenny et al. 2010). Redundant functionality, irrelevant interactivity and inconsistencies in information feedback are also problems to take into account. Finally, implementing conventions that are used on more popular websites can prevent the users from being surprised or confused at the results of the interaction. Such an example would be the double-click for zooming used by Google Maps and that users expect in other map applications (Wardlaw 2010).

The role of symbols and icons must not be underestimated and their design should aim at clarity and accuracy, easy and correct interpretability (thanks to affordance and signifiers), and visual feedback when in use (Resch and Zimmer 2013). Even though the data-ink ratio (Tufte 1983) should be high to limit the footprint of the GUI, a too minimalist icon design might not offer enough clues to allow the users to deduce its functions (Roth and Harrower 2008).

Finally and most importantly, Beaudouin-Lafon (2004) advocates to design interaction and not interfaces because the interface is only a means, whereas the goal is to provide user-system interactions of high quality. Cartographic interactions are defined as "the dialogue between a human and a map mediated through a computing device" (Roth 2013). Thus the interface is of the utmost importance in optimally supporting the dialogue and cartographic interactions.

2.3. Assisted map design process

Beyond issues of usability and human-centered design, one should also consider how the dialogue between the user and the application is designed and how it is able to capture the users' requirements, such as needs and context of use, and to translate them into map specifications (data layers, map scale, symbology, etc.) that the application can handle.

Collecting user preferences via textual menus is difficult, and providing map examples or samples can help the process (Balley et al. 2014) and allow the users to better express their need. Then, the challenge is to be able to infer appropriate map specifications from the user requirements. Balley et al. (2014) mention two different approaches: either following a static reasoning process using rules after having gathered the requirements, such as in the work of Forrest (1999); or reconciling cartographic constraints and the user's preferences in a iterative process, as used by Christophe (2011) for designing map legend.

In the field of assisted map creation, there has been different attempts, such as expert systems (Forrest 1993) or assistance for on-demand map creation via Web Services (Jolivet 2008), to organize and formalize cartographic knowledge and to put it at the disposition of a larger public using a graphic interface. A common thread lies in the gathering and formalizing of cartographic principles from expert and best practices map series. The framework behind the interactions that are tested in this paper follow these previous works, but focus on functionalities for lay persons creating map mashups and with a logic fundamentally independent from the application in which the data are visualized. Also the framework relies heavily on semantic information to deal with cartographic constraints.

3. Graphic user interface and interaction design

This section shortly presents the geoportal, its GUI and functionality, which was used for testing the interaction design choices and then covers the integration of the cartographic functions within the geoportal. Concretely, it presents the interaction concept of the wizard and the warning and error system, that are later evaluated in the usability study.

3.1. Existing geoportal and framework

The geoportal is built on a traditional three-tier architecture leveraging databases to serve maps via Web Map Services (WMS) and the original GUI is built with Scalable Vector Graphics. Service-driven cartographic visualization have proven their potential (Iosifescu-Enescu, Hugentobler, and Hurni 2010, Iosifescu et al. 2013), however the functions could also be coupled to a vector tile-based architecture with styling on the client side. Cartographic principles are integrated within the geoportal via cartographic functions that help the users when they create their own maps with the geoportal content. This includes checking whether the selection of layers is appropriate for a specific map type, re-ordering the layers to prevent unwanted overlaps and a function dealing with visual hierarchy within the map mashups by modifying the style of the background layers (for more information, especially concerning issues with map mashups, see Panchaud, Iosifescu Enescu, and Hurni (2017)). We decided to provide a background style function because a recurring issue found

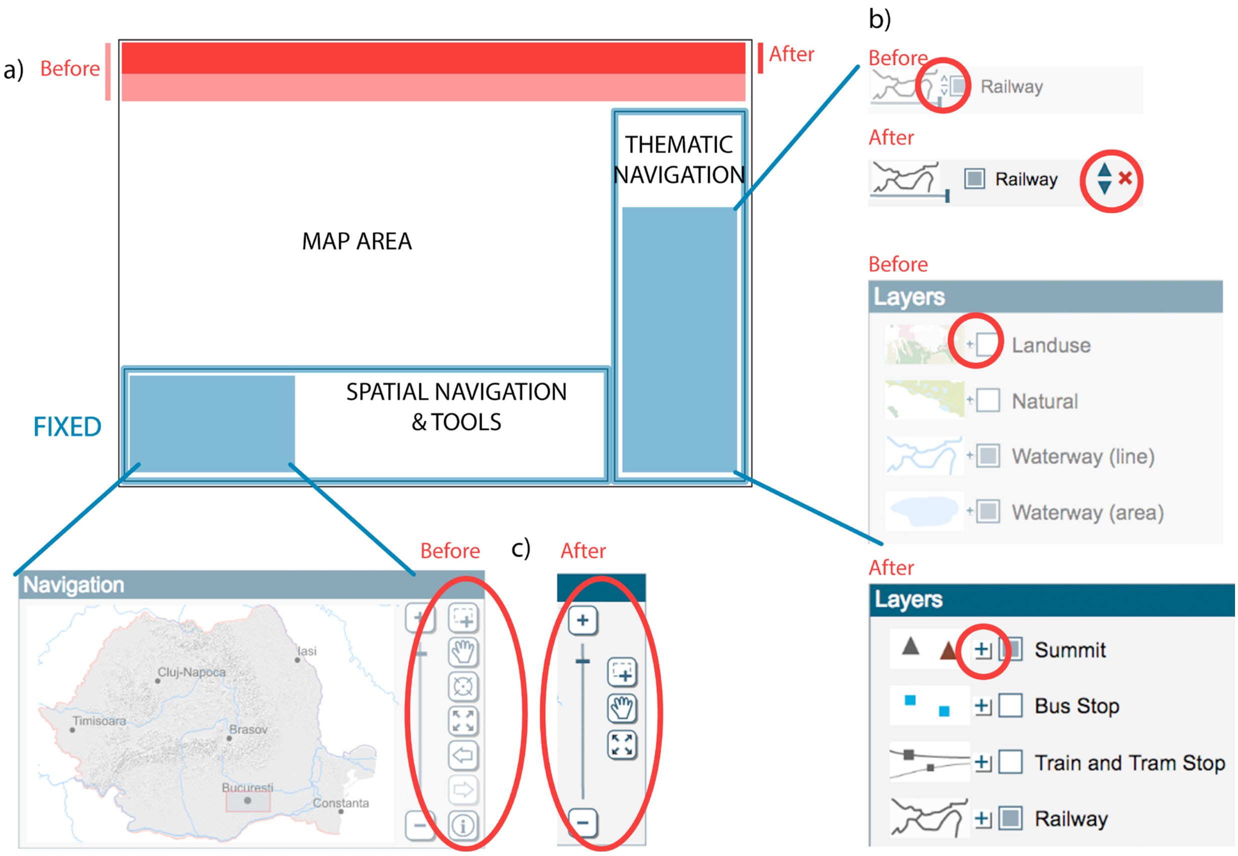

Figure 2. Examples of design changes for the geoportal's GUI.
Note: (a) The large banner at the top was occupying space without serving an important purpose and thus it was redesigned in a much thinner version. (b) Important features, such as adding layers from different map categories to a single user map or re-ordering the layers had icons too small and many users did not notice them. Thus their size was more than doubled with the new design. (c) Icons linked to unused functions and interactivity have been removed.

in map mashups from geoportals is the fact that most layers are already symbolized in saturated color schemes matching a foreground style definition. As the functions mimic different part of the cartographic workflow, a natural design choice for their integration is to use a wizard, allowing to re-create step by step the decision points along the map design process.

Using an existing geoportal GUI (instead of starting from scratch) offers opportunities and constraints on the design process. First, there are benefits in using an existing framework and design that already went through several design iterations because the foundation is solid. At the same time, it gives the chance to do yet another iteration on the general GUI design. However, there are also some constraints as the technologies used are fixed and there might be limitations in what the framework can do.

Figure 2 shows changes realized on the original GUI based on the input of a usability study done on a sibling project using the same GUI framework (Kellenberger et al. 2016), on principles derived from the literature and best practices that were not respected so far, and on the specific project characteristics. The common aspect to the changes was the optimization of the GUI visual footprint: first, most of the space should be given to the map; and second the GUI should not be cluttered in order to give enough space to the important features. Furthermore, some interface features, that had grown over time and were lacking consistency, have been redesigned to offer a smoother and more consistent user experience.

3.2. Wizard integration

As mentioned earlier, a wizard is used to organize the cartographic functions meaningfully. A wizard is a type of user interface that guides the users through a sequence of defined steps to perform a task or solve a problem. They are also called "assistants" and widely used in most operating systems. A wizard should allow to capture the users' requirements in an efficient manner and with a minimal amount of clicks, while offering a pleasant user experience. The integration of the cartographic functions within the GUI followed two major design iteration cycles. The first one includes organizing the cartographic functions and interactions into steps to offer a smooth wizard workflow. We define the different steps as follows: 1. Layer selection; 2. Map definition; 3. Layer order; 4 Visual Hierarchy; 5. Final map. Figure 3 shows the steps and how they related to the cartographic functions. The selection of layers occurs at the beginning because the users were familiar with selecting layers into a user map before downloading them (prior existing geoportal function). The steps 3, 4 and 5 match the existing functionality offered; however, adding support for thematic mapping (i.e. classification and color scheme) would require an additional step in between. As the symbology modifications in step 4 rely on the existing layer styles, there is no need for symbol selection in this specific application, because they are defined by the geoportal.

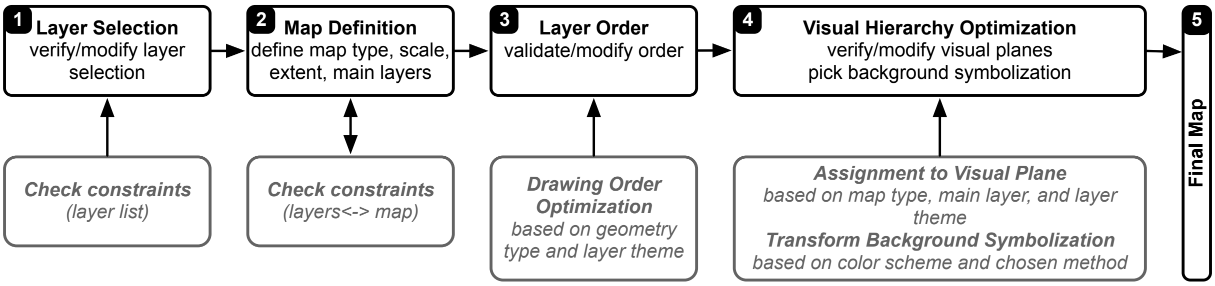

Figure 3. *Workflow concept of the wizard, in black the steps the users go through, and in gray the cartographic functions operating in the background.*

The second design iteration cycle led to the development of a dual GUI, allowing for a "geoportal" mode and a "wizard" mode. Common elements are kept from one mode to the other (e.g. map view, reference map and navigation tools), while specific elements come and go as the user switches between the geoportal GUI and the additional features of the wizard. Going from one mode to the other is always possible thanks to a tab system (Figure 4-a) and there is a large button entitled "Launch Wizard" in the geoportal mode (Figure 4-b).

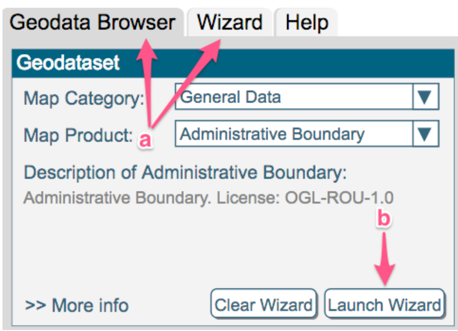

Figure 4. *Part of the GUI showing the switch between geoportal and wizard mode thanks to a tab system (a) and direct access to the wizard (b).*

3.3. Interaction levels

We organize information flows going from the wizard to the user in several levels based on the type, the complexity and the depth of information provided (Table 1). This cascading-type of organization of the interactions helps with providing crucial information at first sight in the interface with little noise, while providing access to more detailed information on demand. Complex information about the inner working of the cartographic functions are available for advanced or curious users, but do not clutter the interface unnecessarily for the other users (Figure 5 for where each level is found).

Level 0 represents the text and parameters visible at first sights in the interface and includes parameter names, selection options, basic instructions, back and forth buttons and window titles. They are designed with traditional UI objects, such as checkboxes, radio buttons and dropdown lists and thus are very easy to understand because they are familiar to the large majority of computer users.

Level 1 interactions provide short additional information about the parameters and cartographic terms in the wizard. They are accessible via tooltips.

Level 2 interactions provide additional content or concept-related knowledge about the cartographic functions and explain the importance and role of parameters. If one already knows about the concept, or content, or is not curious about the inner working of the cartographic functions, one can choose not to interact with this information.

Level 3 interactions consist of warning and error messages due to incompatible parameter values, which might require the user to take action. Warnings do not prevent the user to go to the next step, whereas errors messages do.

Level 4 interactions are detailed explanations about the wizard action afterwards. Depending on the complexity of the functions, different integration strategies have been used: from tooltips to additional text and image content in a dedicated window.

Table 1. *Interaction levels.*

Levels	Definition	Design implementation
Level 0: Interface content	Parameters and textual content available at first sight in the interface.	Part of visual GUI at first sight.
Level 1: Hints	Hints regarding superficial content or technical aspects. Give information about the interface parameters	Tooltip concept.
Level 2: Input explanations	Explain concepts related to input parameters of the cartographic functions	Links to additional content in the message window.
Level 3: Warnings and errors	Raise issues while the cartographic functions are working and checking parameters.	Small icons and popup windows.
Level 4: Output explanations	Explain the results of the cartographic functions that have been accomplished on a specific map and layer combination.	Depends on the complexity of the explanations. Either as tooltip or additional content.

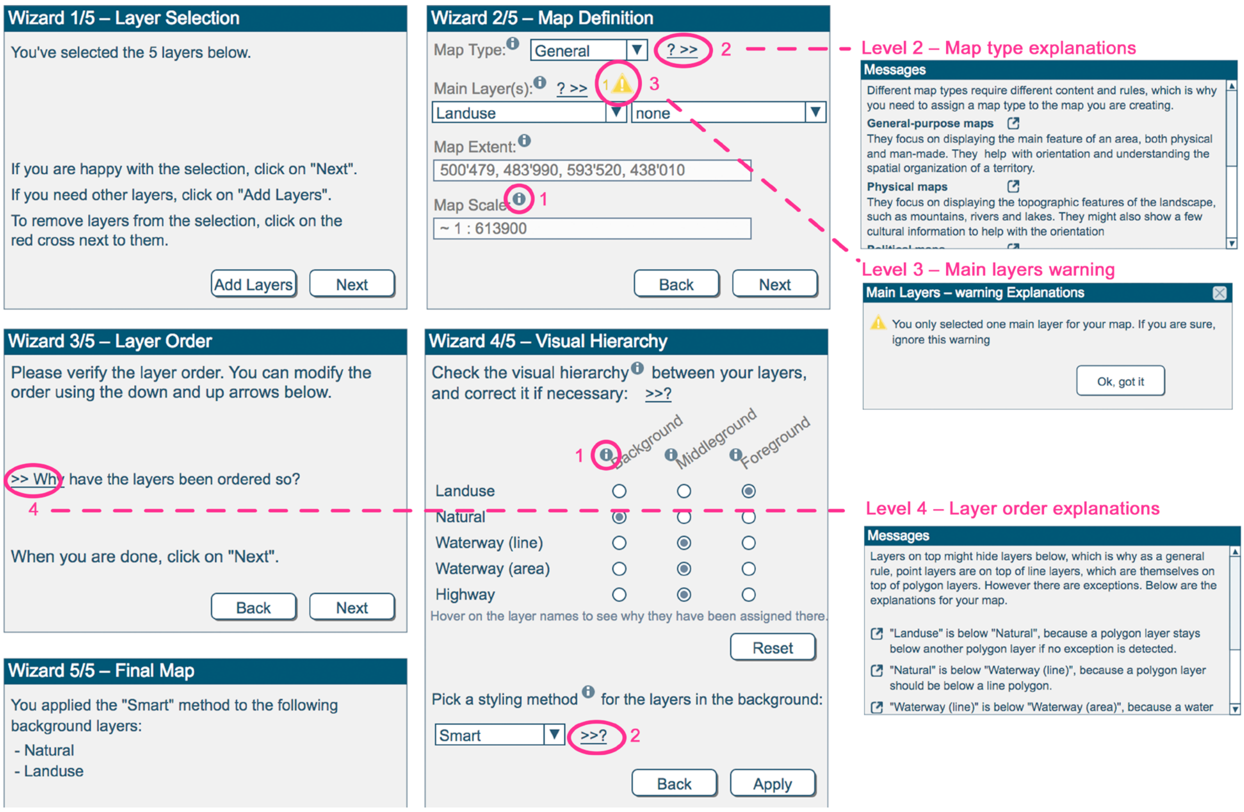

Figure 5. *Wizard steps and different interaction levels.*

3.4. *Error and warning interaction concepts*

There is an important conceptual difference between a warning and an error message. A warning message conveys a cautionary message about something that might be wrong or lacking. When no action is taken upon a warning, the system can go on and assume sensible default values. Thus warning message should be discreet, not hamper the functioning of the system to the next step, and not break the user's flow of thoughts.

