On-demand Base Maps on the Web generalized according to User Profiles

Theodor Foerster[1], Jantien Stoter[1] and Peter van Oosterom[2]

[1]Geo Information Processing Department, International Institute for Geo-Information Science and Earth Observation (ITC), Enschede, the Netherlands

[2]Delft University of Technology, OTB, Section GIS-technology

Thematic content in the form of geodata is becoming increasingly available on the web. However, adequate base map information to support appropriate communication of the thematic content is not available in many cases. This base map information might be served through topographic databases available on the web and optimized by means of automated generalization. This article describes an approach based on user profiles, which formally captures the user requirements (preferences) towards the base map and deploys those profiles in a web-based architecture to generate on-demand maps. Those user profiles, which may differ per user, drive the generalization process and produce base maps on-demand by taking into account the user requirements as well as the thematic content. The research in this article specifically focuses on the technological environment that generates on-demand base maps incorporating four basic concepts in the user profile: 1) topology awareness between the base map and the thematic content, 2) user-specific base map information at a non uniform scale to improve the communication of the thematic content, 3) the map specification and 4) inheritance of user profiles. Both existing and new techniques are explored to realize the environment. The approach is evaluated by applying it to a project in the Netherlands dedicated to disseminating physical planning maps through the Web.

Keywords: Automated generalization, user profiles, web mapping, on-demand base maps.

1 Introduction

Thematic maps are widely used for different applications and become increasingly available on the web. Examples of thematic maps are physical planning maps, soil maps or weather maps. Base maps are often important to display thematic maps as they serve as reference and thereby improve the communication of the thematic content. Base maps can either be served from topographic data or provided by aerial photos (such as provided in Google Earth). Topographic data provide object-specific information and support the user with additional contextual (i.e. interpreted) information for the thematic content. Nevertheless, topographic data are produced for a general purpose at a specific scale range and might contain too much detail for the purpose of a base map. Thus it might be necessary to customize the topographic data to optimally fit the specific thematic content, the specific scale of the map display and the additional information requirements of the specific user.

Automated generalization is highly promising in this respect as it provides concepts and technologies to transform geodata to fit specific purposes and to reduce information (Weibel & Dutton 1999). However, attempts towards customizing base maps on-demand by means of automated generalization for thematic overlays can only be found rarely (Poppe et al. 2006; Mackaness et al. 2007).

This was the starting point to design and implement an architecture for automated generalization of on-demand base maps for thematic maps according to individual user requirements. A technical requirement was the implementation within a web-based architecture for disseminating the base maps on the web. The web-based architecture allows the user to access up-to-date information from remote resources and to dynamically integrate data from different organizations (i.e. one providing the base information, the other the thematic content). The individual user requirements towards the base map are captured by the concept of *user profiles,* which is a common term in mainstream IT (ETSI 2005). A user profile describes the customization of a user interface. In this research, the thematic map is the user interface as it provides user access to the thematic content. The user profiles specify the user requirements regarding the base map related to a specific use of the thematic content. They are modeled in the Unified Modeling Language (UML) and described in a computer-understandable way to enable the web-based dissemination and to support the generalization of the on-demand base map. The web-based architecture is accessible through a browser-based client application and applied to the dissemination of digital physical planning maps on the web.

Section 2 presents concepts and related work and it describes the requirements which drive the customization of the base map. Section 3 presents the methodology by describing the components of the user profile and the designated generalization process, which generates the base map accordingly. Section 4 describes the design and the implementation of the web-based architecture. Section 5 demonstrates the results of the approach based on the two different user profiles for the use case of physical planning. Finally, Section 6 discusses the results and ends with a conclusion.

2 Concepts and Related Work

“Thematic maps are used to emphasize the spatial distribution of one or more geographic attributes or variables…” (Slocum 1999, p. 2). They require a general reference to help the user linking the thematic content to the real world for localization and orientation purposes. Such a general reference is provided by the so called *base map*. It is mostly extracted from topographic databases and consists of a collection of different object classes. The selection of the correct base map objects is a crucial process, as the base map must not interfere with the thematic content or distract the user with redundant content (Slocum 1999).

In current research the separation of the base map and the thematic map is disappearing and the idea of a fore- and background map becomes more dominant. The definition of the fore- as well as of the background is subject to the user. The user can group the thematic object classes and the base information according to his needs and thereby create his own fore- and background. Moreover, the adoption to a specific scale by means of automated generalization might be required for the foreground and the background data. However, in this research we focus on the adoption of the base map (i.e. the background map for a physical plan), as the foreground (i.e. the physical plan) is legally established and therefore fixed. Still, the content of the base map depends on the individual requirements of the user. According to Regnauld & McMaster (2007), the generation of base maps for thematic content is one of the future applications for automated generalization. Literature study only showed minor previous work in this context. Forrest (2005) studied the automatic selection of base map classes to support thematic mapping. In the context of maps for physical planning Stigmar and Harrie (2008) introduced a readability measure to evaluate the usability of such maps. The so-called personalization of maps is presented in Wilson et al. (2010), but with a focus on the selection of features and feature classes and not on the appropriate generalization of features as described in this research.

The following section examines the requirements towards the base map as they are applied in this research. Section 2.2 and Section 2.3 respectively describe related work in the context of automated generalization and architectures for web mapping. Section 2.4 gives an overview of the research and development activities related to user profiles.

2.1 Requirements Towards the Base Map

The user requirements define which contextual information is necessary to optimize the communication of the thematic content and are the input of the user profiles (Section 3). For this research focusing on the dissemination of base maps for physical plans, two fundamental requirements have been identified. These requirements are meant as a reasonable test case for the presented architecture aiming at proofing the concept of user profiles and might be extended in the future. The presented requirements might also be applicable to other applications of base maps such as base maps for soil mapping. Possible points of extension regarding usability research are described in van Elzakker and van de Berg (2009). These results are not taken into account in this research due to their preliminary nature, but might be used as input at a later stage, when they have been validated.

