A WEB SERVICE TO PERSONALISE MAP COLOURING

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Abstract

Offering geospatial data in the World Wide Web (WWW) has developed rapidly in recent years. Today, a lot of data sources are available, many of which provide data by using a Web Map Service (WMS) as interface which is specified by the Open Geospatial Consortium (OGC). In this way, interoperability is achieved: Data and maps are accessible and usable independent of formats, systems, and vendors.

The portrayal output of these services enables users to combine data of different sources. Overlaying these data allows for creating maps serving certain purposes on demand. In simple cases, such an overlay may be just an enhancement of existing maps by some features, in other cases, it may result in entirely new maps, which compose many features of different thematic layers.

However, a problem of this approach appears immediately: Since graphical representation of data from each source is defined on its own, graphical representations of different sources may conflict. As a result, a user may obtain a map which does not meet the requirements of a concise cartographic product. This is due to a non-distinguishability of colours of different feature types. Thus, a significant improvement is achieved by using colours which are well distinguishable by human visual perception. This ensures an exact identification of all features contained in a map. A further improvement can be achieved by taking into account the specific characteristics of the user's perception, digital device, and environment. These factors suggest the usage of well distinguishable colours, which are personalised with regard to the user's characteristics.

Selection and appliance of such colours can be supported by a Web Service. This service acts as proxy server between WMS and users. In order to do so, it involves three main functions:

- *Creating and storing user profiles*: Apart from user name, password and email address a user profile contains information on user's colour vision and display characteristics.

- *Selecting well distinguishable colours*: The distinguishability of colours is modelled mathematically by a distance function. Unfortunately, the standard RGB (Red Green Blue) colour space (sRGB), which is typically used by digital devices, is not suitable: Colour-differences perceived by humans do not correspond to colour-differences calculated from sRGB numbers. Therefore we transform sRGB to the CIELUV colour space, which provides this characteristic approximately. In CIELUV we determine well distinguishable colours by formulating a MAXMIN optimisation problem, i.e. a problem which aims at maximising the minimal distance between all colours. User's profile characteristics are modelled by constraints which are incorporated in the optimisation problem. Solving such a distance problem optimally is algorithmically hard, but an almost optimal solution can be achieved on demand by using methods of nonlinear optimisation and computational geometry.

- *Applying colours on WMS*: WMS, which support the Styled Layer Descriptor (SLD) specification of the OGC, use a default portrayal. This can be overwritten by everyone who requests maps by using Symbology Encoding (SE). SE is also a specification of the OGC and instructs a WMS how to render features.

The Web Service outlined above supports users in creating maps which base on portrayal output of WMS. The support consists in selecting well distinguishable colours, which are personalised to a specific user and his devices in various environments. In this way the recognisability of map content is ensured. The feasibility of the approach has been demonstrated by a prototypical implementation, which successfully generates maps.

1. Introduction

Offering geospatial data in the World Wide Web (WWW) has developed rapidly in recent years. Today, a lot of data sources are available, many of which provide data by using a Web Map Service (WMS) as interface which is specified by the Open Geospatial Consortium (OGC). Such services correspond to a general trend of developing the internet from a pure Client-Server Architecture to a Service-oriented Architecture, which is characterised by a process-oriented point of view. Services encapsulate functions as well as data and provide them platform-independently via public interfaces in a network (cf. Graham 2008). Implementations by Web Services dissolve data from static human-centered contexts and make them also available to other services. Hence, data and maps are not only usable independent of space and time but also accessible independent of specific applications. Users are enabled to combine and to integrate data from one or more sources in order to generate customised maps.

However, a problem of this approach appears immediately: Since graphical representation of data from each source is defined on its own, graphical representations of different sources may conflict. As a result, a user may obtain a map which does not meet the requirements of a concise cartographic product. The main reason is the non-distinguishability of colours from different sources. Thus, a significant improvement is achieved by selecting and using colours which are well distinguishable by human visual perception. This ensures an exact identification of all features contained in a map (Figure 1). Indeed, the unrestricted use of colour is affected by user-specific constraints, particularly by colour vision impairment, colour-reproduction of devices (monitors and displays) and environment-conditions (e.g. a darkened room or bright sunlight).