An error message is, by contrast, much more critical and should capture the attention of the users and instruct them to action in order to remediate to the problem. Without action and modification of the parameters, the system cannot go on. Thus the design and implementation choices for the error message must make them much more noticeable than the warnings.

When a user changes a parameter involved in a compatibility check, the checking is run in the background and an icon appears next to the parameter if a warning or an error is found (Figure 6). At this stage, nothing prevents the user to continue tweaking parameters within the same wizard window. However, when moving on to the next window, if any error message is not resolved, a

Figure 6. *Examples of the implemented error and warning icons.*

pop-up window will appear and block the process while explaining the problem and suggesting corrective actions (Figure 7). Once the issue is solved, the user can move to the next step.

4. Usability test

The usability test focuses on the users' behavior with the tools that were developed as well as on informing on the design choices. More specifically, it tries to point out whether the wizard functionality is found helpful and efficient by the user and in which proportion they look up the explanations and warning while using the tools.

4.1. Design

Participants

In total 9 participants were recruited for the usability study (4 women, 5 men). All were either working or studying at the university, but were not active or trained in the field of cartography. Their participation was voluntary and they were not compensated. All use maps (digital and paper) at least once a month, while 5 of them even several times a week or more often. Their primary map use is way finding and route planning. They also use maps for research and teaching purposes and during their hobbies (e.g. hiking, traveling, and out of curiosity). The number of the participants was estimated in order to cover different levels of familiarity with maps and geoportals: from never used a geoportal (3x), to a few times (3x) and often (3x).

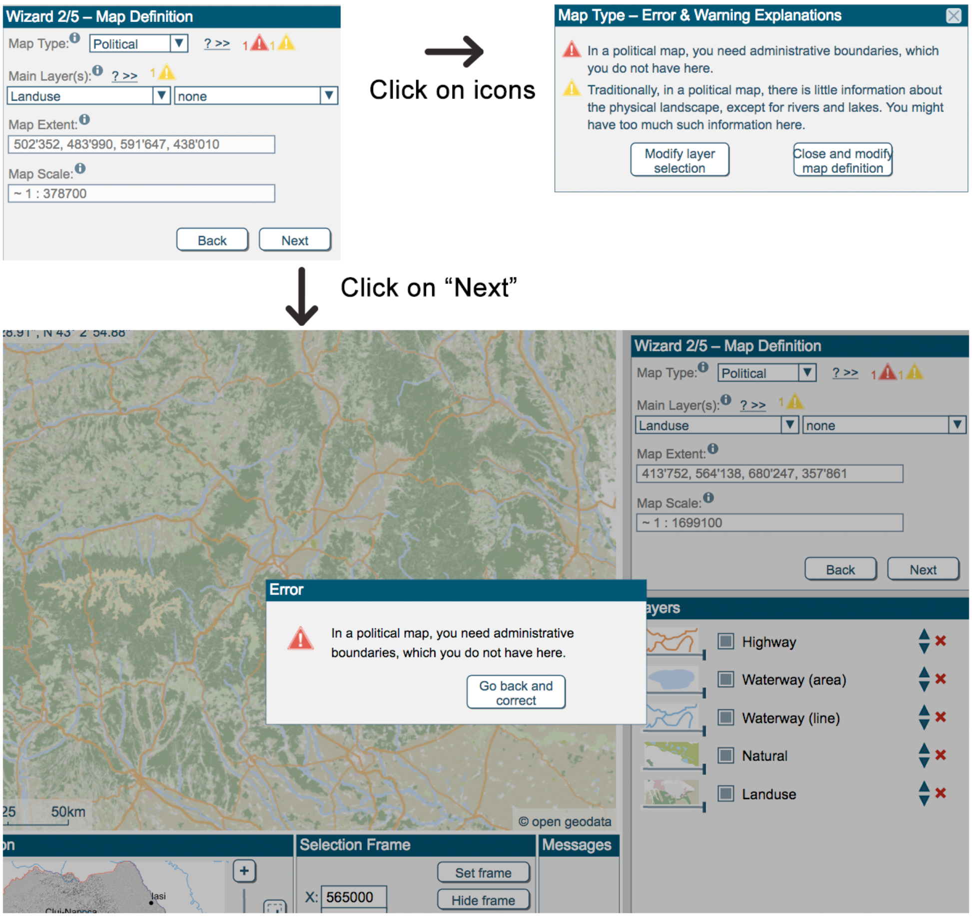

Figure 7. Behavior of the interface when an error is present.

Tasks

A scenario and a series of tasks are developed for the usability testing. The scenario is established in such way that the possibility to use each function arises at one point. An important part of the functions provides general explanations about the inner working of functions or specific explanation about the output of functions for the use case at hand. Thus using the all tools is not necessary to complete the tasks form the scenario. However, this allows to research whether the participants use them or not and in which way and quantity.

The scenario is as follows: "*You want to create an overview map of the Brașov region with the natural parks to have an idea of the protected areas of this region.*"

Then, more detailed tasks and instructions are given to the participants. The tasks are chosen to follow the workflow of the wizard: (1) select layers, (2) verify and/or adjust the map definition parameters, (3) verify and/or adjust layer order, (4) verify and/or adjust the visual hierarchy, and (5) pick a new symbolization method for the background layers.

Procedure

Before starting, the goals and procedure of the usability test are explained to the participants. Then, the usability test consists of a familiarization phase, the actual test, a questionnaire and a structured interview. During the scripted introduction, we explain the project, the tools developed and the goals of the usability study to the participants. Then, the participants have an oriented familiarization time with the geoportal and wizard. Afterwards, the participants receive a scenario and tasks to accomplish. The screen and mouse movements and clicks are recorded during the test, while notes for the structured interview are taken. Next, the participants are given a survey consisting of (1) a User Experience Questionnaire (UEQ) (Laugwitz, Held, and Schrepp 2008); (2) a workload estimation with the NASA Raw Task Load Index (RLTX) (Hart and Staveland 1988); (3) general feedback questions; and (4) a demographic information questionnaire. The UEQ allows to quickly assess the user experience of interactive products, whereas the RLTX helps assess the perceived cognitive workload by the users while using the wizard system as a whole. The structured interview at the end allows to gather more qualitative information about design choices and the participants' impressions.

4.2. Results

Usage of cartographic functions

Figure 8 show how much time each participants spent on the different tasks during the test and how they approach the test. For instance, participants D and E read the instructions carefully and then went straight to the tasks without much exploring, maybe because they were familiar with geoportals and needed less time to carry the tasks; whereas participants A, F and B spent less time on the instructions and much more on exploring the different functions and options of the wizard. It is worth to notice that none of the participants used all the possible functions and explanations (Figure 9). Generally, and not surprisingly, the more functions or help used the longer the participants spent on the geoportal. The general explanations about the main concepts and the warnings were respectively used 53% and 74% of the time.

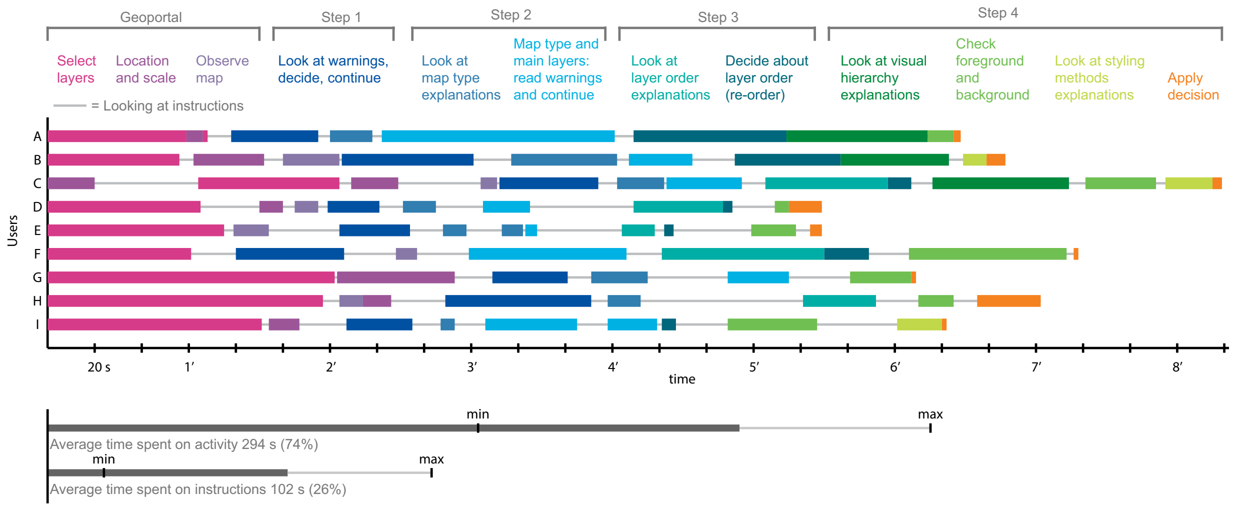

Figure 8. *Time spent on each task or function.*
Note: start point is the participants' first interaction with the geoportal.

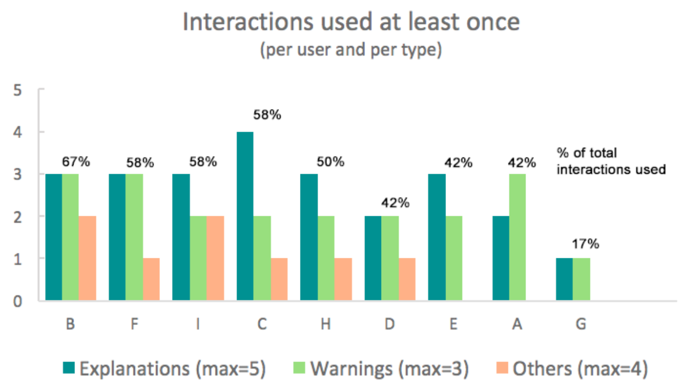

Figure 9. *Number of interactions encountered or used at least once by the users, based on type (general explanation, warning explanations, and others).*

Due to the fact that the scenario and defined task were precise, the participants all reached a similar end result during the test. They all managed to create the map according to the scenario. We show in Figure 10 one example of before/after the layer re-ordering and background functions. Layers that were initially hidden, such as the road network, are not anymore and the strong background layer of landuse has been de-emphasized.

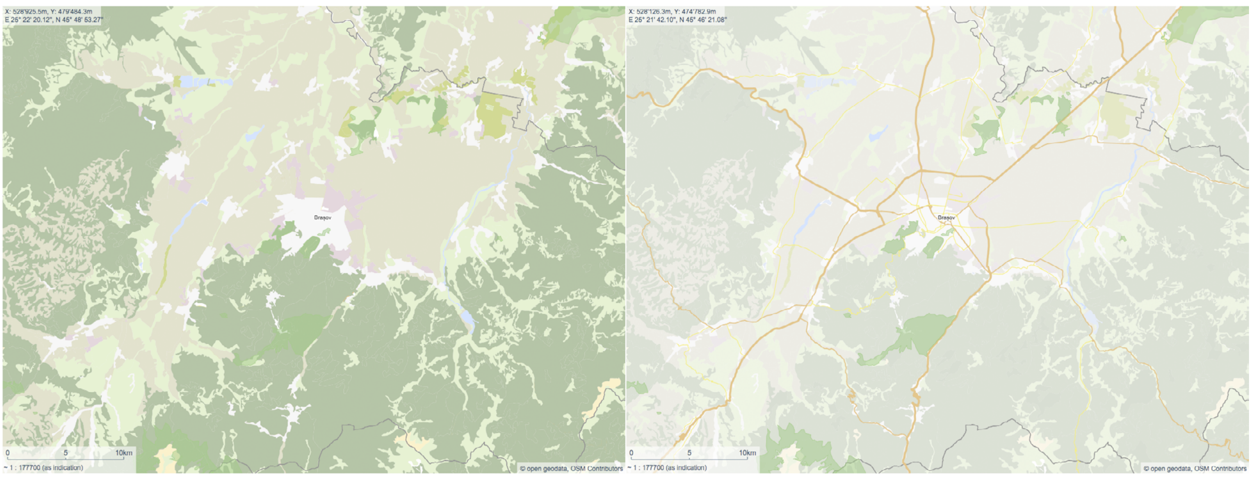

Figure 10. *Example of an initial layer selection of the participants (left) and end result after the use of the reorder and background functions.*

User experience questionnaire

The UEQ is based on 26 pairs of opposing adjectives, which are then averaged into 6 scales: attractiveness (overall impression), perspicuity (how easy to get familiar with), efficiency (tasks can be solved without unnecessary effort), dependability (feeling of control of the interactions), stimulation (how exciting and motivating), novelty (how innovative and creative). The scales range from -3 (extremely poor) to 3 (extremely good). Due to how the scale scores are built and the tendencies to avoid extremities, it is unlikely to observe value beyond -2 and 2. A value of +1.5 is considered good.

The results show the six scales with positive values, of which 4 scales are at or above 1.5: attractiveness, efficiency, dependability, and stimulation (Figure 11). The novelty scale receives the lowest score with a mean of 0.917: however, this score is above what is considered a positive evaluation (>0.8) and it is above the average value from the UEQ benchmark (Figure 12). In conclusion, the participants perceived their overall experience with the wizard as positive especially in regards to attractiveness, efficiency, dependability and stimulation. Based on the individual scores of the perspicuity scale, the application is not perceived as easy (≠ complicated) as it could be (score of 1.1 for the pair), even though the score is above average in regards to the UEQ benchmark. Additionally, the confidence intervals at 95% also stay in the positive range. The benchmark has been set by combining 246 studies using the UEQ result data regarding a broad range of products (business software, web pages, web shops, social networks). Thus comparing our results with the data in the benchmark help interpret the relative quality of our application compared to other products (Laugwitz, Held, and Schrepp 2008).