The first requirement depends on the preference of the user, as the user may want to choose if the initial topological relationships between the base map and the thematic map should remain the same. Topological consistency between the base map and the thematic content helps the user to link the situation on the map to the real world situation and thereby improves map communication. As stated by Kuipers (1982) topological properties of maps are more important in map communication than metric distance or geometric shape. Automated generalization of the base map independent from the thematic map might harm this requirement by applying generalization operations such as aggregation, enlargement or simplification. An example of such a map situation is schematized in Figure 1. In some cases this requirement may hinder the creation of the optimal solution, for instance, if the thematic objects represent only informal (or even fuzzy) boundaries for design (such as an informal physical plan).

Besides maintaining topology between base map and thematic map, the internal topology of the base map should be maintained during the generalization process to avoid misinterpretation of the map. However, this issue is outside the scope of this paper and is for instance addressed by the tGAP tree structure (van Oosterom 2005).

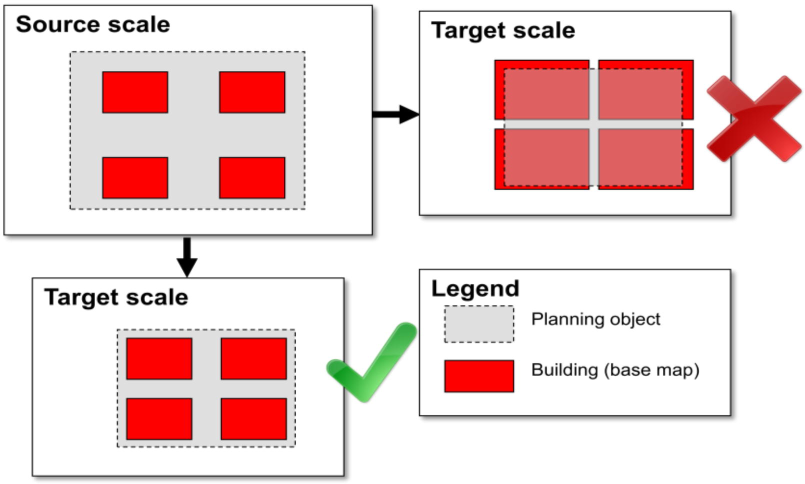

Figure 1: Example of the topological requirement – The base map object has to maintain the original topological relation with the thematic base map object.

The second requirement defined for the user profile in this research is that the user should receive a base map adjusted to her/his specific information needs regarding the thematic map. In particular, the user should receive a more detailed base map for the parts of the thematic content the user is interested in. This has two consequences:

1. Two different users, retrieving the same extent of the thematic content, will get two different base maps, due to their different interests in the thematic content (which imply different relevance of base map objects).

2. Different base map objects of the same class may be displayed at a different level of detail (allowed amount of change/generalization): more detail is maintained below thematic classes that are of interest for the user. The assumption is that this higher level of detail better meets the information demand of the user. The user research related to this project has to test this hypothesis (Section 5.1). The described concept is different, but related to the idea of the variable scale map (Harrie, Sarjakoski, and Lehto 2002). A variable scale map displays the objects located in the center of the map at higher detail. The difference in our approach is that the level of detail is not determined by the location on the map (distance to map center), but is determined by the overlaying thematic object class.

The presented requirements will be modeled in the user profile (Section 3.1) and will determine the automated generalization process (Section 3.2). Apart from these requirements, the zoom level of the map display drives the requirements for generalization.

2.2 Automated Generalization

Automated generalization has been identified in this research as an appropriate tool to generate the on-demand base map. Research on automated generalization has yielded a lot of concepts and applications in the past 20 years. An overview can be found in Weibel & Dutton (1999). Automated generalization matured and is applied in map production at

National Mapping Agencies prototypically, as shown by the French mapping agency, IGN (Lecordix et al. 2007). However, fully automated generalization remains a problem, due to incompatible data models, the intrinsic complexity of data, the lack of appropriate tools and the complex cartographic requirements regarding a readable map (Regnauld & McMaster 2007).

Different views on generalization have been developed (Weibel & Dutton 1999), such as the generalization model by Gruenreich (1992), which separates generalization into *model generalization* and *cartographic generalization*. Model generalization is concerned with the transformation of data according to a target model and cartographic generalization aims at producing maps out of data by avoiding cartographic conflicts. This view defines a clear separation between data and visual representation. The presented work focuses on cartographic generalization for generating on-demand base maps.

2.2.1 Constraint-based Generalization

Beard (1991) proposed the concept of *constraint-based generalization* as a new concept and standing term. Constraint-based generalization is considered to overcome the problems of rule-based generalization. Rule-based generalization (McMaster & Shea 1992) resulted in complex systems, which were difficult to update and maintain, as rules turned out to interfere. Rules define the generalization process as a procedure which transforms objects. Contrarily, constraint-based generalization specifies only the final outcome without describing how to achieve it.

In this article we extend the concept of constraint-based generalization, by introducing a more general concept of map specification. A map specification consists of constraints and optimization goals. Constraints in this case are adopted from database theory and describe a fixed condition, which has to be achieved or preserved by the generalization process. Optimization goals are meant to be guidelines which might be met under certain conditions but do not need to be. Optimization goals thereby capture Beard's concept of constraints.