Figure 1. Example of integrating data from different sources

In this paper we present an approach of ensuring the conciseness of ad-hoc maps by selecting colours which are well distinguishable with regard to the user's specific visual perception, monitor, and environment. The remaining paper is organised as follows: The next section shortly discusses the technical background of obtaining data via WMS. The third section outlines an architecture which combines WMS with a Web Service in order to create personalised maps. Furthermore, the components of the latter are described in detail. The last section gives a short conclusion.

2. Requesting data via standardised interfaces

A standardised interface for requesting maps has been specified by the OGC. In order to use the interface in the manner outlined in this section, three specifications have to be implemented: The *OpenGIS Web Map Server Implementation Specification (WMS),* the *Styled Layer Descriptor Profile of the Web Map Service Implementation Specification (SLD-WMS)*, and the *Symbology Encoding Implementation Specification (SE)*.

The WMS describes a service which visualises geospatial data; if it is requested by a client, a WMS produces a spatially referenced map as a digital image file. In most cases images are rendered as raster graphics (e.g. GIF, JPG, and PNG); vector graphics (Scalable Vector Graphics, SVG) are also possible, but not widely used. The current version of the specification is 1.3.0 (de La Beaujardiere 2006).

Requesting a WMS bases on the Hypertext Transfer Protocol (HTTP) and particularly its methods GET and POST (Fielding et al. 1999). A service is referenced by a Unified Resource Locator (URL, Berners-Lee et al. 2005). An example for a GET-request, which returns a map, is given in

```
http://www.example.net:8080/Path?
        VERSION=1.3.0&REQUEST=GetMap&CRS=CRS:84&
        BBOX=-95.15,21.534,-77.987,45.712&LAYERS=Layer1&
        STYLES=&WIDTH=540&HEIGHT=320&FORMAT=image/png
```

Syntactically, the query part (behind the “?”) contains name-value-pairs, separated by ampersands (“&”). The first parameter (name=”VERSION“, value=”1.3.0”) denotes the version of the specification document. The desired operation is determined by “REQUEST”. The extend of the requested map is specified by a bounding box (“BBOX”) which is interpreted in reference to the used coordinate system (“CRS”). The map content is defined by the requested map themes (“LAYERS”) whereas the styling is given by “STYLES”. Finally the resolution and the image format are stated by “WIDTH”, “HEIGHT” and “FORMAT”. Parameter values which are provided by a service can be requested by the operation “GetCapabilities”.

A WMS only offers rudimentary options to influence the graphical layout of maps. The parameter “STYLES” allows for using a predefined list of styling options which are provided by a WMS. Thus, only the owner of the service is able to determine graphical representations. This restriction is overcome by the *SLD-WMS* which defines an enhancement of the WMS described above. It enables users to submit their own styling options to a WMS. These options have to be formulated as Symbology Encoding (SE) which will be shortly explained below. A SLD-WMS uses the parameters “SLD_BODY” or “SLD” instead of “LAYERS” and “STYLES”. “SLD_BODY” contains a SE string as value; “SLD” contains a URL which links to a SE document somewhere in the WWW. The current version of the SLD-WMS specification is 1.1.0 (Lupp 2007).

The *Symbology Encoding Implementation Specification* describes a XML application to define styling options of geospatial data. The current version is 1.1.0 (Müller 2006).

Styling options are declared by formulating rules which may have an influence on the drawing of an entire feature class or on a selection of features. In a nutshell, the available styling rules implement the well-known visual variables (e.g. MacEachren 1995), which determine the portrayal of points, lines and areas:

- *Point Symbolizer* draw a graphical representation of a point. Such a representation is either configured directly by SE (called Mark) or references a graphic file from an external URL. Whereas the first generates simple geometric objects (e.g. squares, circles) with specific properties (fill, stroke), the latter may be an arbitrary image. Furthermore, properties like size and direction may be determined.
- *Line Symbolizer* represent line geometries by attributes like colour, width or line-style (dashed line). It is also possible to represent a line by an external graphic (cf. Point Symbolizer).
- *Polygon Symbolizer* visualise two-dimensional geometries by representing the inner area and the boundary line. While the first is filled either by a single colour or an external image, which is repeated inside the inner, the latter is defined as a Line Symbolizer.