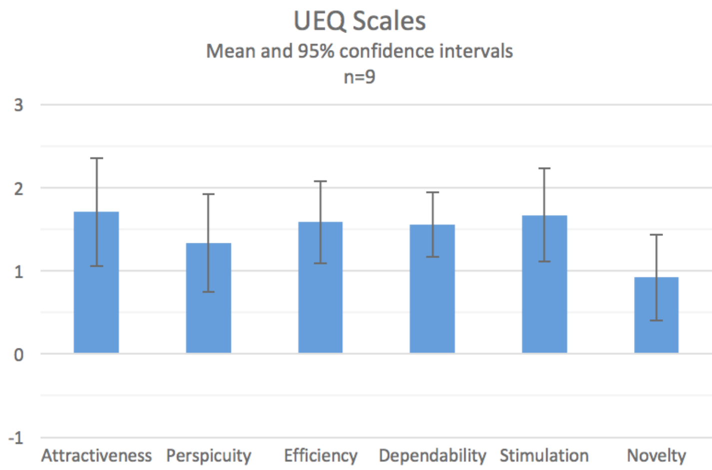

Figure 11. User experience evaluation. Means and confidence intervals of the UEQ scales.

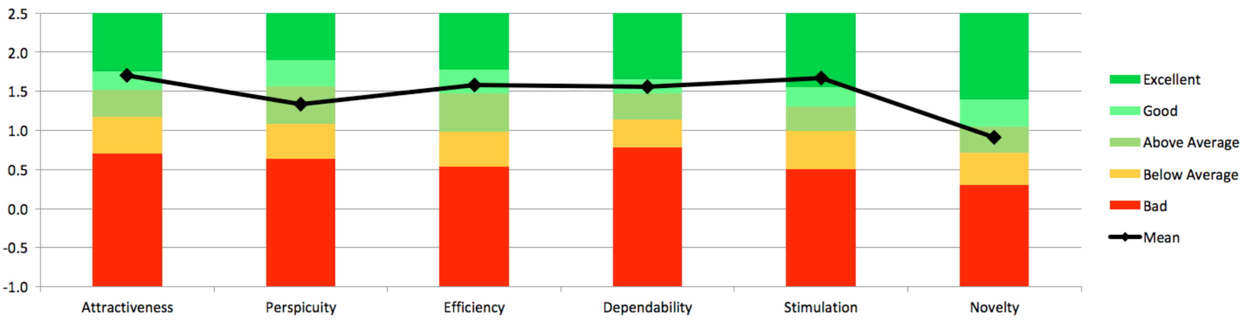

Figure 12. UEQ Benchmark. The scales are all above average, good or excellent.

Perceived workload and feedback

The raw scores of the TLX in Figure 13 show that participants perceive the physical demand and the frustration as being low. The performance score is 1 for a perfect performance and 21 for failure and with a mean of 5.33, it indicates that participants felt they achieved their tasks to a large extent. Score variations for performance and physical demand are small among the participants.

However, accomplishing the tasks is perceived as requiring a higher mental demand, which is not surprising because the wizard offers insights into complex cartographic design processes and rules. The average effort required and the average temporal demand are just below the 11 middle mark threshold. The temporal demand is the workload with the most disperse distribution, which can be explained by the fact that time is subjective and because fulfilling the tasks could be achieved with or without spending time on the additional information and help provided.

From the UEQ, we saw that the application was perceived as slightly complicated, but it did not lead to frustration or failure as shown by the RTLX.

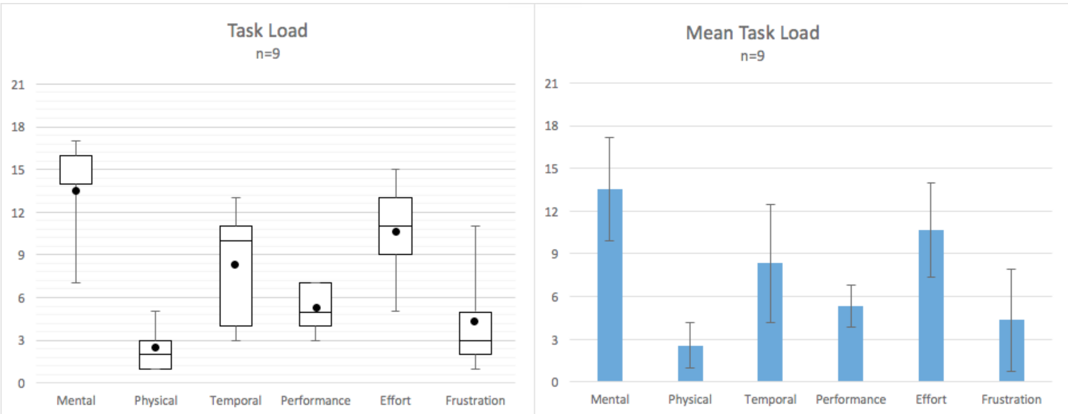

Figure 13. *Perceived workload. Left: box-and-whisker plot displaying, the minimum, 1st quartile, median, mean (black point), 3rd quartile and maximum; Right: mean and standard deviation for each RTLX scale.*

For the general feedback questions, participants had to answer the following 7 questions in Table 2 from "Strongly agree" (=5) to "Strongly disagree" (=1). Due to how the questions were phrased (positive or negative), a low or high average values can both be positive in meaning. Thus, the averages have been re-aligned from 1 to 5, with 5 being the positive meaning. The re-aligned scores were also used in the clustered matrix (Figure 14). The clustered matrix shows 3 very positive participants (I, A, G), 5 positive participants (C, H, F, B, D) and one average evaluation from participant E.

The participants found the additional information about the cartographic functions helpful while also agreeing they were well integrated. The participants did not perceive they were many mistakes, which corroborate the results of the RLTX regarding frustration, effort and performance. Furthermore, the participants did not agree that the system was complex or cumbersome to use. However, their opinion was a little bit more split on statement about how easy the system is to use. The also disagreed with the statement about inconsistencies in the system and making mistakes, showing a positive evaluation of the wizard overall. Finally, while there is no correlation between their evaluation and the time the participants spent on the system, the general feedback scores

Table 2. Average to the feedback questions. Re-aligned scores: 5 = positive evaluation, 1= negative evaluation.

Questions	Average	Re-aligned average
I found the system unnecessarily complex	1.78	4.22
I thought the system was easy to use	3.78	3.78
I found the various functions were well integrated	3.89	3.89
I thought there was too much inconsistency in this system	1.78	4.22
I found the system very cumbersome to use	1.89	4.11
I found the additional information about the cartographic functions helpful	4.67	4.67
I thought that I was making many mistakes	2.33	3.67

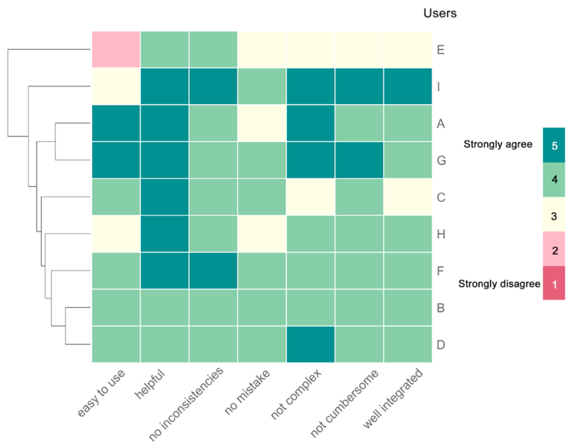

Figure 14. Clustered matrix of the feedback scores for each user.

seem to be negatively correlated to how the participants estimated their task load (higher general feedback score - lower task load estimations) with a Pearson correlation coefficient of -0.77 and p value of 0.014. This fact is not surprising, however, with only 9 participants, one should interpret this only as a marked trend.

The structured interview at the end allows to gather qualitative aspects and the reasoning behind choices or actions of the participants. We quickly review here the points that either were mentioned several times or that are of special interest. The reasons mentioned for the positive feedback about the additional information concerned mostly the opportunity to discover an often unknown field and to learn something. Moreover, having an access to the rationale behind the cartographic functions was appreciated, which might explain the high score of the helpful question. The reason for which only two participants used the icon image to discover pictorial information instead of only textual appeared quickly in the qualitative feedback: even though the icon was mentioned in the familiarization phase, the participants either did not realize it was an icon and/or were too focused on the text itself. This is clearly a design choice that needs further improvements. Suggestions for improvement were to change its color, transform it into a link within the text. More generally, links and interactive features should be in a more differentiated color than the rest of the interface as several participants mentioned that interactive features were difficult to spot at first. Additionally, several participants commented on the lack of more significant feedback when a layer is added to the user map as well as the absence of sign that would indicate that the layer is already in the user map. However, the implementation of the warning and error differentiation with yellow and red was well understood overall, as well as in regard to the seriousness of the message conveyed.

5. Discussion

The usability test revealed both successful and flawed aspects of the interaction and GUI design, both in terms of understanding the wizard application and its actions and of pure interface design.

First, the results revealed some misunderstanding in the language used within the interface. There appears to be a need for a short introductory section explaining the main vocabulary used. Beyond a clarifying role, it could also play the role of a general documentation that can be used as a reference any time. For instance, the terms "map type", the different layer categories and some other fundamental terms could be better explained. Additionally, there has been come confusion among the participants as to the extent of the wizard actions. After certain warning or error messages, some participants expected the wizard to automatically correct some parameters, whereas the wizard was built as to let the user decide on those cases because they are open-ended questions, thus depending on the user's purpose for the map. More specific feedback should be considered in certain case to prevent any doubt. Besides, building auto-correcting functions should be incorporated into future developments.

Then two weaknesses of the interaction design were uncovered: 1) the process to add layers to the user map and where the user map was, and 2) the icon that would lead to illustrations of the explanations. First, the conceptual understanding of the duality between "data browser vs. user map" and how to add layers to the user map were not optimal. The process could be better supported by providing better visual feedback when a layer is added to the user map and to signal which layers are already in the user map. This could be realized by shadowing or highlighting layers already present and by issuing a short disappearing message stating that the layer has been successfully added to the user map when the user adds a layer. Second, the icon allowing to open an image demonstrating the text explanation has been too poorly designed and participants did not realize it was an icon or were just too focused on the map and text to click on it. Thus, a redesign is more than warranted and some solution could involve turning the icon into either a link, another color, or a miniature with a function to enlarge.

Next, successful aspects of the interaction concept were also demonstrated by the test. One of these aspects is the frequent use of the warning and error messages. The participants applied a strategy of trial and error while trying different options as a means to understand the explanations in relations with changes in the map parameters and in the map itself. The messages, which are specific to the user maps in question, are thus complementary to the general explanations: they deliver the same information but put into perspective. It helps the participants understanding the general rules in regards of their unique specific context. Besides, the distinctions between warning and error messages was well understood, likely because it was built on known signifiers and conventions by using red for error and yellow for warning, with which participants were familiar.

The fact that participants found the additional information helpful and appreciated discovering something new has interesting implications for geoportals: it does not only support designing optimal interface for helping the users create better designed maps, but also paints the geoportal as an entry tool for learning about cartographic design rules as it does not require any specialized software or dealing with raw data.

When looking at the result of single users across the different scores and evaluation, there a few interesting facts to mention. The "worst" evaluation came from participant E, which is also the participant that spent the least time on the geoportal and one of the 3 that did not use all the different types of interactions. Whereas, participant C spent the most time and gave an overall positive evaluation. Participants I and H, who gave the system the best evaluation, spent an average time on the wizard, but used a very different amount of the interactions and functions. Interestingly, they both never had used a geoportal before. Participants G is an outlier in the use of the interactions (only 2 types and 17% in total), however the general feedback scores were ones of the highest and the RTLX scores are the second lowest Additionally, participants A and E used only two types and in a similar amount, however, their general feedback and RTLX scores are very different. Thus the amount of help used does not seem to be linked to whether the participants found the system user-friendly and easy to use.

The results also show the emergence of different usage profiles among the participants. It would support the assertion that the wizard can be successfully used without accessing each level of information, and the wizard users might benefit from the possibility to choose between different interface designs with different complexity. However, due to the relatively small number of participants, it must be considered carefully.

Finally, the interest and high use of warning functions as a discovery and trial-error tool suggest that, because cartographic functions and knowledge are at times complex, the participants found that having the map showing (instead of a text telling) what was meant was an invaluable help. It means that when building interactions with cartographic functions and knowledge, one should take care of providing the explanation not just in a "telling" form, but importantly in a "showing" form, such as sample map or an immediate change on the user map. Learning by doing (and by seeing) seems to adequately apply to the relation between cartographic knowledge and cartographic interactions here.

6. Conclusions and outlook

Our goal was to investigate potential integrations of cartographic functions and knowledge in an existing geoportal framework. After reviewing the state of the art in user interaction, usability and previous experience in mapping platforms, we built an interaction levels model and showed different types of interactions with and feedback from the system to the users. Then, we tested the integration of smart cartographic functions and knowledge with a usability study. Insights gained through this study will help improve the actual platform and move towards a broader and more hands-on approach to sharing cartographic knowledge.

Feedback and results of the user experience show that the overall experience with the cartographic functions and the wizard workflow was positive as proven by the enthusiasm of the participants, their curiosity about the cartographic content, and the different indicators regarding ease of use, task load and qualitative feedback. However, it also revealed areas with potential for improvements, such as the implementation of the images for the explanations and some unclear terminology.

From this work, we gather the following guidelines that are relevant for the integration of smart cartographic functions and knowledge into mapping platforms:

- Functionality action and output should be clear to the user.
- Help and explanations about the functionality should come in different forms and through different pathways (telling vs showing and general vs case-specific)
- Accommodating for a diverse target audience is challenging, but providing several levels within the interface support the tasks successfully.
- Providing users with ways to explore the content and knowledge by themselves and interactively should be favored as it leads to a positive user experience.

This paper and its usability study show that implementing cartographic functionalities in geoportals with an open approach can be successful, enjoyable for the users, and not perceived as cumbersome. Cartographic wizards and similar approaches to integrate cartographic knowledge and functions should be more often considered in geoportals as a means to attract the users, to offer sound cartographic visualizations of the geoportal data, and to further promote the platform.

Furthermore, there is still a large potential for development in terms of interface/interaction design and cartographic functionalities. Beyond enhancing the actual geoportal GUI based on the results of this study, future work will focus on providing a more differentiated interface while keeping access to the additional cartographic knowledge similarly available. Additionally, developing smart functions that suggest corrections and apply them will be another priority. This is challenging because it requires to convey a precise feedback to the user about what and why is being executed without being too obstructive in terms of user experience and smooth workflow. Finally, providing a positive user experience and enabling the users to reach their goals should stay at the center of all these new developments.

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V Synopsis of results

This thesis covers several aspects related to cartographic functions and knowledge, from cartographic conflicts, to knowledge formalization and cartographic interaction design. It developed a new approach to the resolution of specific cartographic conflicts in the context of map mashups and user maps on online mapping platforms, such as geoportals. To do so, it proposed a contextual map model to formalize and open up cartographic principles in the form of functions implemented directly onto those platforms and in relation to the actual maps created by the users. The next sections review the work achieved in relation to the research questions (RQ) that were defined at the beginning.

RQ1– Which (and how) cartographic conflicts found in user maps on geoportals can be resolved with the help of cartographic principles about symbolization?