Cartographic generalization applies the map specification and performs the transformations on the map accordingly. By describing the final map, the map specification also provides a user oriented-view on automated generalization processing. This eases the configuration of the generalization process also for non-expert users of generalization systems (Beard 1991). To satisfy multiple optimization goals (i.e. the condition might be met) on the same object optimally, the concept of importance has been introduced (resulting in an overall optimization goal based on the relative importance levels). The importance guides the generalization process regarding which optimization goal is more important to be met over another (Ruas 1998). Applying importance values to specific optimization goals in an automated way to achieve the desired generalization is difficult and might require manual interaction. The effect of importance values of optimization goals differs per map situation and it is thereby also difficult to determine importance values for complete maps in an interactive way. Finding an approach to determine such importance values in an automated way is subject to future research.

As it already appeared in this section, the terminology in the context of constraint-based generalization is overlapping with the concept of constraints in database theory. Steiniger and Weibel (2007) for instance refer to constraints as hard constraints and optimization goals as soft constraints. However, we propose, that the term constraint is used as in the database theory, that is 'hard constraint' and that the term optimization goal is used instead of 'soft constraint', as optimization is actually involved when solving this type of problem. Both concepts are summarized under the term map specification, which will be used within this article.

2.2.2 Agent-based Generalization

Cartographic generalization is considered to be an optimization problem (Sester 2005), as the cartographic objects interfere on the limited map space and the legibility of the cartographic objects has to be maintained as much as possible. One of the most promising approaches is the application of a Multi-Agent System (Wooldridge 2002) for cartographic generalization (Barrault et al. 2001), which has been adopted in this research.

In the agent-based generalization each of the cartographic objects is controlled by an agent, which satisfies the proposed constraints and maximizes the optimization goals. Different models have been developed on how such agents interact (Duchene & Gaffuri 2008). The most interesting model in the context of generating on-demand base maps is the AGENT model (Ruas 2000) which is able to control objects regarding their topological relations. It allows the generalization process to maintain the original topological relations if necessary and thereby meets the first requirement towards the base map (Section 2.1). A single cartographic object is controlled by a *micro agent* and a group of cartographic objects (i.e. a group of micro agents) is controlled by a *meso agent*. The *macro agent* controls all cartographic objects of the map display to meet global constraints and optimization goals. A macro agent can be considered to be a special type of meso agent, as it also controls a set of objects. The concept of macro agents is not applied in this paper, as the identified requirements address only specific sets of cartographic objects partitioned by the thematic content.

2.3 Web-based Architectures for Web Mapping

Web-based architectures for geo-information applications are embedded in Geo-Information Infrastructures (GII) and are realized by means of Web Services (Yang & Tao 2006). Web Services are distributed software components on the web communicating meaningfully through common Web Service interfaces. They overcome the lack of platform independence and the lack of required availability of existing monolithic systems (Gottschalk et al. 2002).

The Web Service interfaces for geo-information applications are defined by the Open Geospatial Consortium (OGC) and the International Organization for Standardization (ISO). The family of standards for Web Services as established by the OGC and ISO addresses geodata provision (Web Feature Service), geodata portrayal (Web Map Service & Styled Layer Descriptor) and geodata encoding (Geography Markup Language). The Web Map Service interface specification (WMS) is commonly used to portray geodata at a certain scale and with a given extent on the web (OGC 2004). The WMS serves maps as images opposed to vector data. In most web-based architectures, the WMS renders these images based on vector geodata as for instance served by WFS instances.

Besides the WMS interface specification, two user models have been specified for further customization of web maps. The *Styled Layer Descriptor* (SLD) describes cartographic models for web maps. It enables the customization and exchange of the symbolization of a map (i.e. the cartographic model) and is thereby closely related to the WMS interface specification (OGC 2007). Besides SLD, the *Web Map Context* (WMC) specification has been defined by the OGC, to store and exchange a map view by describing the different map layers, their style and other properties (OGC 2005). A similar approach has been taken by software vendors with their proprietary project files (e.g. ESRI ArcGIS project file). Both standardized approaches have been implemented in different software systems and are integral parts of current web mapping applications, such as uDig: udig.refractions.net and mapBuilder: communitymapbuilder.osgeo.org. These user models are appropriate for on-demand web mapping but are not able to express instructions for automated generalization, as they do not provide any concept to describe processing rules or constraints and optimization goals for generalization. Finally, it is not possible to formulate any requirements regarding the relation between the base map and the thematic content as described in Section 2.1.

Generalizing maps on-demand for web mapping applications gained considerable attention. Cecconi (2003) proposed a derivation-oriented view for on-demand web mapping by introducing intermediate scales, which need only small adjustments to be suitable for the final target scale. He claims that this approach would significantly increase the performance of on-demand web mapping. Sabo et al. (2008) also investigated on-demand web mapping and proposed Self-Generalizing Objects (SGOs). The concept of SGOs is based on data enrichment to capture relevant patterns. Based on the enriched database it is possible to perform on-the-fly generalization. Additionally, other projects have been carried out to develop suitable Web-based architectures for automated generalization such as the WebPark project (Burghardt et al. 2004) and the GiMoDig project (Sarjakoski, Sester, Sarjakoski, Harrie, Hampe, Lehto, and Koivula 2005). In the context of Web Services, the concept of progressive transfer has also been investigated (de Vries & van Oosterom 2008; van Oosterom 2005). Overall there is no literature available or any project documented which addresses on-demand web mapping based on individual user requirements by means of automated generalization nor which investigates customizing base maps for supporting thematic maps.