3. Personalised colouring

There are a lot of data sources available in the WWW, many of which provide data freely by using the WMS interface described in the last section. The scope of data ranges from individual features of a particular theme to complete topographic or thematic maps. Combining these sources allows for creating ad-hoc maps for certain purposes. This is exemplified by the following scenario (cf. Figure 1): A topographic map which contains multiple colours is overlaid by line objects (cycle paths) to enhance information content. Several paths are tagged by cultural themes and have to be differentiated. The data are available by WMS and SLD-WMS, respectively. Assuming that the portrayal of the topographic map is fixed whereas the portrayal of the cycle paths may be determined by users, the task is to portray the cycle paths in such a manner that a concise map is obtained, i.e. that each cycle path is well distinguishable from the topographic map as well as from all other cycle paths and can be identified effectively by users. The portrayal options are given by the visual variables which are applicable by using the Line symbolizer described in the last section.

In order to represent line objects, we consider variables “size”, “shape”, and the three dimensions of colour (hue, value, saturation) as most applicable. The required distinguisability is primarily achieved by using well distinguishable colours, to be precise, by using the variable hue, which is most suitable to represent the nominal information of the cycle pathes (cf. MacEachren 1995).

However, an effective use of colour depends on some specific characteristics and properties:

- Nearly 8 percent of males and 0.4 percent of female are affected by different types of colour vision impairment (Wyszecki & Stiles 1982). They cannot distinguish between certain colours which people with full colour vision recognise correctly. Observers who are conditioned with the most common form of colour vision impairment are called dichromats. Their eyes miss one of three colour receptors so that they perceive colours as a mixture of only two instead of three independent primary stimuli (Wyszecki & Stiles 1982).
- Reproducing colours is always device-specific, i.e. it depends on different types of monitors and displays. These differences are caused by technology of colour production on the one hand and poorly chosen monitor settings (brightness, contrast), on the other hand (Fraser et al. 2005).
- Perceptibility and distinction of colours on displays depend significantly on ambient light, e.g. the perceptibility of a stationary display in a darkened room is much better than the perceptibility of a notebook display in bright sunlight.

Thus, the problem of representing line objects, which was already described above, can be solved by an identification of well distinguishable colours that also incorporates user's visual perception and the technical properties of displays, monitors, etc.

3.1 Architecture and activity

Figure 2 illustrates the architecture of a prototypical implementation which forms the basis to the practical solution of the described problem: Assuming that a user has created a user profile and has stored his personal information on a server (A) which provides a personalisation platform (The functions of this platform will be described in detail in section 3.2). In order to create a map, a typical Web Map Client, which is made available by several servers in the WWW, has to be loaded in the user's web browser at first (1). Such a Web Map Client provides tools to request and combine data sources conveniently.