Based on a detailed examination of existing national and regional public geoportals, the most ***common cartographic conflicts in map mashups*** in geoportal and similar online mapping platforms have been identified. Concretely, the geospatial data available in a selection of geoportals have been surveyed and map mashups scenarios have been investigated to identify cartographic conflicts. These conflicts, or shortcomings, could be organized into three main categories: drawing order, unaddressed scale problems and lack of visual hierarchy. Issues with the drawing order led to unwanted overlaps and occlusion of map objects. The unaddressed scale problems led to congestion, coalescence, and even imperceptibility when data meant for a larger scale were displayed at a smaller scale. The lack of visual hierarchy found its roots in a tendency to symbolize layers in geoportals using a standalone approach, and thus compromising the building of a proper visual hierarchy when the layers are combined into a single map. Additionally, many geoportals offered satellite images which, due to their rather saturated colors, are difficult to integrate with other data without transformation in regards to the visual hierarchy.

Then, the reasons behind these conflicts have been analyzed and related ***cartographic principles or best practices*** have been assigned to the conflicts in order to help resolve them, such as the principle of visual planes within a map and the figure-ground principle from the Gestalt theory that plays an important role in the overall visual and organizational hierarchy of a map. Issues regarding the drawing order of layers and the unaddressed scale problems have been informed by best practices in the context of map design. The provided list of the most common cartographic conflicts in user maps in the context of geoportals and the associated cartographic principles resolving them represents guidelines for identifying and addressing symbology weaknesses of geoportals.

RQ2 – How to formalize cartographic principles into actionable functionality for their integration within a geoportal?

A ***contextual map model*** has been defined to describe the state of any user map in geoportals or similar mapping platforms. Such model is needed to formalize the cartographic principles in relation to the list of cartographic conflicts. The model consists of the different map components, symbology features and semantic information. It constitutes the foundation on which the cartographic functionality is developed. Furthermore, the model has been designed to be expandable, in order to support additional cartographic areas of knowledge when needed, such as thematic symbolization rules. The model has been developed in an iterative way, informed by both the map structure and the parameters required for cartographic functionality.

Alongside the contextual map model, we created s***mart cartographic functions***. Combined with the contextual map model, they form a cartographic framework for the formalization of cartographic knowledge into actionable functions that can resolve cartographic conflicts in user maps on geoportals. More specifically, the following functions have been developed: reordering of the layers to avoid unwanted overlaps, constraining the map content to avoid cartographic faux pas, and supporting a better visual hierarchy by assigning layers to the background and foreground and by offering changes of symbolization for the background layers. These functions improve the overall quality and legibility of the map while helping the user to avoid missteps in the creation of the maps. Another added value for the geoportal is that the data can be reused in an optimized context, offering an improved map representation.

RQ3 – How can interactions and interfaces be designed to support opening up cartographic knowledge in a geoportal?

The implementation of the ***geoportal technologies*** based on a review of the state of the art was realized. It provides a concrete and real-life scenario for the implementation of the cartographic functions in a geoportal (see below for the proof of concept). Technologies belonging to each tier of a classical three-tier architecture have been combined to provide a working geoportal accessible to the public, including a database management system, web services and a graphic user interface (GUI).

The ***proof of concept*** of the smart cartographic framework represents a major result because it not only allows to test the framework in a real setting, but it also gives the opportunity to experiment diverse choices of design integration within the GUI. To implement the framework, a wizard was developed on top of the existing geoportal's GUI. This integration of the functions and design of the wizard showcased the potential of such functionality for the practice of neocartography. The implementation allowed to conduct a usability study in an optimal setting and to receive feedback about the functions from the target users. The study showed that when cartographic functions are implemented in a geoportal with an open approach, the application can be successful, enjoyable for the users and perceived as usable and useful.

Thanks to the usability study, ***guidelines for designing user interactions*** in the context of sharing cartographic knowledge via the graphic user interface could be developed. For instance, it could be demonstrated that options to explore freely the content and knowledge should be offered to the users and that, although challenging, providing different levels within the interface allows to support a diverse audience. These guidelines and the overall results of the usability study represent important insights and a starting point for further studies on how to optimally open cartographic knowledge and design user interactions to support it.

Closing the cartographic gap

One main objective of this thesis was to develop solutions to close the cartographic gap and contribute to supporting a sound and successful practice of neocartography. As mentioned in the *Introduction*, the access to cartographic knowledge and principles for casual mapmakers and neocartographers is not optimal and often difficult. Thus, several tools developed in the course of this thesis are made available online for the general public to try out, use, reuse and expand on the core functions (see the links in Table 1). The framework is written in JavaScript, which runs in every modern browser, and was kept separated from the implementation-specific parts of the proof of concept. This separation and use of a widely supported language ensure that the contextual map model and smart cartographic functions can be transferred and combined with other online map platforms, which might be based on different technologies.

Table 1. *Overview of the results.*

Common cartographic conflicts	The most common cartographic conflicts found in map mashups and the related cartographic principles and best practices are analyzed and described in Chapter III *Smart cartographic framework and functionality*.
Smart cartographic framework	The developed framework consists of a contextual map model and smart cartographic functions. Different aspects of the framework are discussed in the Chapters III and IV and a detailed description of the model can be found in *Appendix A — Contextual map model.* Available at https://github.com/npanchaud/cartowiz-lib/
Proof-of-concept implementation	The implementation integrates the smart cartographic functionality using a wizard into a real-life example as proof of concept. It leverages the geoportal technologies, geospatial data and web services from the Geoidea.ro project. A use case scenario, which has been recorded on the proof-of-concept platform, is described in *Appendix B — Use case scenario*. Technical details of the implementation are available in *Appendix C — Technical implementation.* Available at http://geocarto.ethz.ch/cartowiz/
Guidelines for user interactions	A set of guidelines is derived from the user experience and usability test conducted in Paper IV in Chapter IV *Opening up cartographic knowledge*.
Research website	A summary of the research is accessible to the general public, with concrete examples and videos. Available at https://npanchaud.github.io/cartowiz/

VI Concluding remarks

1. Relevance to science and society

The thesis contributes to bridging the cartographic gap by providing online access to cartographic knowledge to non-professional mapmakers, and in direct relation to the mapmaking process. From a scientific point of view, several areas relevant to cartographic research have been investigated and developed: the formalization of cartographic principles for the resolution of cartographic symbolization conflicts; the transfer of cartographic knowledge to the practice of neocartography; and the evaluation of interaction designs for cartographic functionality. Furthermore, the work undertaken supports societal aspects such as the democratization of cartography and an easier access to cartographic tools and knowledge for the non-professionals on platforms where data are both stored and published.

The validity of the cartographic framework developed in this thesis has been tested empirically for the formalization of cartographic principles into functions for the practice of neocartography. The framework and the cartographic functions demonstrate how user-created maps can be satisfactorily improved and how cartographic shortcomings can be solved thanks to a light infrastructure on top of a geoportal. As the developed framework is open and available to anyone, it further allows for others to expand the formalization effort already achieved, and eventually, to provide cartographic functions relying on principles not taken into account in this thesis, such as thematic cartographic aspects.

Transferring cartographic knowledge associated with the developed functions to a neocartographic environment (i.e. aimed at casual and non-professional mapmakers) contributes to bridging the cartographic gap regarding access to knowledge. The openness and transparency of the functions enable retrieving the decision points and important parameters and thus promote the access to that knowledge.

The formalization process and the considerations about the complexity of cartographic principles show some key aspects and challenges to take into account for further efforts, not only in formalizing cartographic knowledge in the context of neocartography, but also, more broadly, for other areas of cartographic research. For instance, the formalization process and subsequent testing corroborate the importance of default values derived from best practices or literature in dealing with the complexity of cartographic functions for casual mapmakers.

The usability study carried out allows to gain constructive insights into designing user interactions with cartographic functions within a geoportal. More specifically, the study highlights the modes of interactions preferred by users and provides concrete foundations for designing interfaces and interactions in the context of online neocartographic environments. Additionally, the positive results from the study about the users' experience confirm the legitimacy of bringing cartographic functions into geoportals and the users' interest for them. The study results also substantiate the need for further development in the field of open and smart cartographic functionality for neocartographers.

The development of smart cartographic functions for the online practice of neocartography supports and allows a broader use of cartographic principles and techniques outside the realm of professional mapmakers, by facilitating access to cartographic knowledge, both as formalized open content and as concrete functions. Moreover, the cartographic functions, combined with the wizard, allow to produce a map symbolization that respects and exemplifies cartographic principles. Thus, they can be used as an educational tool to get familiar with these principles.

Furthermore, as the democratization of cartography continues, the traditional role of professional cartographers is called into question. A potential answer and novel role for cartographers as enablers is emerging from this thesis. As map users are making their own maps with tools, data and knowledge found online, professional cartographers have the new task to provide the public with reliable tools and resources of high cartographic quality to support optimal mapmaking processes and best possible results for these new actors in cartography.

Finally, integrating cartographic knowledge and functions into the geoportal generated a high interest for the platform, as the usability study demonstrated. Therefore, such functionality should be more often considered as a means to attract users on geoportals and similar platforms. It can be used to offer sound cartographic representations of the data provided by geoportals and to further promote the use of geoportals and online mapping platforms for a wide range of purposes. Moreover, it fosters reuse of (public) geospatial data in contexts beyond their original use, which, as stated in the Geoidea.ro project and already proven many times, can ultimately generate added value for the society.

2. Outlook

This thesis demonstrates the need for, and potential of, smart cartographic functions for the practice of neocartography. However, the results achieved only open the door of smart map creation in the context of online mapping platforms and neocartography. Several other traditional areas of cartography could also be formalized into usable functions for the neocartographers. For instance, thematic mapping functions, and more specifically classification and color schemes, could create tremendous added value, as many public geoportals offer statistical data across many subjects. In addition, developing functions that automatically correct suboptimal parameters or that suggest alternative layers (for instance, same theme, but at the appropriate scale) could prove to be valuable for novice users who might not feel confident enough to make those choices. Suggesting viable alternatives could be powered by artificial intelligence techniques similar to a recommendation engine and learning from the cumulative practice of previous users, not as a constraint, but as an assistant. Functionality for both thematic cartography and proposing alternatives in terms of content and function parameters will require additions and extensions to the object catalogues already present. More generally, semantic aspects should further be added to the framework because, in the same way that cartographers rely heavily on the meaning of their data for designing maps, smart cartographic functions of high quality are only possible with rich and detailed semantic information available.

The debriefing interviews after the usability study reveal several interesting wishes of the participants, such as a dark background style or a sepia option that evoke filters existing on many social network applications. The interest of the participants in such representations indicates that the framework could gain additional value from research at the convergence of art and cartography. The different interaction designs show promise, but they should be further explored in combination with differentiated user profiles, especially with the addition of an expert profile, that would give users the possibility to control the whole process. Testing whether users can still produce high-quality maps while having more control over the function parameters could be of benefit for the customization of future interfaces and interactions. For instance, it could help to determine at which point too much freedom or too much control in the interface becomes detrimental to cartographic quality. As the background symbolization functions rely on calibration parameters, it could be informative to test user access to these parameters (as sliders, for instance) and investigate whether, with similar warning and help functions, users are still able to produce optimal maps. Two other areas of interest should be explored: using the framework in another environment than the one of a geoportal would allow to test its stability and interoperability; and providing a library or rules as services for other applications, such as desktop GIS or data visualization libraries, could broaden the use of cartographic principles beyond the strict realm of cartography.

One core motivation behind this thesis was the opening up of cartographic knowledge, especially with regard to the practice of neocartography. Thanks to a systematic research about the formalization and then the investigation of user interactions with cartographic functions, this thesis demonstrates that the developed framework is suitable for the purpose of opening up cartographic knowledge to a wider audience. However, several questions remain open regarding whether users retain knowledge in the long term about the functions, whether they would be able to reuse that knowledge independently of the applications, and whether this “in context and hands-on” approach is more efficient than a traditional course or book on the subject.

Finally, because cartography finds its richness at the crossroad between science and art, it might never be possible to fully formalize cartographic knowledge and practice. However, cartographers, as enablers, should thrive to provide rich cartographic functionality to the non-professional mapmakers in order to inspire them and help them enjoy the practice of mapmaking. Thus, keeping the cartographic gap small, and more generally, providing sound cartographic tools, that are supported by cartographic principles and best practices, should also be an important part of future research in cartography.

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Acronyms

DBMS	Database Management System
FE	Filter Encoding
FTP	File Transfer Protocol
GEOIDEA.RO	Geodata Openness Initiative for Development and Economic Advancement in Romania
GDAL/OGR	Geospatial Data Abstraction Library/ OGR Simple Features Library
GIS	Geographic Information Systems/Science
GPS	Global Positioning System
GUI	Graphic User Interface
HCD	Human-Centered Design
HSL	Hue-Saturation-Lightness color space
HSV	Hue-Saturation-Value color space
HTTP	HyperText Transfer Protocol
ICA	International Cartographic Association
INSPIRE	Infrastructure for Spatial Information in Europe (EU directive)
JSON	JavaScript Object Notation
LCH	Lightness-Chroma-Hue color space
OGC	Open Geospatial Consortium
QGIS	QuantumGIS software
RGB	Red-Green-Blue color space
RTLX	NASA Raw Task Load Index
SDI	Spatial Data Infrastructure
SE	Symbology Encoding
SLD	Styled Layer Descriptor
SOA	Service-Oriented Architecture
SVG	Scalable Vector Graphics
UCD	User-Centered Design, see HCD
UEQ	User Experience Questionnaire
VGI	Volunteered Geographic Information

WCS	Web Coverage Service
WFS	Web Feature Service
WPS	Web Processing Service
WMS	Web Map Service
WMTS	Web Map Tile Service
W3C	World Wide Web Consortium
XML	Extensible Markup Language

Appendices

Appendix A – Contextual map model

This appendix presents the contextual map model (Figure 1) and defines its terms and their relations. The contextual map model is an important component of the framework developed in this thesis because it is the foundation used to define the cartographic rules and functions. The CartoWiz framework, consisting of the model and functions, is available at https://github.com/npanchaud/cartowiz-lib/ and can be used to further formalize cartographic principles.

The model and its components are first described below and then a simple example of the implementation of the model within the framework is discussed.

1. Map

There are several definitions of what a map is and at the same time, everyone has an idea of what a map is (Tyner 2010). In this thesis, a map is defined as a graphic representation that shows geographic features, spatial relationships, and/or spatially referenced phenomena. Creating this

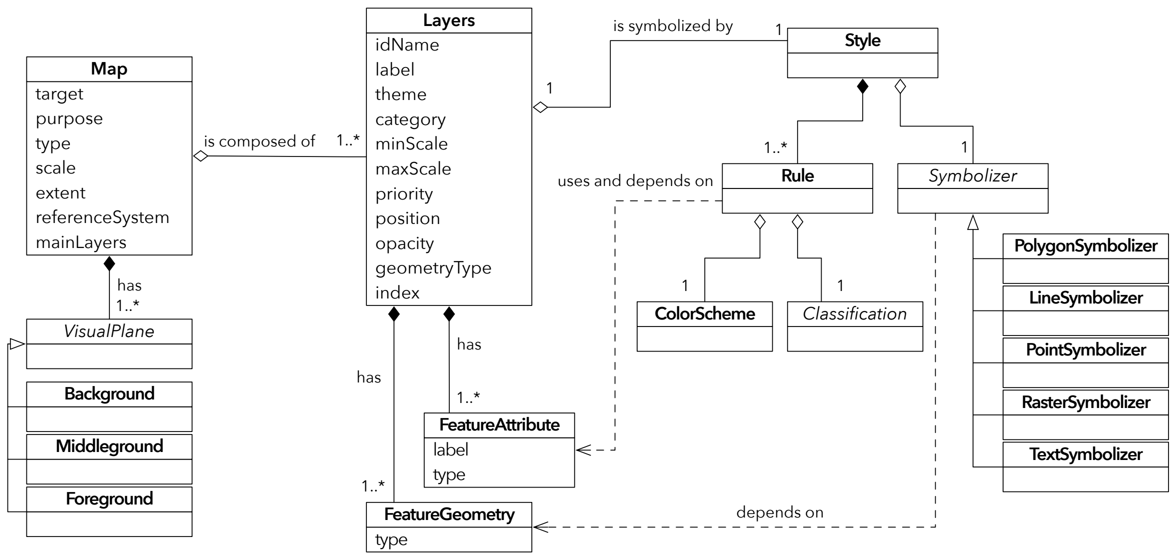

Figure 1. Contextual map model of the CartoWiz framework.

graphic representation is called the mapmaking process and is a broad term referring to the creation of maps at any scale, for any medium, and with any tools.