2.4 User Profiles

User profiles have received a lot of attention in research and development in the wider community of web-based information systems, mobile telecommunication, and other modern ICT applications in which different types of human users are involved. Therefore this section gives a short overview of these developments (currently outside the geo-information sector). There are even specific conferences and journals devoted to the topic of user (profile) modeling; for example the annual conference series 'User Modeling, Adaptation, and Personalization' (UMAP) and the journal 'User Modeling and User-Adapted Interaction' (UMUAI). The aim of user (profile) modeling is to develop interactive computer systems that can be adapted or adapt themselves to their current users. Moreover, the aim is to investigate the role of user models in the adaptation process. Fink and Kobsa (2002) describe a generic User Modeling System (UMS) consisting of a dictionary component which includes a user model (users' interests and preferences), a usage model (persistent storage of interface events), a system model (application domain taxonomy) and a service model. Their presented UMS also includes a user learning component to support the acquisition and maintenance of user interests and preferences from usage data, and updates individual user models (including using predictions for missing values in individual user models from models of similar users and applying domain inferences). The UMS architecture supports external clients for both providing information about the user to the UMS, and also retrieving current information about the user from the UMS via an access control system.

According to *European Telecommunications Standards Institute* (ETSI 2005) a user profile is "the total set of user-related information, preferences, rules and settings, which affects the way in which a user experiences terminals, devices and services". The user profile enables the customization of an interface (in combination with the service behind the interface). The ETSI Specialist Task Force 342 organized a workshop in January 2009 with the name "Personalization and User Profile Management Standardization". Its goal was to produce two documents (standards): User Profile Preferences and Information (ETSI 2009b) and Architectural Framework (ETSI 2009a). The standardization of user profiles is important, because different clients and services should work well together to implement user-driven applications. Traditionally, the preferences that can be set by users are not consistent between different services. More specifically, the user profile is organized as shown in Figure 2: personal information (about or related to the user), human centered preferences (overall user preferences that are valid for a wide variety of services), service category related information and preferences (related to service categories and specific services), and device related information and preferences (related to device categories and specific devices). These four issues are adopted in this research as possible types of user profiles and will be referred to as *ETSI categories*.

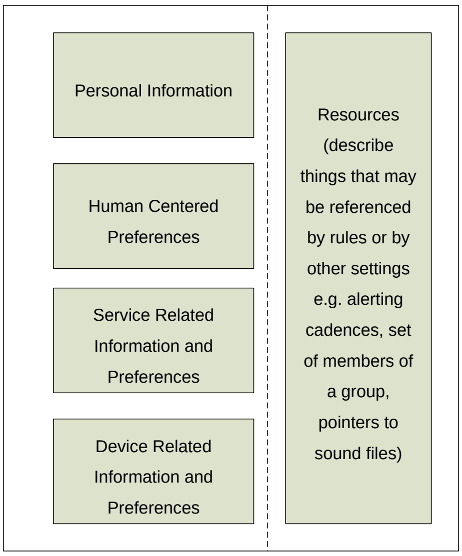

Figure 2: General user profile organization (from ETSI 2009b).

One important requirement of the ETSI's Architectural Framework was to support personalization and profile management. User profiles can contain a large number of settings and preferences. When users first create profile specifications, the creation task can be greatly simplified if the profile specifications are created from templates (inherited from other existing profiles), which can be then further amended by the users to suit their individual needs. A number of operations support the maintenance of profiles; e.g. create new, modify, copy&paste and delete. The profile data may be manipulated by different actors such as service providers and end users.

In the context of customizing base maps, these efforts already show the benefits of inheriting user profiles. Therefore the concept of inheritance is essential in our approach. As stated before, the term user profile is also applicable regarding our approach, as it aims at configuring the map, which is the interface to the thematic content (e.g. physical plan).

3 Methodology

Based on the requirements towards on-demand base maps (Section 2.1) and the insufficient approaches of user models for web maps (Section 2.3), this section presents the concept of user profiles for on-demand base maps that overcomes the limitations. The user profile describes the requirements (Section 2.1) in such a way, that a generalization process can use it as an input and produce an on-demand base map accordingly. First, the key aspects of the user profile including a conceptual model of the profile in UML will be examined (Section 3.1). Thereafter Section 3.2 will show the integration of the user profile into a generalization process.

It is outside the scope of this paper to present a specific and comprehensive exchange format for user profiles. We consider the development of such a specific exchange format as an iterative engineering task, which is supported by a wide set of modeling tools such as Enterprise Architect™ (Sparx Systems 2009).

3.1 Key Aspects of the User Profile

The user profile is meant to drive the generation of the base map. To propagate the user requirements for the base map to the generalization process, several key components have been specified. They reflect the concepts as introduced in the previous sections and are listed as follows and explained below:

- Selection of the applied foreground/background classes
- User-specific base map symbolization
- Map specification
- Awareness of topological relationship between base map and thematic map (as generic requirement towards the base map)
- Generalization requirement regarding the topological relationship between the base map and the thematic content
- Inheritance of user profiles.

The *fore/background selection* defines the object classes that are part of the thematic context and the ones that are part of the base map. This information is important for the generation of the base map, as it identifies the thematic classes and the base map classes.

As the aim of the user profile is to support the customization of the base map, the *base map symbolization* might also be user-specific. Therefore the user profile contains the cartographic model of the base map linked as a SLD document. The cartographic model enables the generalization system to detect the cartographic conflicts on the map. In a more general setting (of multi-source Internet cartography), one could imagine that there is also a second or third symbolization specified for every object class (layer) in case there are conflicts with the symbolization of other object classes (which have higher importance, i.e. are less allowed to change).

Also the map specification is part of the user profile as it provides an essential input to the automated generalization process. As already mentioned, the map specification describes the constraints and optimization goals which are specific to the designated user of the user profile. The constraints and optimization goals are modeled as elements of the map specification.

Additionally the user profile models the requirements expressed in Section 2.1 using a *topology awareness list* and a *generalization matrix*. The topology awareness list defines if the topological relationships between specific thematic classes and specific base map classes should be preserved. The *generalization matrix* describes the level of detail (allowed amount of change/generalization) of each base map class in relation to each thematic class by weighting the specific each element of the map specification.