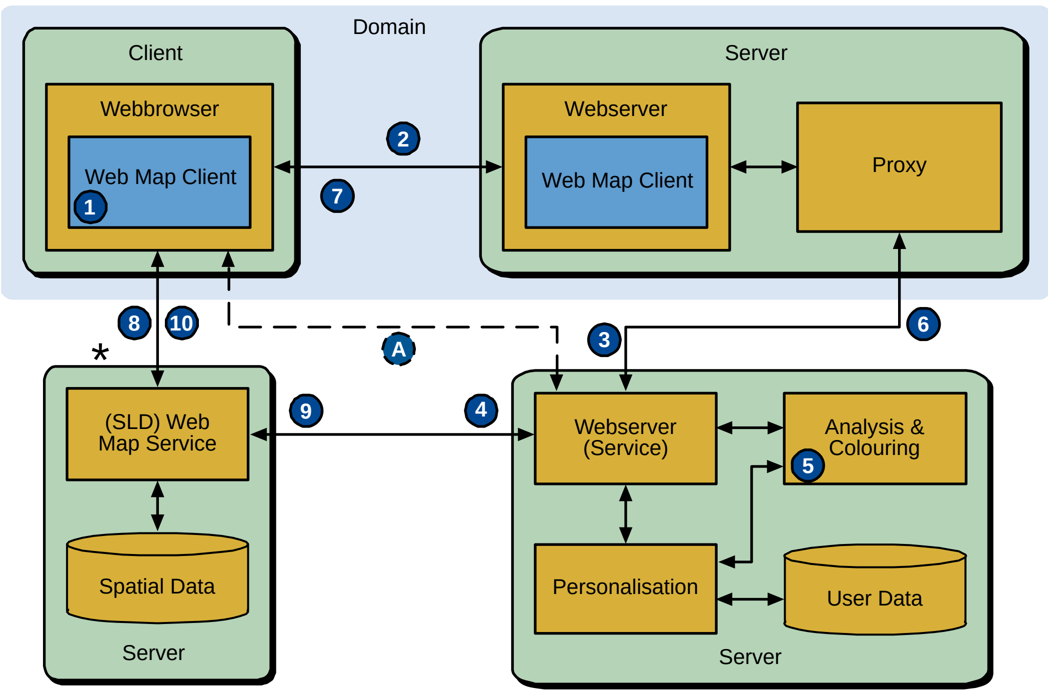

Figure 2: Architecture and activity of creating personalised maps from different sources (* indicates “multiple”)

The user enters the URLs of the WMS from which he wants to get data, and his user name, by which he is registered on the personalising server. The user’s input is sent to the Web Map Client’s origin server (2) which acts as a proxy and transmits the input to the personalisation server (3). This server requests capabilities documents and example data from the WMS, specified by the URLs (4). These documents and data are analysed to find out which styles and colours are provided by the requested WMS (5). The analysis is done by an Open Source graphics program (ImageMagick, *www.imagemagick.org*). Next, the well distinguishable colours are calculated (5). The process incorporates the user’s personal information which is identified by the user name (The calculation will be further explained in section 3.3). In conjunction with values of other visual varibales (e.g. size), the colours are transcribed as SE documents und stored on the personalisation server. The URLs of these documents are returned to the proxy (6) which transmits them to the client (7). Finally, the client requests the desired WMS by GetMap operations (8). The requests involve the parameter SLD which contains the URLs of the SE documents as values. The WMS obtain these documents (9), apply them to the map creation and sends the resulting images to the client (10).

A similar process is proposed by Chesneau et al. (Chesneau et al. 2005) who aim at improving colour contrasts of risk maps automatically. Unlike the present paper, Chesneau et al. do not build their process on the WWW but on a Geographic Information System and they do not incorporate user’s personal information. Furthermore, whereas they select colours from a knowledge base, our approach uses an optimisation method which will be described in section 3.3.

3.2 Creating and storing user profiles

The personalising component has to offer functions which allow for collecting and storing user data as well as providing this data for use in a map creation process. In the WWW, such a personalisation is typically implemented by setting up server-side user profiles. A user creates a profile by entering an anonymous user name, an e-mail address, and a password. For the purpose, described in this paper, information about vision impairment and used displays are required.

Vision impairment: In the simplest case, a user knows about his vision impairment and specifies it directly. In other cases, a user has to take vision tests that use colour plates. Such tests and their validity as a colour vision screening are described in Kuchenbecker et al. (Kuchenbecker et al. 2007).

Display profiles: A user is enabled to enter the calibration state of several displays (e.g. stationary display, Notebook, Personal Digital Assistant). In the simplest case, a user specifies that he has calibrated his display by means of professional calibration tools (tools and procedure are described in e.g. Fraser et al. 2005). If no calibration has been carried out, users are advised to install a tool which allows for visual calibration. Such a calibration primarily means visual adjustment of gamma settings (Fraser et al. 2005). Finally, a user has to confirm his input by checking some test images, which in turn gives an almost correct evaluation of a display's quality.