In the model, a map is thus composed of at least one layer and has several important properties for the map design process, such as a type, a scale, and one or two main layers. It also has several visual planes.

1.1. Map types

Maps are usually classified into several types according to their functions, content and/or scale (Robinson et al. 1995, Slocum et al. 2009, Tyner 2010), but a single classification upon which cartographers all agree does not exist. Furthermore, borders between different map types can be fluid, depending on the map content and purpose. However, for this thesis and the definition of the model, the following map types were established (Figure 2 for illustrations of the different types).

General-purpose maps (also called reference maps sometimes) focus on displaying the main features of an area, both physical and man-made. They help with orientation and understanding the spatial organization of a territory. They usually do not emphasize any specific topic. Finally, they do not display thematic data except in some rare cases, but then always in direct relation to the orientation purpose.

Physical maps focus on displaying the topographic and natural features of the landscape, such as mountains, rivers, and lakes. They might also show a few cultural information to help with orientation. Finally, they do not include thematic information.

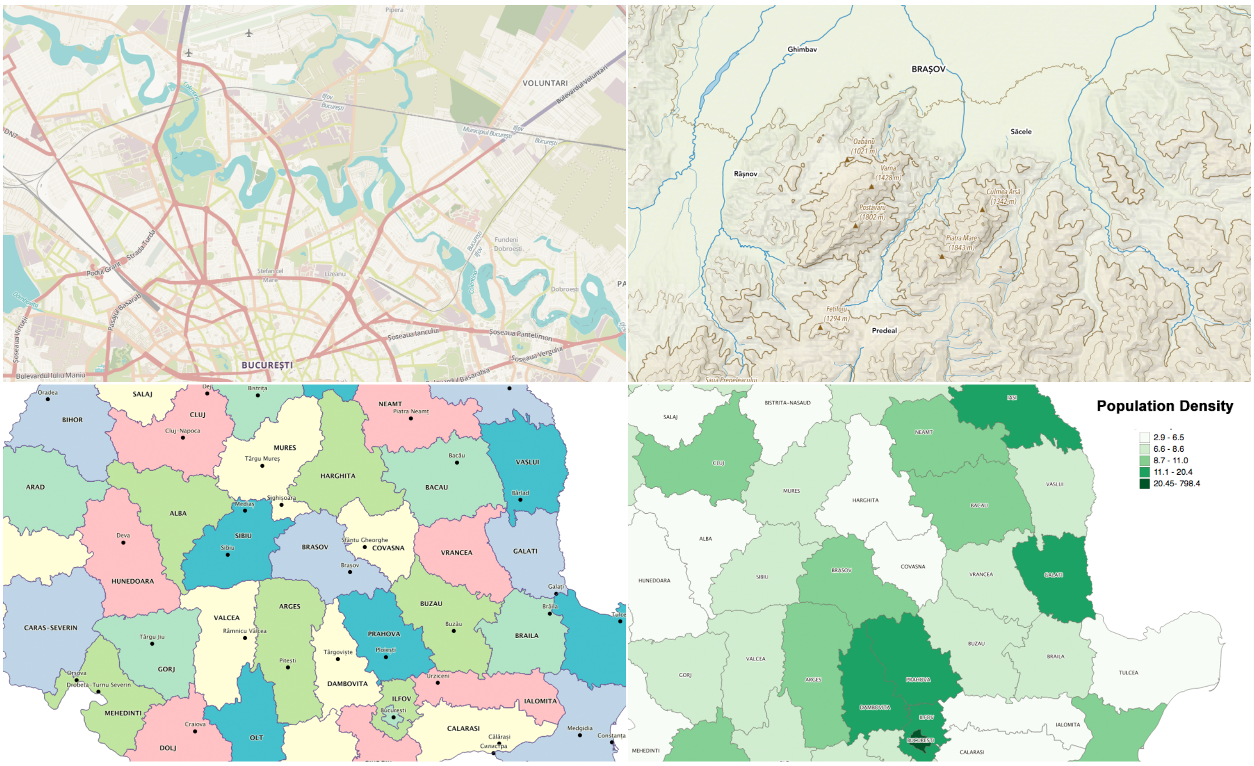

Figure 2. *Examples of a general-purpose map, a physical map, a political map, and a thematic map (from left to right, top to bottom).*

Political maps focus on showing administrative boundaries (national, regional, and/or local) and labeling places (cities, regions, countries, etc.). They rarely show details of the topography, but might display rivers and water bodies to help with orientation. Like physical maps, they also do not depict thematic data.

Thematic maps focus on a specific topic and display thematic data, such as statistics for administrative units or pollution values for streams. They show some geographic and cultural features for orientation purposes, but focus on spatial data with attribute values.

The model was built to allow the addition of further map types. For instance, maps with very precise purpose, such as geology maps, cadastral maps or navigation maps, have specific rules and symbolization standards that could be formalized into cartographic rules and added to the existing model.

2. Layers

In cartography, the meaning of the data represented in the map impacts the choices regarding symbols, colors and representation methods. Thus, the contextual map model provides semantic support for the layer content, which is used by the smart cartographic functions to decide on map content, layer order and visual hierarchy. The semantic information regarding layers is organized on two levels: categories and themes.

2.1. Layer categories

The layer categories allow to broadly distinguish layers with different content. The following four categories are part of the model.

The *Map image* category describes layers that are actually complete maps, with several themes combined and symbolized as a whole. Thus, they must be treated differently than other layers. Examples are scanned maps or topographic maps offered as one layer.

The *Natural* and the *Cultural* categories represent geographical features. They are concrete objects in the real world, meaning that one can go to the location shown on the map and see them. Natural geographical features that are natural object (not man-made), for instance a mountain, a river or a forest; whereas cultural geographical features have been made or shape by men, for examples an airport, a road, or a building.

Thematic information usually does not represent features on the ground but values associated with administrative areas, a delimited perimeter or points of measurement, such as for population density or pollution levels.

2.2. Layer themes

Layer themes offer a more detailed distinction of the content of the layers. The list in Table 1 has been created based on the survey of 21 national or regional geoportals aimed at the general public and is described in Chapter III *Smart cartographic framework and functionality*. This list covers 90% of the themes found in the geoportals and aims at mimicking the thematic organization and content most commonly available on those geoportals.

Table 1. Layer themes overview.

Theme	Geometry type	Examples
Administrative boundary	area	National or departmental borders
Transport	point, line, area	Rail network, bus stop, airport
Hydrography	point, line, area	Lakes, rivers, waterfall
Landuse	area	Commercial surface or farmland
Landcover	area	Forest or urban zone
Cadastre	point, line, area	Parcel ID or border
Buildings	point, area	Building footprint or centroid
Geology and soil	point, line, area	Rock or soil type, rift and fault, dip of bedding
Biodiversity and nature	point, line, area	Natural reserve perimeter, measurement station
Energy	point, line, area	Electrical lines, power plants production
Meteorology and climate	point, line, area, raster	Measurements stations, temperature and precipitations data
Population and society	point, line, area	Inhabitant, age distribution, unemployment, election results
Relief	raster	Shaded relief generated from the Digital Elevation Model
Topographic or base maps	raster	Scanned or digital version of the national topographical map
Satellite imagery	raster	LANDSAT imagery or imagery from the home institution
Ready to use maps	raster	Scanned historical paper maps, littoral or nautical maps

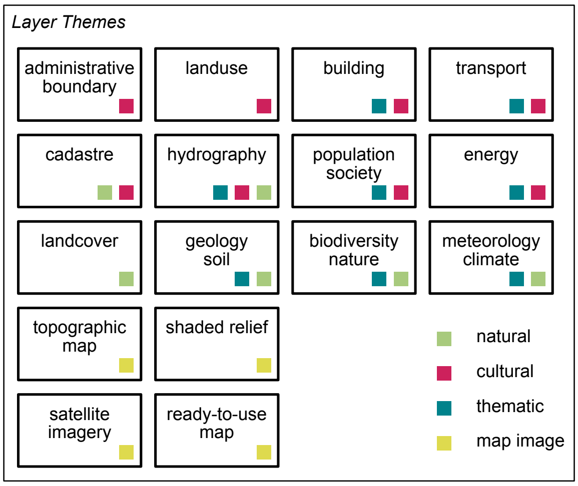

Figure 3. Layer themes and their relations to layer categories.
Source: Paper I in Chapter III (Panchaud et al. 2017).

In Figure 3, the layer themes and their categories in which they appear in geoportals are represented based on the results of the geoportal survey (Panchaud, Iosifescu Enescu and Hurni 2017).

3. Visual planes

Visual planes allow to organize the layers belonging to the map on several visual hierarchical levels based on their importance for the map. Combined with proper symbolization, it helps the map reader to perceive the organization of the map. The most important layers, which are the ones that pertain to the main map topics are placed in the foreground, while supporting information, such as a base map, belong to the background. The model supports a third plane in the middle for more flexibility. Indeed, according to (Spiess 1970), any well-designed map should have a least two levels, one for the main topic and one for background information. Cartographers can insert additional levels for a finer visual differentiation (Robinson et al. 1995).

The model supports the definition of three different visual planes and the framework also offers a function to assign the layers to the optimal visual plane based on the map type, and the layers' categories and themes. Finally, the framework provides different methods to modify the symbolization of the layers in the background to improve the overall visual hierarchy of the map.

More information about visual planes and visual hierarchy can be found in maps in Paper II in Chapter III *Smart cartographic framework and functionality*.

4. Style

A style is a set of parameters that defines how the features (for a vector layer) or dots (for a raster layer) are represented, i.e. drawn, on the map. The parameters are either assigned identically to all the features or dots of the layer or according to rules based on the attribute values associated with the features or dots.

To represent features on a map, one uses visual variables. The original set of visual variables has been defined by Bertin (1967) and then has been refined and extended, especially with regard to the digital map media. The original visual variables included color, value, shape, size, texture, and orientation. Later sets of variables added saturation and hue (equivalent to the color variable of Bertin), location (x and y coordinates), arrangement, focus or crispness, resolution, transparency, spacing, and perspective heights (Morrison 1974, MacEachren 1995, Krygier and Wood 2005, Dent,Torguson and Holder 2009, Slocum et al. 2009, Kraak and Ormeling 2011). In online mapping platforms and geoportals, the most used variables are size, shape, hue, value, saturation, transparency, and orientation.

The implementation described in this thesis uses symbolizers and rules to define the symbolization of each layer and its features. Each of these components is described in the section below from an implementation point of view, which means that they are dependent on the technological choice to use the Web Map Service (WMS) and Styled Layer Descriptor (SLD) standards. However, many of the common visual variables are available within other frameworks as well.

4.1. Symbolizer

A *Style* object can have several instances of a same *Symbolizer*, and each of these instances is associated with one or more rules. There are different symbolizer definitions for each different geometry types (point, line, area, and raster) and for labels. *Symbolizers* allow to assign colors to features, to define the thickness and colors of their contour,s to apply symbols to points, as well as many other parameters. The most used parameters in this thesis are the color and transparency options: they are used in the functions that change the background style.

4.2. Rules

A *Rule* objects allow to assign symbolizers to only a subset of the features belonging to a layer based on their attributes, both qualitative or quantitative. To build a rule, there need to be three components: an attribute, an operator, and an attribute value. For instance, the attribute can be “population _density”, the operator “<”, and the value “1000” and if the rule is coupled with a symbolizer that fills areas red, then all the administrative areas with a population density higher than 1000 will be drawn red. Rules can be combined and lead to complex style definitions that are scale-, layer-, and attribute-dependent, thus allowing for elaborated map symbolizations.

4.3. Color schemes

In the model, color schemes are defined as an array of colors, which are combined with the classification element, in order to build the rule element. There are three main types of color schemes (Figure 4). However, is also possible to have a color scheme of a single color, for any layer in which all features are represented uniformly, e.g. for the layer “lakes”.

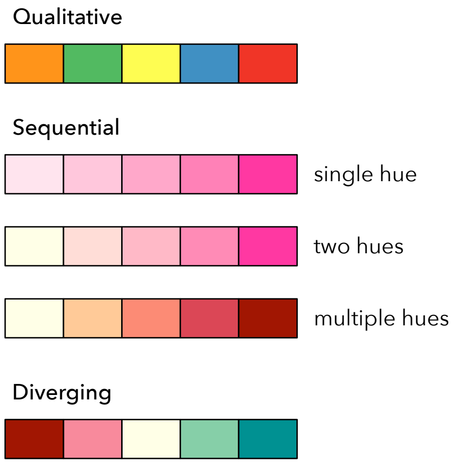

Figure 4. *Color schemes.*

A qualitative color scheme is made of different colors that do not show any relation beyond differentiation of features into separate categories: features with the same colors belong to the same categories and different colors indicate different categories. A sequential color scheme represents a gradation between colors, from low to high. Such color scheme usually plays with lightness values to show the steps, from light for low to dark for high. Sequential color schemes can be generated based on one, two or more hues. Examples of topics represented with a sequential color scheme are for instance danger map (ordinal) or population density (numeric – ratio). Diverging schemes are used with data departing from a central value, usually represented with a light color and then emphasize both ends of the scheme with two different darker colors.

Table 2. *Data scales and their properties (based on Slocum et al. 2009 and Zhang 1996).*

	Properties			
Data scales	**Categorization, grouping**	**Ordering, ranking**	**Numerical difference, magnitude**	**Absolute zero**
Nominal	Yes			
Ordinal	Yes	Yes		
Interval	Yes	Yes	Yes	
Ratio	Yes	Yes	Yes	Yes

Table 3. Color schemes and data scales.

Color scheme	Works with data scales	Example
Qualitative	Nominal	Landuse
Sequential	Ordinal	Low, medium, high quality of life
	Interval	Temperature
	Ratio	Monthly precipitations average
Diverging	Ordinal	Lower, average, higher quality of life
	Interval	Standard deviation of the monthly temperature average
	Ratio	Increase of literacy rate

The use of different types of color scheme is linked to the type of data scale. Table 2 shows the properties of the different data scales and Table 3 the relation between data scales and color schemes). Nominal data such as landuse type (farmland, industrial, commercial, etc) are qualitative data and can be thought as labeling categories. Ordinal data scales are data in which there is an order or a gradation, but the steps between the gradation are not known. An example could be the quality of life in cities described as low, medium, and high. Interval and ratio scales are numerical and have a gradation, of which we know the exact value between the steps. The difference between them it that the interval scales do not have a true zero: population density is a ratio scale because a 0 density means the absence of population, whereas a temperature scale is an interval scale because 0° C does not mean there is an absence of temperature, the 0 is set "arbitrarily" to the temperature at which water freezes.

4.4. Classification

In order to represent geospatial data meaningfully on the map, it often requires organizing features belonging to a same layer into classes. Each class is symbolized in a unified manner and its relation to the other classes gives information about how the data relate to each other. For instance, symbols indicating the size of a phenomenon can increase as the value of the phenomenon increases, such as the number of inhabitants represented as a circle for each city.