Finally, to model user hierarchies and to avoid redundant user profiles, it is possible to specify a so-called *parent user profile*. The child user profile inherits all attribute values of such a user profile (e.g. map specification, symbolization) or might overwrite specific attribute values if necessary. This single inheritance model is chosen for the user profiles, because it is less error-prone than multiple inheritance (Booch et al. 2007). Moreover, an inheritance model for user profiles is also proposed by ETSI, as described in Section 2.4.

It is important to note that the user profile does not specify a (fixed) symbolization regarding the thematic content (i.e. thematic symbolization), as this is included separately in the final map display according to the layer concept. The UML model specifying the components of the user profile as introduced in this section is given in Figure 3. The topology awareness list and the generalization matrix are modeled as sets of tuples defining the relation between thematic and base map classes. The elements of the map specification have a name and a value property attached and they include the constraints and the optimizations goals. Additionally each element of the map specification has two operations, one of them performs the map specification element (i.e. *performMapSpecElem()* in the UML model) and the other operation allows the generalization matrix to weight the map specification element (i.e. *weightMapSpecElem()*). Weighting the map specification element is not related to the concept of importance as described in Section 2.2.1, but is used to scale the specific objects directly.

The base map specific aspects of a user profile are incorporated in the topology awareness list and the generalization matrix.

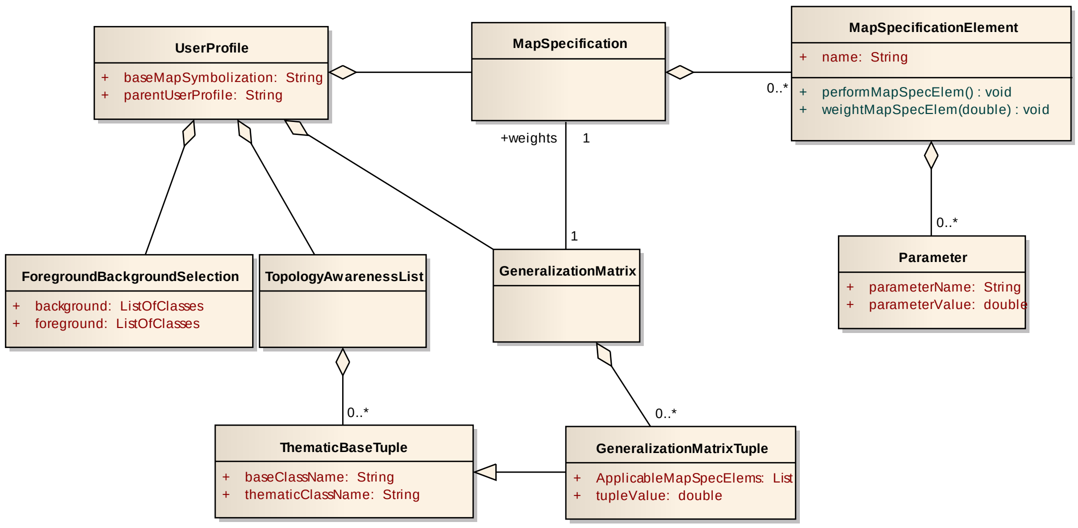

Figure 3 The UML model of the user profile.

It is important to note that the inheritance of user profiles (i.e. parent user profile) and the incorporation of a user-specific map specification (consisting of constraints and optimization goals) into web mapping applications have not been proposed yet. Both aspects are not base map specific and might be incorporated into any on-demand web mapping application empowered by automated generalization.

The two following paragraphs will introduce the two base map specific aspects in more detail.

Topology Awareness List

The topology awareness list defines at class level which base map objects have to maintain the original topological relations regarding the specific thematic content. It allows modeling the topological consistency of base map objects towards thematic classes. This is specifically interesting in the application of physical planning, as different types of physical planning objects might require maintaining topological relations with the base map object (Section 2.1).

Generalization Matrix

The generalization matrix refines the supplied map specification to drive the base map generation process according to the specific thematic content (Section 2.1). It relates any thematic class to any class of the base map and assigns to each of these relations a specific map specification weight (msw). This weight updates the constraint or optimization goal value (v) assigned to a specific base map object, which is topologically inside a specific thematic class. The map specification value (msv) of the updated map specification element is computed by Equation (1).

$$msv = v \times msw \qquad (1)$$

The meaning of the value of msw is analog to a magnifying glass or the zoom in/out tools in maps:

- If msw > 1, the level of detail will increase (more important)
- If msw < 1 the level of detail will decrease (less important).

To implement the meaning of msw, a weighting function is attached to each map specification element (weightMapSpecElem() in Figure 3).

To quantify the map specification element, map units play an important role to define the distance between and extent of cartographic objects. The map units are expressed as number of pixels. The display showing the browser-based client application has a resolution of 72 dpi (pixels per inch). As an example, let us assume that there is a map specification element which describes that two buildings should always have a minimum distance of 50 map units between each other (i.e. the distance between the cartographic features on the map). Applying now a weight of 0.5 decreases the level of detail. Thus the modified map specification element applies subsequently a distance of 100 map units as the value for the minimum distance between two buildings. In the given example the weightMapSpecElem function for the preserve distance map specification element applies internally an inverted value to realize the decrease/increase of level of detail. To keep the generalization matrix more flexible, it is possible to attach to each map specification weight a set of applicable map specification elements. This enables to weight distrinct map specification elements differently.