In order to use personalised information, the access to it is of great importance: On the one hand, data has to be secured from unauthorised access, but has to be unobstructedly available for map creation, on the other hand. This has been realised in a two-stage system: Information on vision impairment and display properties which are needed for map creation are released by specifying a username. Thus, this data are accessible for everyone, but kept anonymous outside of the system. Explicit reading and writing access to the complete user profile requires a login with password.

3.3 Selecting well distinguishable colours

The selection of well distinguishable colours is formulated as an optimisation problem which is solvable by mathematical methods. As a basic precondition, the subjective act of human colour perception requires an objectified description in a framework (colour space) which provides an appropriate metric according to human visual perception. RGB colour spaces, which are typically used to reproduce colours on displays, do not offer such a property: Colour differences perceived by humans do not correspond to colour differences calculated from RGB numbers. Indeed, an approximately uniform colour scaling system is given by the CIELUV colour space in which the distance of colours is defined by the Euclidean distance (Wyszecki & Stiles 1982). If the distance exceeds 45 units of length, colours are generally observed as well distinguishable (Nagy, Sanchez & Hughes 1990). Thus, the optimisation problem aims at maximising the minimal distance in the CIELUV colour space. Such a problem is called a MAXMIN or MAXIMIN problem (e.g. Erkut & Neuman 1989); if it is applied to the selection of colours it can be formulated as:

Let F be a set of m colours. Each colour is determined by its location in a usual three-dimensional colour space (working colour space) and may not be changed.

Find a set X of n colours, such that the minimum distance of the location of any colour from X to the location of any other colour from X as well as to the location of any colour from F in a uniform colour space (optimisation colour space) is maximal.

The assumption that sRGB is used as application colour space and the CIELUV as optimisation colour space results in the activity chain illustrated in figure 3.

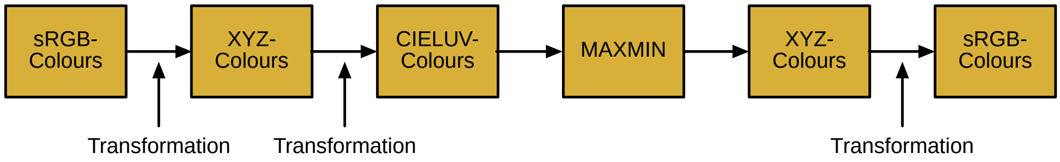

Figure 3. Activity chain of calculating sRGB colours with maximal distance

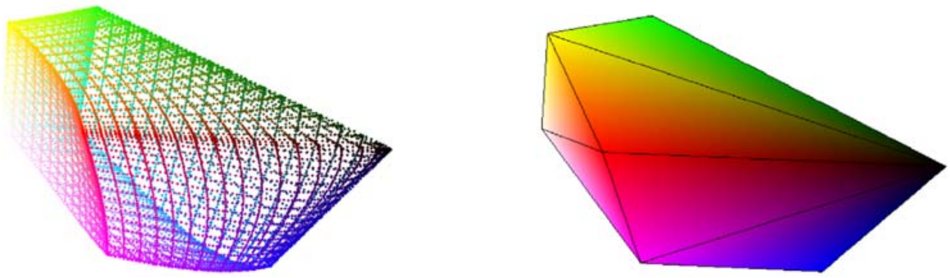

Figure 4. Transformation of the sRGB cube to the CIELUV colour space: Illustration of the transformed body in the left and its approximation by a polyhedron in the right

The entirety of colours available for optimisation forms a three-dimensional body which results from transforming the sRGB cube into the CIELUV colour space (left part of figure 4). The right part of figure 4 illustrates the triangulation of the body's convex hull that may be represented as a convex polyhedron which is created by the intersection of hyperplanes or half-spaces. A hyperplane is described as a set of the form

$$\{x \mid a^T x \leq b\}, \text{ where } a \in \Re^n,\ a \neq 0 \text{ and } b \in \Re .$$