In the model, each classification object describes the number of classes and their thresholds and refer via the Rule object to the attribute that is used for the classification as well as the color scheme. The thresholds and number of classes are used in combination with the attribute names and values, and colors of the color scheme to generate the style. In the proof-of-concept implementation, this information is stored and organized with SLD and accompanying standards Symbology Encoding (SE) and Filter Encoding (FE), and then used to tell the WMS how to symbolize the data.

For more information about classification methods and how to compute them, please consult to a reference book, such as *Thematic Cartography and Geovisualization* from (Slocum et al. 2009).

5. Implementation

This section explains succinctly the implementation of the contextual map model and shows concrete examples of code. The contextual map model and more specifically the Map object is in the form of a JSON (JavaScript Object Notation) object, which is attached to the window object of the browser. Because of the JSON format, the Map object is easy to manipulate with JavaScript and it does not require much space because it is only a text format.

5.1. Map object

The map parameters are set as properties and the layers belonging to the map are stored in an array of objects; each layer being an object in itself (Figure 5). Certain parameters of the map are stored in arrays of parameters, such as the list of layers belonging to the main layers the list of layers belonging to the back-, middle- and foreground.

5.2. Layer object

The structure of the Layer object is similar to the one of the Map object. The layer parameters are object properties and other features, which are objects themselves, such the attributes and the style information, are attached to the layer as arrays of objects (Figure 7).

5.3. Style object

The structure of the style object is straightforward and matches color information with a symbolizer and a rule (Figure 6). Due to the nature of the work, the style focus on color and transparency information, but it can be expanded to include other parameters, if need arises. The rule allows to match the color information with concrete features within the layer.

5.4. Warnings

When the framework detects issues with the user map, it stores the warnings and errors in arrays attached to browser window similarly to the Map object (Figure 8). The framework provides functions to request warnings or errors that have been issued.

For the framework implementation in this thesis, it was chosen to display the results of these functions either in a message panel or in pop-up windows in case of errors that require action from the user (see *Appendix B — Use case scenario*).

```
"myMap": {
  "type": "General",
  "scale": "222300",
  "extent": ["517'445", " 483'990", " 576'554", " 438'010"],
  "referenceSystem": 31700,
  "mainLayersArray": ["Parks", "OSM Amenity"],
  "foreGround": ["Parks", "OSM Amenity"],
  "middleGround": ["Water streams original", "Water bodies original", "Highway original", "Populated
    places"],
  "backGround": ["Shaded Relief", "Landuse original", "Natural"],
  "layersArray": [{
      "idName": "ro_relief_shaded",
      "label": "Shaded Relief",
      "theme": "relief",
      "category": "",
     ...
  }, {
      "idName": "ro_osm_landuse_pl_org",
      "label": "Landuse original",
      "theme": "landuse",
      "category": "cultural",
     ...
  }, {
      "idName": "ro_osm_natural_pl_org",
      "label": "Natural",
      "theme": "nature",
      "category": "natural",
     ...
  }, {
      "idName": "ro_osm_waterway_ln_org",
      "label": "Water streams original",
      "theme": "water",
      "category": "natural",
     ...
  }, {
      "idName": "ro_osm_waterway_pl_org",
      "label": "Water bodies original",
      "theme": "water",
      "category": "natural",
      ...
  }, {
      "idName": "ro_osm_highway_ln_org",
      "label": "Highway original",
      "theme": "transport",
      "category": "cultural",
      ...
  }, {
      "idName": "ro_natura_parks",
      "label": "Parks",
      "theme": "nature",
      "category": "thematic",
     ...
  }, {
      "idName": "ne_10m_populated_places",
      "label": "Populated places",
      "theme": "society",
      "category": "cultural",
      ...
  }]
}
```

Figure 5. *JSON implementation of the Map object (the layers have been shortened for this example).*

```
"style": {
    "symbolizer": "polygon", //polyong, line, point, raster, text
    "parameter": "fill", // fill, stroke, etc.
    "colorScheme": ["#ddf2c9", "#9dca8a", "#fff0b7", "#b4d0d0", "#ffffff"], //color scheme
    "rule": {
        "type": "propertyIsEqualTo",
        "property": "natural",
        // attribute values matching the colorScheme array
        "values": ["grassland", "wood", "beach", "water", "glacier"]
    }
}
```

Figure 6. *JSON implementation of the style object. Style objects are attached to layer objects.*

```
{
  "idName": "ro_natura_parks",
  "label": "Parks",
  "theme": "nature",
  "category": "thematic",
  "minScale": "1000",
  "maxScale": "3000000",
  "priority": true,
  "position": "foreground",
  "opacity": 1,
  "geometryType": "polygon",
  "index": 6,
  "attributeArray": [{
      "name": "id",
      "type": "integer"
  }, {
      "name": "nume",
      "type": "nominal"
  }, {
      "name": "cod_nat",
      "type": "nominal"
  }, {
      "name": "typ",
      "type": "nominal"
  }, {
      "name": "numar",
      "type": "double"
  }],
  "style": {...}
}
```

Figure 7. *Layer object (the style object has been simplified). Layer objects are attached to map objects.*

```
"warningListLayersSel": [
    ["warningThematic", "Warning", "Thematic layer(s)", "The wizard does not support thematic layers
        yet. They will not be taken into account for the symbolization."],
    ["warningLanduseThematic", "Warning", "Thematic and landuse overlaps", "Combining polygonal
        layers representing landuse and thematic data will lead to overlapping features and lesser
        readability of the map."]
],
"warningListMapType": [
    ["errorNoBoundary", "Error", "Administrative boundaries absent", "In a political map, you need
        administrative boundaries, which you do not have here."],
    ["errorThematic", "Error", "Thematic layer present", "In a political map, you cannot have a
        thematic layer, which you have here."],
    ["warningNatural", "Warning", "Too many natural layers", "Traditionally, in a political map,
        there is little information about the physical landscape, except for rivers and lakes. You
        might have too much such information here."]
],
"warningListMainlayers": [
    ["warningOneMainLayer", "Warning", "Only one main layer", "You only selected one main layer for
        your map. If you are sure, ignore this warning"]
],
"warningListScale": [
    ["warningTooDet", "Warning", "", "The following layer has a larger scale than the map. Thus it
        might be too detailed: OSM Amenity. "]
]
```

Figure 8. *Warning and errors arrays: each belongs to a certain category and has an ID, a type, and a message.*

Appendix B – Use case scenario

1. Initial situation

This section illustrates the different functions of the framework and proof of concept via a use case scenario. It allows to go through each step, potential conflict and resolution of the framework as implemented in the proof of concept. The scenario is as follows:

> A citizen and casual mapmaker will go to visit natural parks in the region of Brașov and wishes to prepare a map at two different scales showing the location and access to the region, as well as the different amenities and local roads to the parks.

The scenario is built in such a way as to provide meaningful examples, containing layers with different geometry types and categories, and at two different scales.

2. Layer selection

The user selects layers pertaining to the purpose of the above-mentioned scenario: starting with the ones most important for the map's purpose – parks, amenities and roads layers (Figure 1)– then adding some additional supporting layers. We assume that the user is not familiar with the content

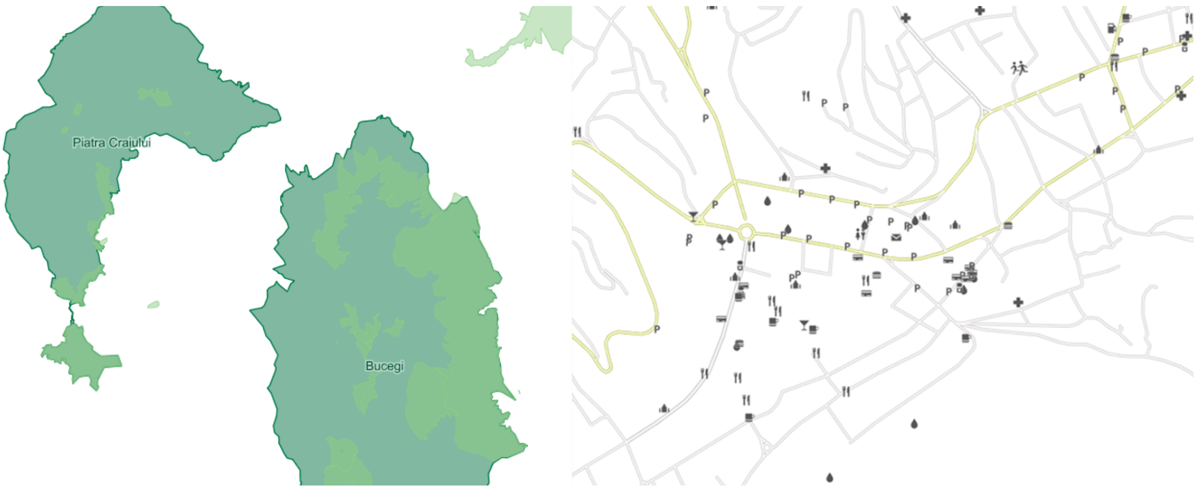

Figure 1. Natural parks (left) and amenities and roads (right) are the main layers of the map.

of the geoportal and might thus go back and forth between the different map products before settling on the final selection of layers and which would result in a potential chaotic initial drawing order of the layers. During the selection of the layer, the user can see at any time which layers are already in the user map by switching to it (Figure 2). When the layer selection is done, the user can start the wizard.

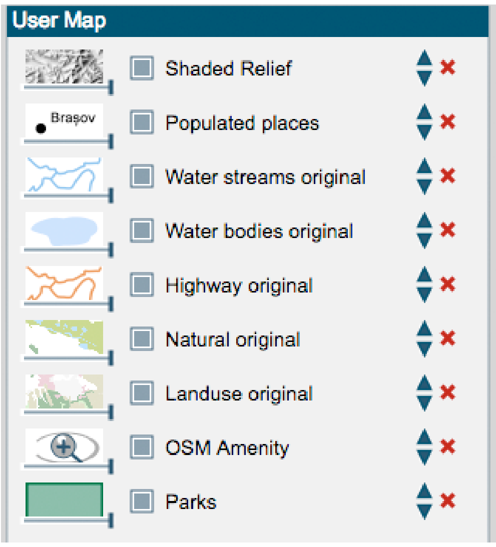

Figure 2. *User map panel with the user layer selection.*

3. Content constraints

The content constraints happen at stages 1 (Layer Selection) and 2 (Map Definition) of the wizard. At these stages, the framework can already detect some potential conflicts based on the layer selection and map parameters.

3.1. Layer list

At the start of the wizard and based on the selected layers, the framework can already bring a couple of warnings (Figure 3) to the user attention. Because the park layer is a thematic layer, a first warning explains that thematic layers are not supported for the symbolization stage. This means that the symbolization of thematic layers will not be adapted. Then, another warning regarding the combination of polygonal thematic layers and landuse layers is issued, because it can lead to unwanted overlaps if not dealt with at a later stage (see stage 4 of the wizard for the symbolization adaptation). By clicking on the warning, a window opens with detailed explanations (Figure 4).

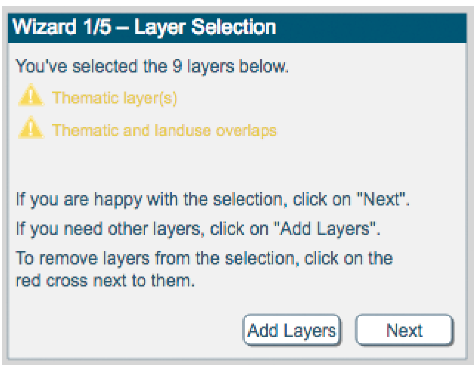

Figure 3. *Wizard window 1 – Layer Selection and associated warnings regarding the layer list.*

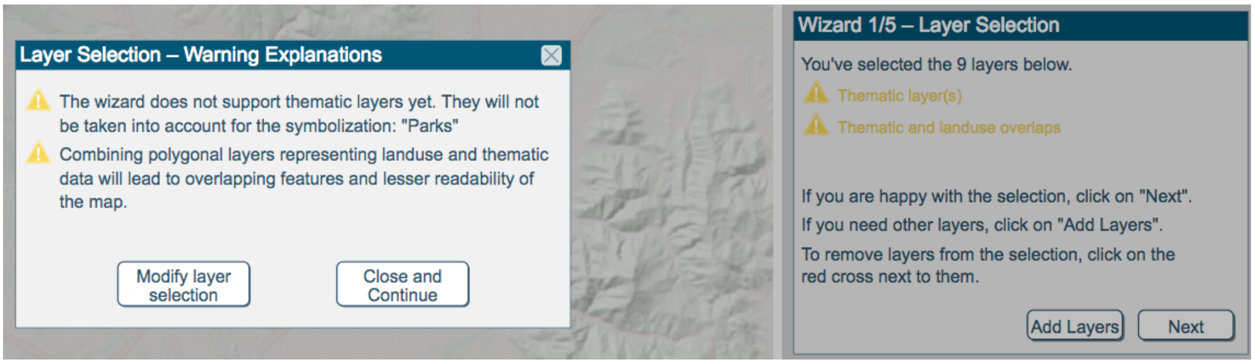

Figure 4. Warnings related to the layer list in the scenario.

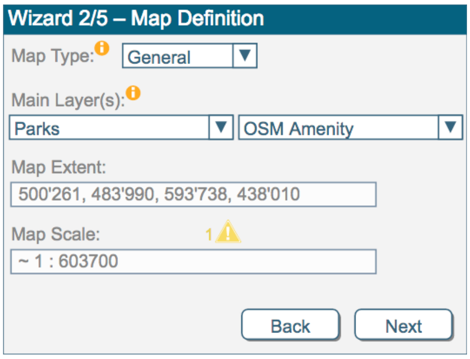

Figure 5. Wizard window 2 - Map Definition with the map parameters and warning signs related to map type and content.

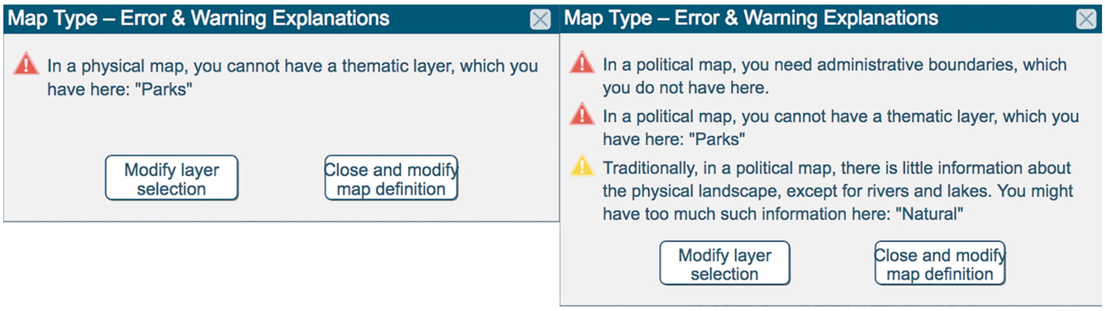

Figure 6. Conflicts due to map type and layer list incompatibility.

3.2. Map type and content

At the second stage of the wizard, the framework checks for compatibility issues between the map parameters, such as the map type and scale, and the layers selected and their parameters (Figure 5). For instance, if the user picks a political or a natural map for their map, there will be warning and error messages (Figure 6).

3.3. Main layers

In the second wizard window, the framework preselects layers that have a high probability to be the main layers of the map and lets the user adjust them. Warnings are issued if the user chooses not to have main layers or only one in the map, but it does not prevent going to the next stage, whereas picking twice the same layer as main layers triggers an error icon and message, which prevents the user from moving to the next stage.