The introduced map specification weight is different from the concept of importance of optimization goals (Section 2.2.1), as the map specification weight does not change the importance of the optimization goals. Weighting the map specification element has a real effect on the level of detail of an object (i.e. amount of allowed change to a certain object), whereas the importance of an optimization goal only plays a role in particular map situations in which two optimization goals compete with each other and influence the level of detail of an object not directly. Thus the two concepts can be applied complementarily.

3.2 The Generalization Process Generating the On-demand Base Map

This section presents the different stages of the generalization process and examines at which stage the listed aspects steer the generalization process. The generalization process has to meet specific prerequisites to handle the user profile. This is achieved by preprocessing the user profile (Figure 4). At first, the process initializes the user profile by taking the indicated parent user profile into account. The process adds the inherited properties to the properties of the local user profile. Thereafter the process loads the data for the foreground and the background of the map according to the described selection in the user profile. This allows the process to link the two types of content and to customize the base map with respect to the thematic content. The symbolization of the thematic content is defined in advance and is not subject to change regarding a specific user. One of the important properties of the symbolization is the cartographic line width for calculating the shape of the specific objects. This will enable the process to detect any conflicts with a base map object, if necessary. Before generalizing, the zoom level of the map has to be determined by using the extent (bounding box) and the size (width, height) of the requested map. The zoom level is important to calculate the map units for sufficiently performing and evaluating the generalization process leading to the best result.

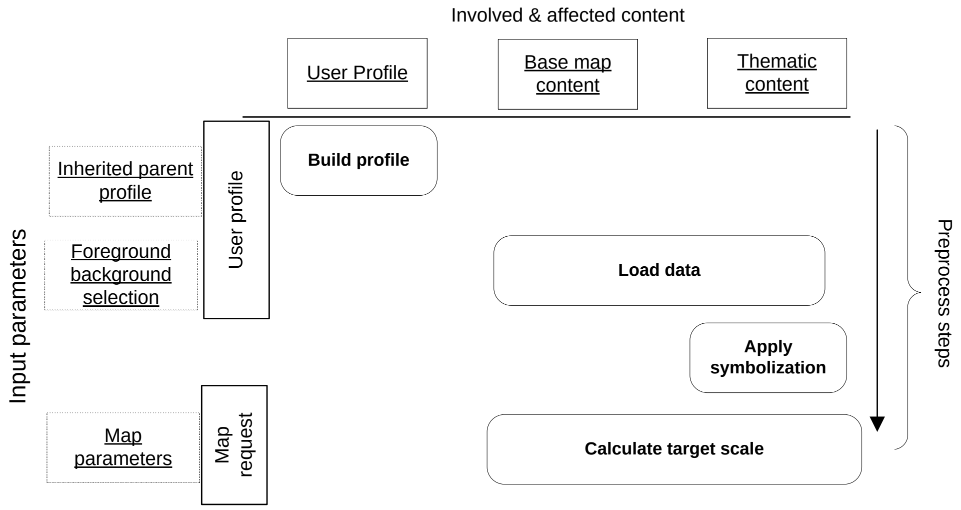

Figure 4 Generalization preprocess to initialize the user profile and load the data.

Figure 5 depicts the actual generalization process as described below. As a first step, the process applies the symbolization provided in the user profile to generate cartographic base map objects. This allows the process to detect and solve the conflicts on the final map (base map & thematic content) according to the given constraints. Then the map specification of the user profile is attached to the micro agents controlling the base map objects. The map specification is the basis for the generalization matrix, which weights the containing map specification elements according to the thematic overlay. The generalization process initializes the set of micro and meso agents (i.e. the AGENT model; Barrault et al. (2001)) according to the generalization matrix and attaches the supplied map specification elements to them. The meso agents are derived from the thematic objects and group the base map objects to steer the generalization of the base map objects (Section 2.2.2). This process results in an internal configuration of agents as depicted in Figure 6. The map specification elements attached to each of the base map objects will be weighted based on the values of the generalization matrix. Additionally, based on the topology awareness list certain meso agents are configured to preserve the topological relations between the thematic content and the base map objects. Based on the configuration of the agents, the process performs the generation of the map by optimizing the portrayal according to the map specification.

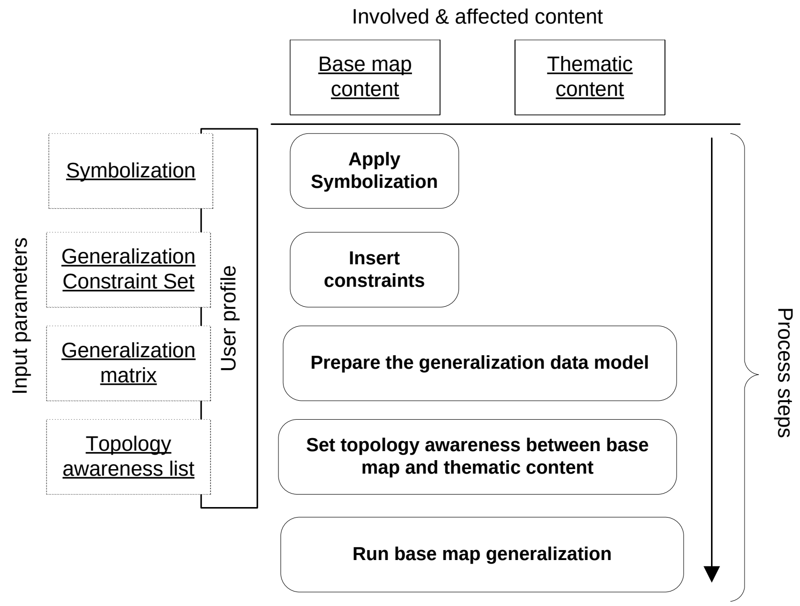

Figure 5 The generalization process to customize base maps according to a specific user profile.