Formulated in a mathematical notation, the problem MAXMIN is written as (detailed description of the formulation and notation of optimisation problems e.g. in Boyd & Vandenberghe 2004):

MAXMIN	maximize	$\min\left(\left\| X_i, Y_j \right\|_2\right)$,	$i = 1,\ldots,n,\ j = 1,\ldots,m+n,\ j > i$
	subject to	$a_k^T X_i \leq b_k$,	$i = 1,\ldots,n,\ k = 1,\ldots,9$,

where $Y = (X, F)$ denotes the entire set of given and searched colours; each colour Y_j is represented by its coordinates L_j, u_j, v_j in the CIELUV colour space. $\| \ \|_2$ denotes the Euclidean distance between two points:

$$\| X_i, Y_j \|_2 = \sqrt{(L_j - L_i)^2 + (u_j - u_i)^2 + (v_j - v_i)^2} \ .$$

The polyhedron of the optimisation colour space is modelled as intersection of nine hyperplanes.

Similar problems of colour optimisation have been described in related papers (Carter & Carter 1982, Campadelli et al. 1999, Glasbey et al. 2007). All authors, however, do not take given colours into account, i.e. the set F of colours is an empty set. Furthermore the papers differentiate between the methods of solution; none of them aimed at finding a solution on demand.

Finding a solution on demand, i.e. in a period of time which is required by a typical request in the WWW, is of great importance for purposes of a Web Service. However, MAXMIN is a nonlinear problem which is characterised by a large number of locally optimal solutions which are not optimal in a global sense. Classical descend methods find a locally, but usually not the globally optimal solution. In general, global optimisation problems are computionally hard to solve (NP-complete).

In order to obtain an almost globally optimal solution on demand, a three steps method has been developed which integrates several standard methods and solution paradigms. The three steps may be briefly characterised by “Finding starting points”, “Improve the location of these points”, and “Detect suboptimal solutions”. The first step is based on the essential observation that points on the polyhedron’s boundary are well suited as starting points. Consequently, the method is initialised by randomly placing n points on the boundary. Then, these points are moved on the boundary in such a way that their minimal distance is approximately maximised. In the second step, the points are used as starting points in a local optimisation method (to be more precise, the Sequential quadratic programming (SQP) method (Fletcher 1987)) which improves the points’ location by maximising the minimal distance between the points all over the polyhedron. The last step uses a three-dimensional Voronoi-diagram (Okabe et al. 2000) to detect suboptimal solutions and to identify possible improvements. The Voronoi-diagram is used to find the largest empty ball (cf. Toussaint 1983). This is the largest ball which centre lies inside the colour space and which contains no colour of the set Y. If the radius of the ball exceeds the minimal distance calculated so far, a suboptimal solution is found and the most poorly placed colour is displaced by the centre of the largest empty ball. The method is further explained in Steinruecken (Steinruecken 2009).

User’s personal information is incorporated as constraints which results in clipping the available colour space. Further cartographic rules (e.g. finding a colour ramp which varies only in colour’s value) may also be incorporated as constraints.

4. Conclusions

We have described a Web Service which supports users to create ad-hoc maps by combining different data sources available in the WWW. The service aims at colouring the objects in a map in such a way that they are well distinguishable. Finding such colours is realised by formulating an optimisation problem which maximises the minimal distance between all colours (MAXMIN problem). The display and vision characteristics of the users, which are stored as user profiles, are modelled within this problem as constraints. The difficulty lies in solving the problem on demand. In order to do so, the main contribution of this paper is a three steps method, which incorporates a randomized identification of starting points, a local optimisation method, and a global geometric algorithm. Altogether, a good solution is achieved in a few seconds. The selected colours ensure the perception of map objects for a specific user and a specific device. An exemplary result has been illustrated in figure 1.

The described Web Service is implemented prototypically and can be tested on http://colour.ikg.uni-bonn.de. A suitable Web Map Client which allows for creating own maps is also available on this side.

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