3.4. *Scale*

The framework also signals the user when the optimal scale range of the layer does not comprise the map scale (Figure 7). It does not prevent the user to keep the layer in their map, however, the issue is raised and explained. In this use case, the amenities layer is thought for a map at a large scale and at that point, the user still has the map scale set on a much smaller scale. In that specific situation and layer, there is even a scale-based symbolization of the layer on the server side and the layer is not visible at that actual scale.

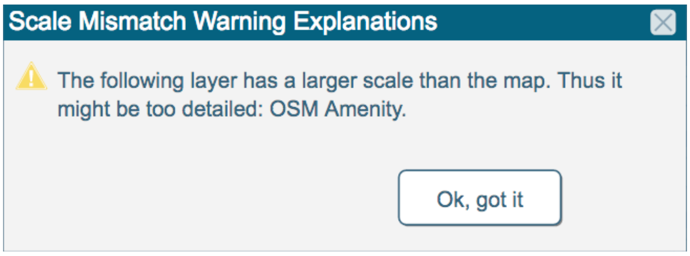

Figure 7. *Conflict due to scale mismatch.*

4. Layer drawing order

At the third stage of the wizard (Figure 8), the layers are re-ordered to optimally display all the features and to prevent unwanted overlaps (Figure 9). Additional considerations are taken into account to order the layers, such as the layer categories (e.g. a thematic layer will be drawn above a natural layer with the same geometry type) and the layer theme (e.g. administrative border, often represented by polygon geometries, will be drawn above other polygon layers). At this stage, the user can decide to adapt the suggested order by using the down and up arrows next to each layer.

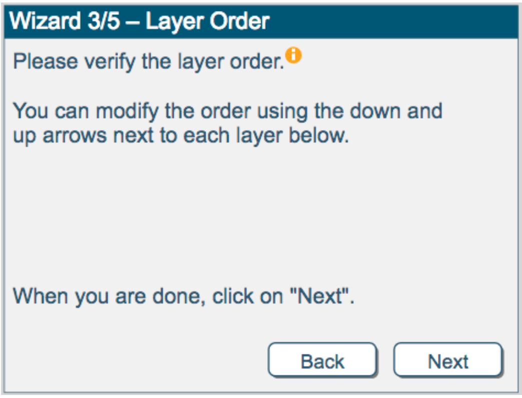

Figure 8. *Wizard window 3 – Layer Order.*

5. Visual hierarchy

Issues with the visual hierarchy in the map are dealt with during the fourth stage of the wizard and in two steps. First, the framework assigns each layer to one of the three visual planes. The user can make changes to the visual plane assignment, if the automated results are not satisfying. Second, changes in symbolization can be applied to the background layers to improve their contrast with the main layers and thus supporting a better overall visual hierarchy in the map.

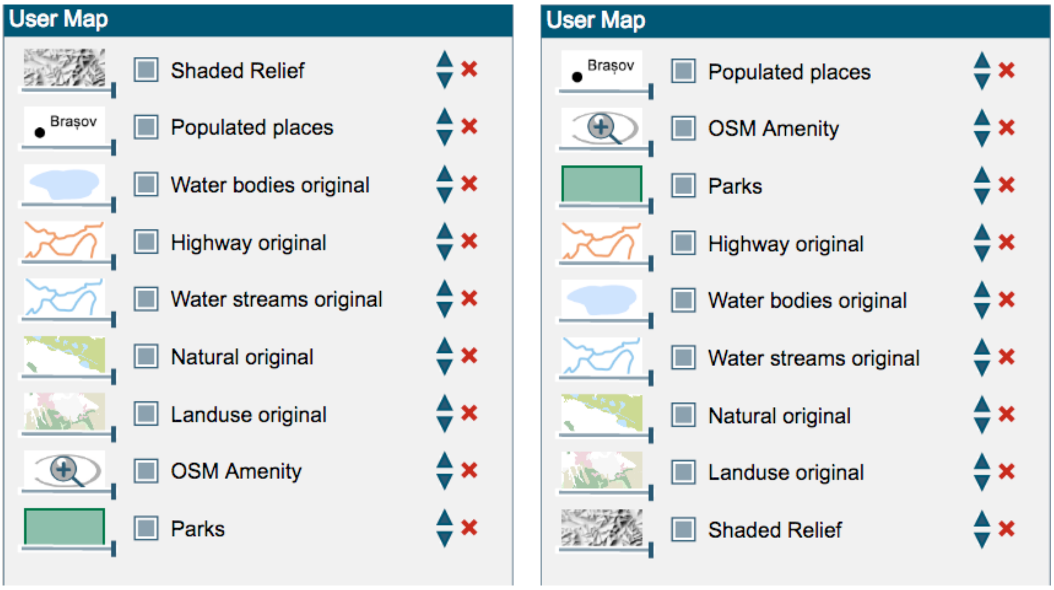

Figure 9. *Layer stack before (as added by the user) and after the re-ordering according to cartographic best practices as implemented in the framework.*

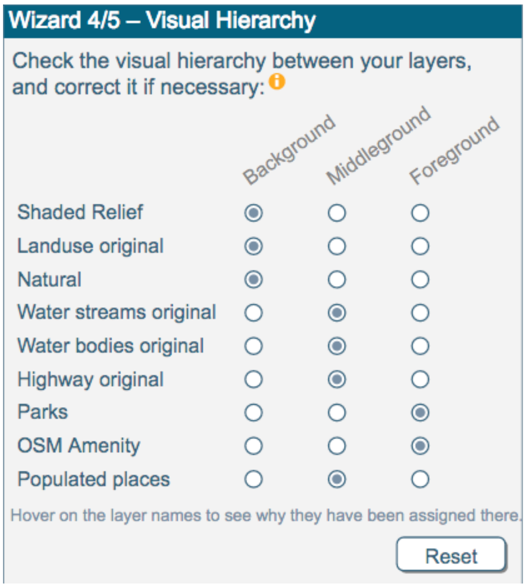

Figure 10. *Assignment of the layers to the three visual planes.*

5.1. Visual plane

The layers defined as the main layers of the map are automatically assigned to the foreground, here the parks and the amenities. Then, polygonal layers and raster data that are of the natural category and that are not water-related are assigned to the background, here the landuse, natural and shaded relief layers (Figure 10). Later, rules specific to each map type play a role and might modify results from the general rules. Any layer that has not been assigned is left in the middle ground. The user can adapt the assignment and reset the original one if needed.

5.2. Background symbolization

The framework offers three different methods of symbolization for background layers: grayscale, desaturation, and smart background. All three methods leverage the principle of figure-ground and increase of contrast to improve the overall visual hierarchy of the map. They are described in detail

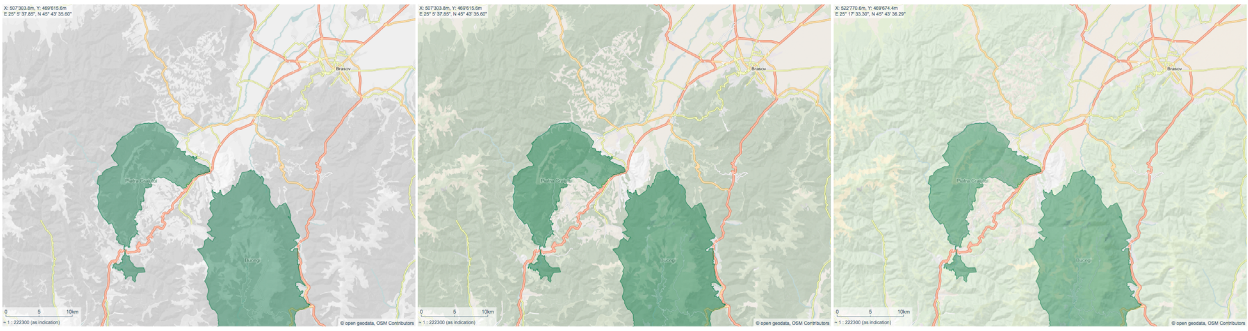

Figure 11. Different background symbolization methods: grayscale, desaturation, and smart background.

in Paper II *Smart cartographic background symbolization for map mashups in geoportals: a proof of concept by example of landuse representation*. In Figure 11, you can see the different results for the use case presented here at large scale. Part of the small scale map with the amenities is shown in Figure 12.

5.3. Transparency

Additionally, there is also a function dealing with changing the transparency setting of layers in certain conditions. These conditions consist mainly of overlaps of polygon layers and the presence of map image or relief in the background of the map. An approach to polygon overlaps between layers involves increasing the transparency of at least the top layer and potentially of both to guarantee that features on both layers are visible. The same approach can be used when a shaded relief and landuse information are present in a map to display a fused symbolization of a shaded relief colored according to the landuse categories. In this case, both layers should have some transparency. Moreover, any transparency modification of the landuse symbolization are taken into consideration by the background symbolization methods because a transparent layer gives an impression of reduced chroma and because the combination with a relief adds a grayish impression to the other layer, thus the changes in the methods are adapted when transparency is added.

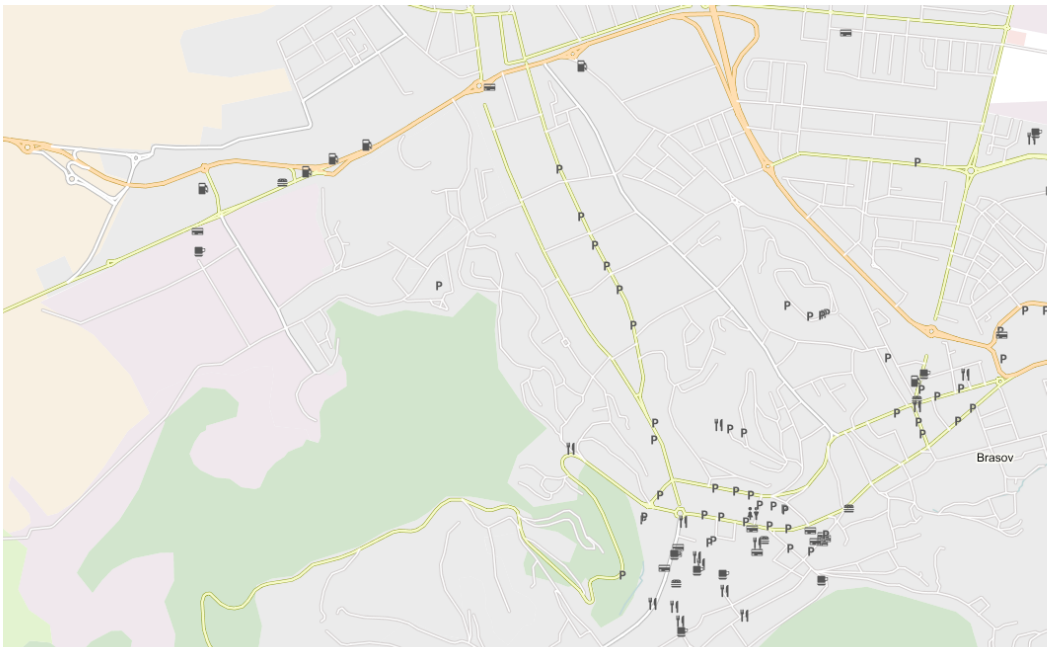

Figure 12. Smart background symbolization with amenities near Brașov.

Appendix C – Technical implementation

1. CartoWiz framework implementation

This section reviews shortly the different components of the CartoWiz framework implementation within the proof of concept. The CartoWiz library is one of the main results of this thesis and is written in JavaScript. Because the library is implementation-independent, it means that for the proof of concept, additional scripts were needed to provide links between the GUI and the core library: the wizard and the additional GUI scripts (Figure 1). The wizard, added on top of the existing GUI, is the interface between the users and the CartoWiz functionality. In the middle, there are implementation-specific scripts, which are linked to both the GUI and the CartoWiz logic, and JSON parameters files, that hold semantic and technical information about the layers in the geoportal.

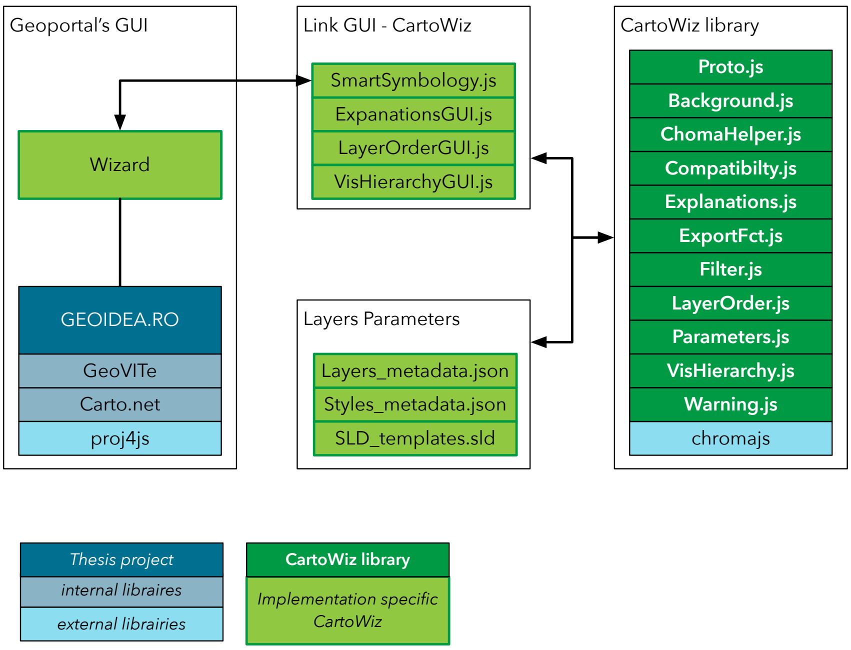

Figure 1. Components of the CartoWiz implementation.

Additionally, the geoportal's GUI relies on the succeeding additions to the Carto.net framework, the GeoVITe framework and then the Geoidea.ro project, and on a couple external libraries.

Carto.net

The Carto.net framework is a collection of scripts that enables the creation of a web-based map interface. It is based on Scalable Vector Graphics (SVG) for the Graphic User Interface (GUI) elements and JavaScript for interactivity. It a was developed at the Institute of Cartography and Geoinformation, ETH Zurich and served as the foundation for the GeoVITe project.

The Carto.net framework is published under a GNU Lesser General Public License and is available online with detailed tutorials at http://www.carto.net/papers/svg/samples/index.shtml.

GeoVITe

The GeoVITe (GEOdata Visualisation and Interactive Training Environment) project has been developed since 2004 at the Institute of Cartography and Geoinformation, ETH Zurich with the goal of providing an overview of, on-demand access to and download possibilities of geospatial data over the Internet to ETH employees. The core of the framework relies on the Carto.net framework, to which additional capabilities have been added. The GeoVITe framework is built on a three-tier architecture, that was also used in this thesis. In 2016, the GeoVITe project has been rebooted with other technologies in the framework of the Geodata4SwissEdu project.

Geoidea.ro

The Geoidea.ro project was instrumental in assembling the required geoportal technologies, geospatial data for the work achieved in this thesis. It is built upon the GeoVITe and Carto.net frameworks. For more information about the project, please refer to the section *Geoidea.ro project*.

Proj4js

Proj4js is a JavaScript library that transforms coordinates from one reference system to another. It plays a small role in the Geoidea.ro project dealing with coordinates transformation for the name search capabilities. It is available at http://proj4js.org.

Chroma.js

Chroma.js is a JavaScript library that manipulates colors, color spaces and color transformations. It serves as helpers for the functions dealing with background symbolization in the CartoWiz framework. It is available at https://github.com/gka/chroma.js.