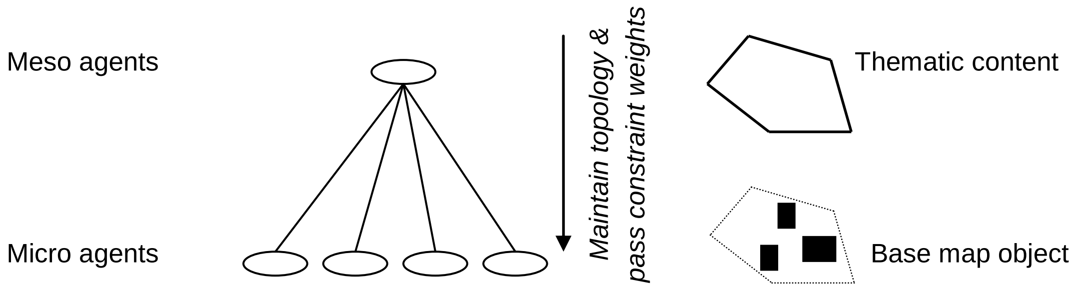

Figure 6 AGENT model applied for customizing base maps using topology awareness list and generalization matrix.

4 Implementation of the Web-based Architecture for On-demand Base Maps

As the approach for on-demand base maps has to be embedded into a web-based architecture, this section will present the core component of the architecture, the so-called generalization-enabled WMS. Furthermore it will describe how the user profiles are embedded into the architectural workflow. A complete overview of the architecture is also described in Foerster, Stoter, and Lemmens (2008). As the described architecture is based on standards, it can easily be integrated into existing service architectures of organizations such as National Mapping Agencies. Foerster and Stoter (2009) proposed a concept to embed this architecture into RO-online, the Dutch portal for physical plans: www.ruimtelijkeplannen.nl.

4.1 The Generalization-enabled WMS

The WMS interface has been chosen, as it provides the state-of-the-art approach for delivering maps on the web such as physical plans. For instance within the INSPIRE initiative the WMS interface is the foundation for a European-wide standard to deliver maps by means of the INSPIRE view service (Network Services Drafting Team 2008). Additionally, empowering a WMS with automated generalization capabilities has already been successfully applied in the context of on-demand web mapping (Burghardt et al. 2004; Cecconi 2003).

The generalization-enabled WMS plays a key role in the architecture. It delivers base maps on-demand according to the specific user profile by applying the generalization process described in Section 3.2. In this research the web map service implementation of the GeoServer application server has been used (www.geoserver.org, Deoliveira (2008)). GeoServer is available through an open-source license and provides a java-based programming interface, which can connect to databases and middleware components. Thus GeoServer has been linked to the software Clarity by 1Spatial (Hardy et al. 2003). Clarity provides functionality for the automated generalization processing and has been chosen for this research, as it applies agent-based generalization (Section 2.3.2) and has shown some promising results (Lecordix et al. 2007; Regnauld 2007). The necessary data (base map data and plan data) are retrieved from WFS instances. The geodata as well as the user profile are processed on-the-fly. The architectural workflow and the implementation of the generalization-enabled WMS are described in Foerster et al. (2008).

The browser-based client application for the generalization-enabled WMS is based on mapbuilder. The client application works in any browser, which supports client-side JavaScript. The browser-based client application accesses the base map and the thematic content. It allows the user to select the correct user profile in advance through a separate web page. Thereafter, the client application performs the appropriate request based on the chosen user profile, extent and zoom level to retrieve the desired map. In particular, the client application retrieves the base map and the thematic content as separate layers from different WMS instances and overlays them locally. This allows the user to combine the layers with different data and enables the flexibility of the architecture. Figure 7 depicts a screenshot of the client application, which displays the municipal physical plan on top of the on-demand base map containing generalized buildings (and for illustration purpose only, it also shows the original outline of the buildings).

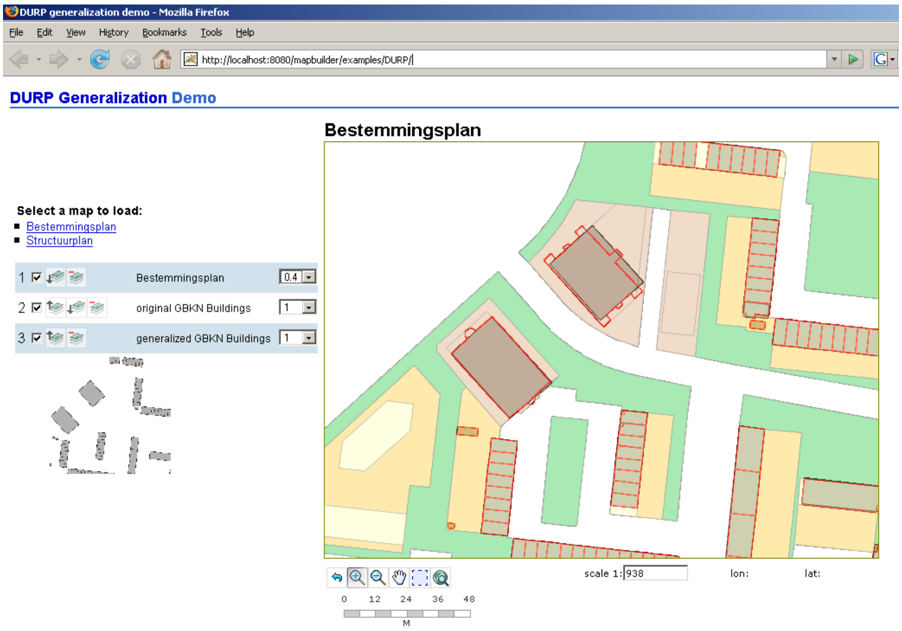

Figure 7: Screenshot of the developed browser-based client application. Map depicts red outline shapes of original buildings, gray shapes of the generalized buildings and a physical plan on municipal level. The final map presented to the user will not contain red outlines of the original buildings, which have only been included to show the effect of the generalization process.