2. Wizard detailed workflow

The figures in this section show the detailed workflow behind the implemented wizard. The wizard allows to link the functionality of the framework with the geoportal and to offer a graphic interface to the user. Each box in the figure represents a function. Each function has a color code that indicates its role or purpose according to the legend in Figure 2. White boxes represent functions that bind the GUI to the framework by responding to user interactions and by calling the appropriate functions from the framework. They also parse the results of the framework functions and apply any change required to the map. The arrows between the functions show how the functions are linked, either by being called by another function, by a user action or under certain conditions.

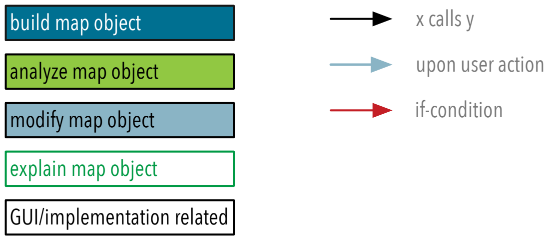

Figure 2. Legend for the detailed workflow.

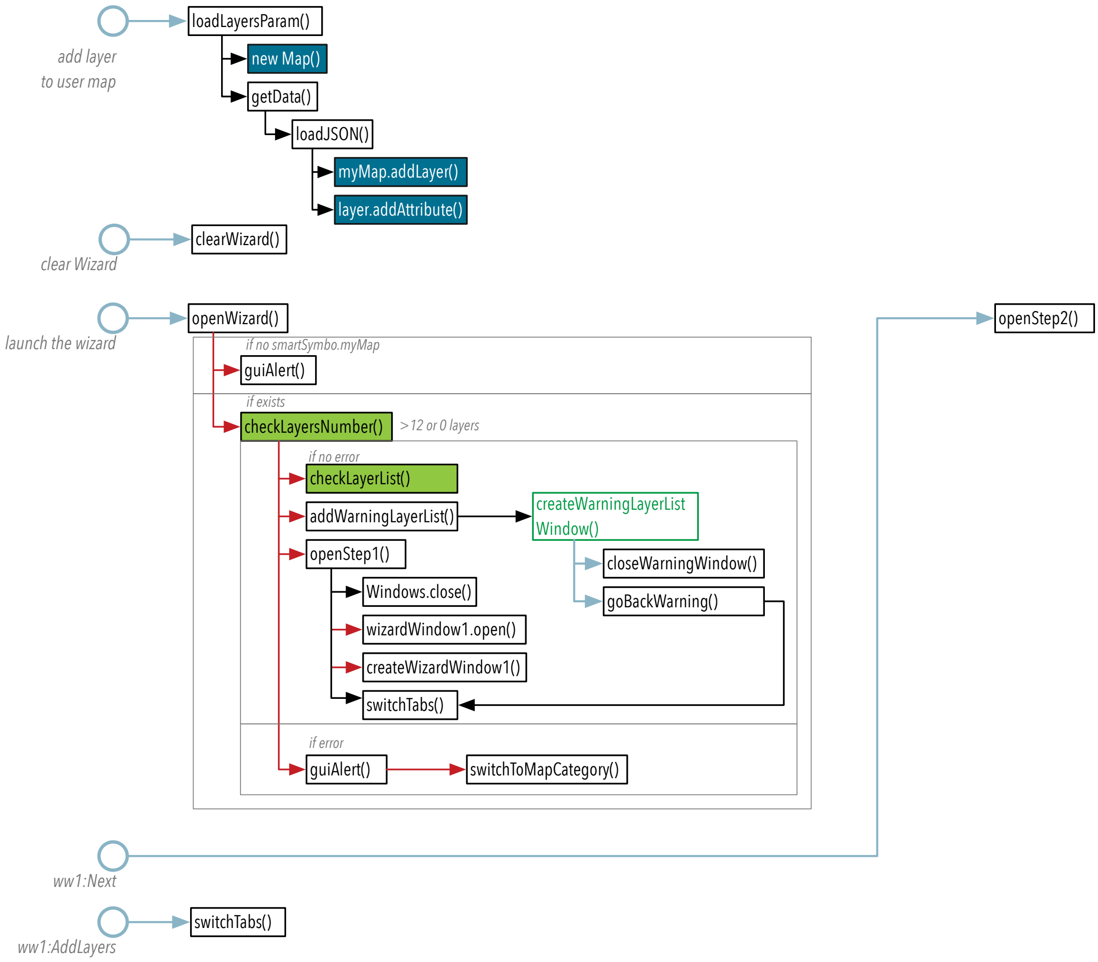

Figure 3. Wizard workflow, stage 1.

The white boxes with green text stand for functions that display in the GUI explanations about the function parameters, the map, the results of functions or the warnings and errors. The dark blue, light blue and green boxes are part of the framework and interact with the contextual map model.

Figure 3, Figure 4, Figure 5 and Figure 6 represent the different stages of the wizard. In stage 1 (Figure 3), the layers are selected, the wizard launched and some compatibility checks are run.

In stage 2 (Figure 4), the map parameters are defined and further compatibility checks are done regarding map type, map scale, and layer semantics.

In stage 3 (Figure 5), the layers are re-ordered to prevent unwanted overlaps. This stage also offers users the possibility to modify the drawing order of the layers, which is enabled by the functions in Figure 7.

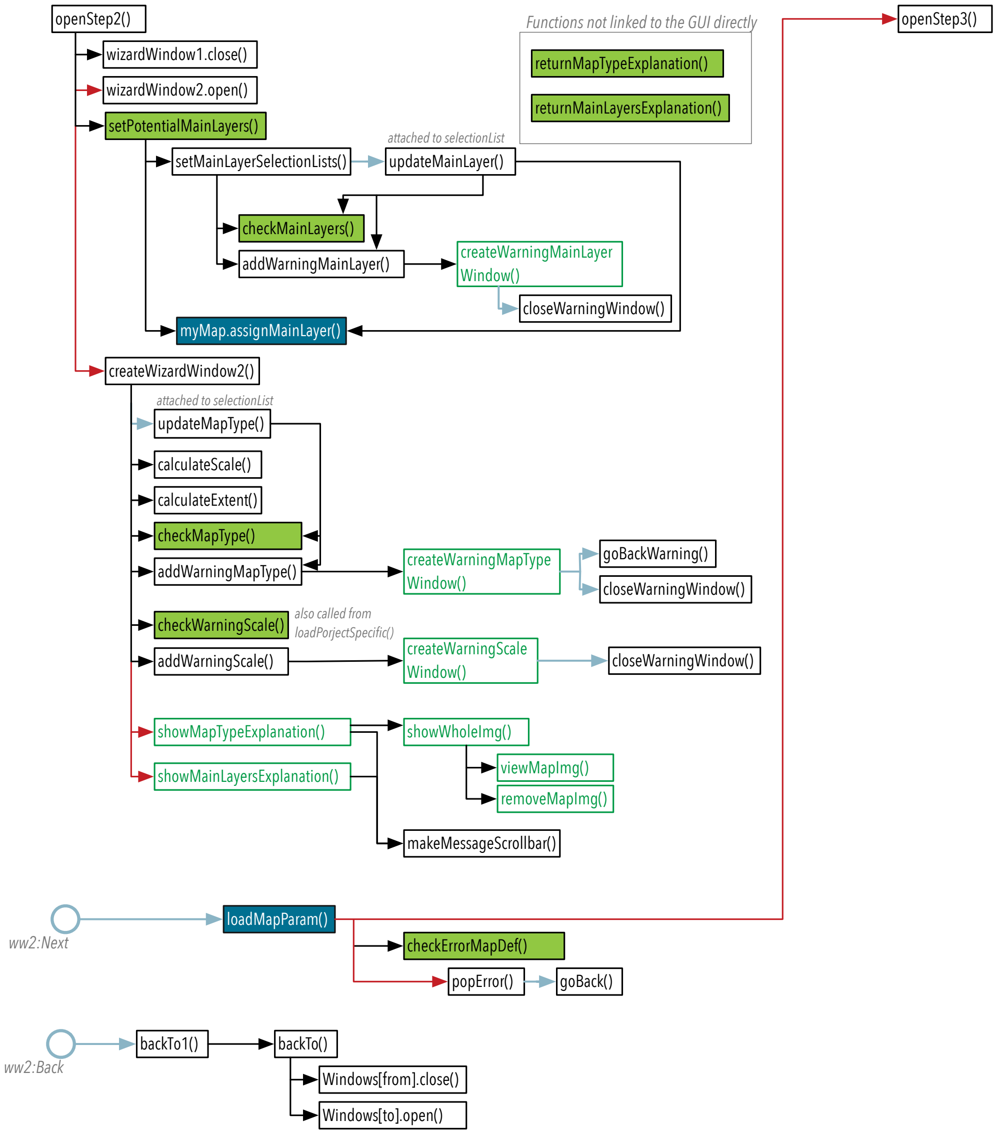

Figure 4. Wizard workflow, stage 2.

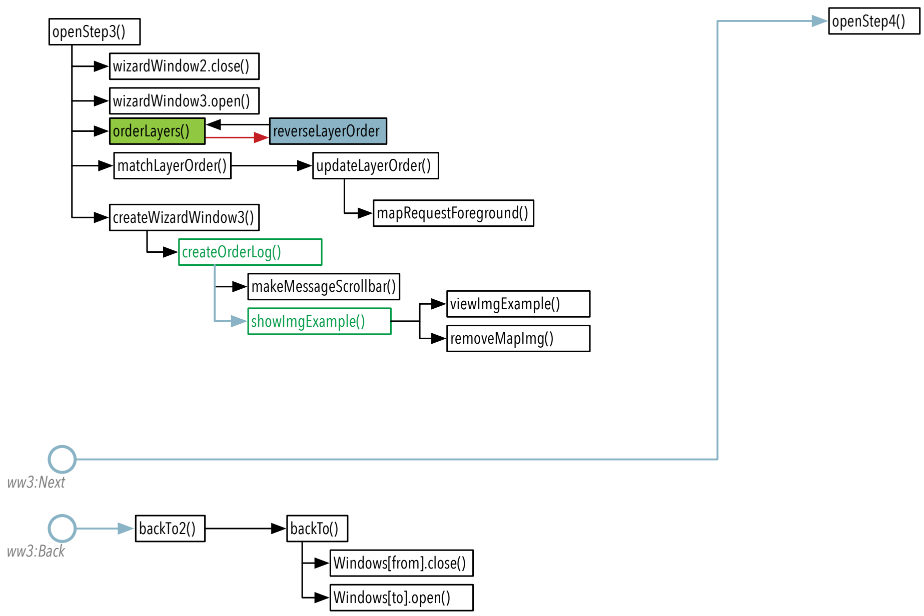

Figure 5. Wizard workflow, stage 3.

Stage 4 (Figure 6) deals with visual hierarchy and symbolization for background layers, while stage 5 offers a summary of the symbolization changes performed and offers a function to export the map description from the framework.

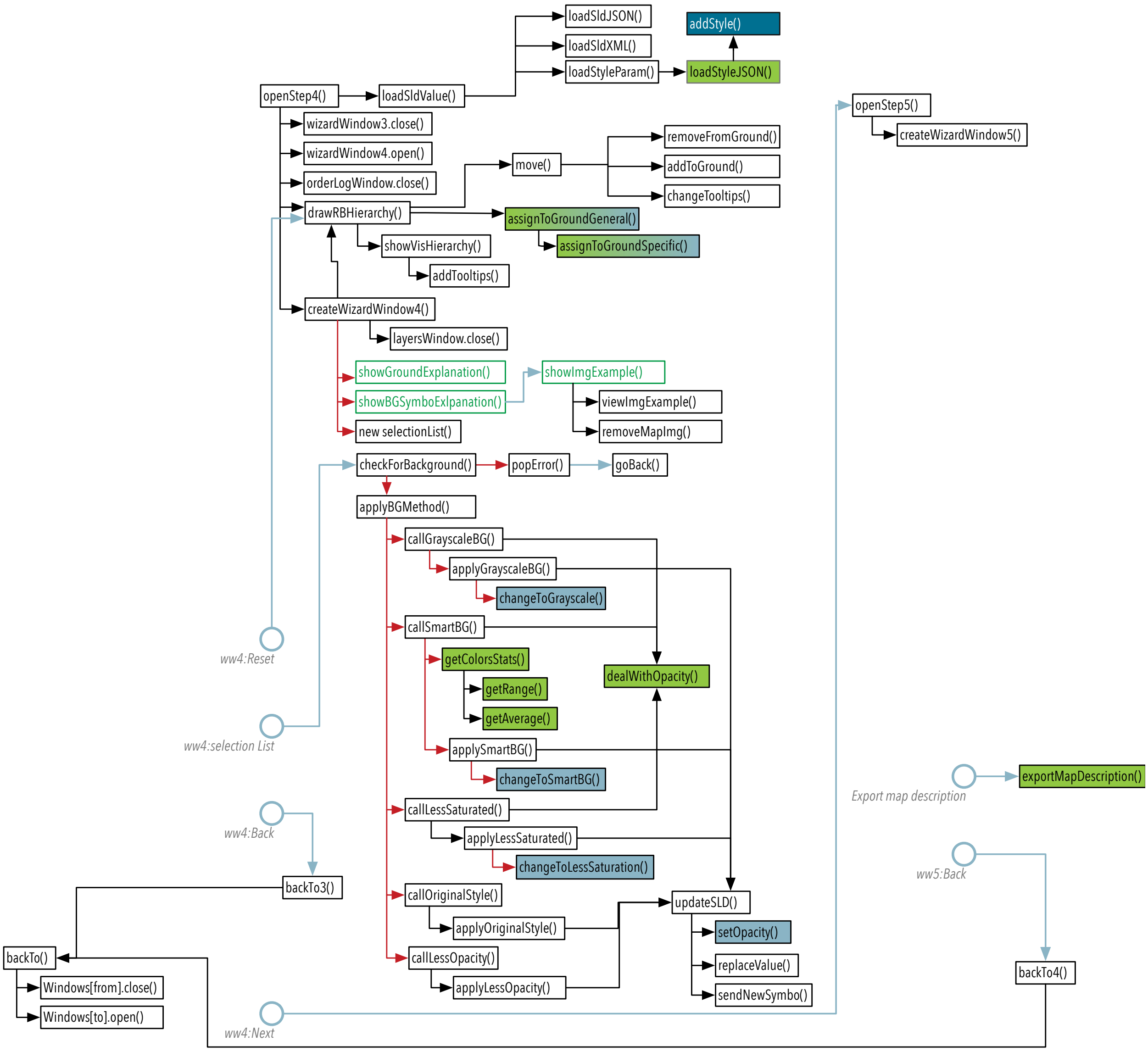

Figure 6. Wizard workflow, stages 4 and 5.

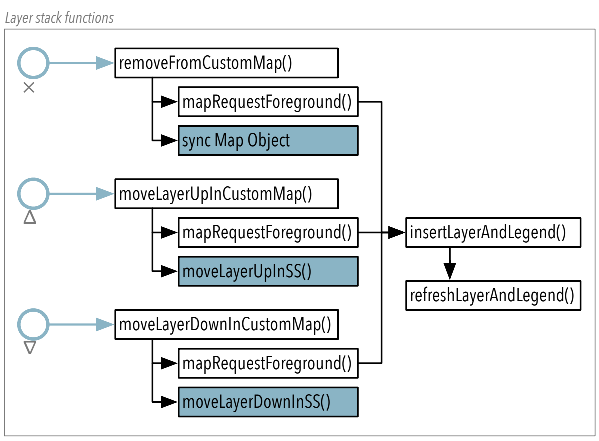

Figure 7. Layer stack functions.

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