The final map and its layers are specified in the WMC document, which is internally linked by the client application to one of the user profiles. The WMC document and the user profile link SLD documents. The combination of the available standardized user models (WMC & SLD) with the user profile enable to describe a map in a comprehensive and flexible way (the specification of the final maps can be changed without changing the architecture). This combined approach describes the layout of the map (without the actual data), including extent, selected layers, symbolization and map specification.

This combined approach covers the most important ETSI categories (see Figure 2, Section 2.4). The proposed user profile and the SLD document are related to human centered preferences. The application of WMC documents in the architecture allows the service provider to specify service related information and preferences. This also demonstrates that the combination of these aspects provides a means to specify the preferences of the user towards the map comprehensively. This combined approach is sufficient, if the architecture has only to be integrated into a single type of client application (e.g. a web browser application). In case of a more heterogeneous environment device related information and preferences might become necessary as well.

4.2 Embedding User Profiles in the Web-based Architecture

As the generalization-enabled WMS serves different maps for different types of users, the user profiles have to be propagated at the same time the base map is requested. Additionally, the requirement to process user profiles instantly is related to the stateless nature of OGC Web Services (ISO/TC 211 2005). Thus all the required information (i.e. the user profile, zoom level and extent) has to be gathered at the same point of time at which the request is received. Based on the user profile, the base map is generated on-the-fly and sent back to the client. The requirement for instant processing of the user profile has some implications for the WMS interface, which therefore had to be extended.

According to the WMS interface specification, any map is retrieved using the GetMap operation. The GetMap operation is extensible by so called vendor-specific parameters, which can be defined as optional input of the service. However, a requirement is that these parameters must not be mandatory and the service must not stop working if such an optional parameter is missing in the specific request.

A vendor-specific parameter has been specified. This parameter references the user profile according to which the map has to be generated. The generalization process incorporated in the WMS retrieves the user profile using this location reference and processes it as described in Section 3.2. An example of such an extended GetMap request is shown in Listing 1.

```
http://myWMS?Request=GetMap&SERVICE=WMS&BBOX...&userprofile=
http%3A//anotherServer/thisUserprofile.xml
```

Listing 1: Sample GetMap request incorporating a reference to a user profile.

Including a reference to the user profile instead of including the specific content of the user profile in the request avoids exceeding the maximum size of a URL. Additionally, using references enables caching and is helpful when considering an implementation in a production environment. The reference to the user profile can be used as an identifier for already processed user profiles. It allows performing the customization process once, but reusing the result multiple times. However, it has to be made sure, that an update of the user profile is also propagated to the generalization process (incorporated in the generalization-enabled WMS). This requires specific update strategies, which check after a specific timeout or a specific event, if the user profile has not changed yet. Additionally, as the generalization process involves remote data services, which might be updated frequently, the cached generalization results might become outdated. Thus selecting a specific caching strategy requires careful analysis (Sivasubramanian et al. 2007).

The GetMap operation provides the extent and the width/height of the map, which can be used to calculate the scale of the map. The information about the initial extent of the map and the involved layers is provided by the WMC document, which is internally linked in the client application to the user profile. The WMC document is only a source of information for the client to retrieve the initial map. In the course of user interaction with the client application (zooming, selecting layers), the map is changing and the client application uses its internal state to specify the applicable requests to the specific services.

Regarding the service communication, the generalization-enabled WMS requests the thematic data and the base map data for customizing the base map from the WFS instances as referenced in the user profile. However the WMS does not incorporate the thematic data in the final base map layer served to the client application. The client application has to fetch the thematic map layer separately from its original source (according to the WMC document). This leads to communication overhead for the client application, as it has to trigger two services, but increases its flexibility. Additionally, the client can already display the thematic data while waiting for the base map to be generated. Finally, the separation of thematic and base map layer increases the usability of the client application. Note however that the generalization process generating the base map has to be aware of the thematic content.

5 Results of the Applied Use Case for Physical Plans

To demonstrate the concept of user profiles and the presented web-based architecture for on-demand base maps, this section provides a map example to show the effect of user profiles for different users and their effect on the generalized base map. The presented concept is applied to the DURP ondergronden use case, which is described in Section 5.1. In Section 5.2 the map samples are illustrated, which have been generated using the presented architecture.

5.1 The DURP Ondergronden Use Case

The research presented in this paper is applied to the application of physical planning maps in the Netherlands. Such maps consist of planning objects for which the boundaries are legally established. An instance of a physical planning map is depicted in Figure 8. These maps become digitally available according to the new information model for physical plans called IMRO *(in Dutch: Informatiemodel Ruimtelijke Ordening)* (Ottens 2004). In this model the physical plans are detached from their original reference, on which they were drawn – i.e. the topographic map. The base map is no longer legally a part of the physical plan in the Netherlands. Consequently, the physical plan data need to be combined with a base map before it is offered as a map to the user. The questions to be answered in the *DURP ondergronden research project* (base maps for digital physical plans) is 1) how should the base map look like to optimally support a specific user of physical plans; and, in a more technical context, 2) how to generate and disseminate this specific base map on the Web on-demand? The second part of the question has been covered in this paper. The first part of the question requires intensive usability research and is covered in another part of the DURP ondergronden project (Poppe et al. 2006).

Figure 8 Example of a physical planning map (municipal plan with 1:5K topographic base map) – in the current static approach, this base map would not have been adapted while zooming. Map as delivered through the Dutch physical planning portal Ro-online.

As physical plans are produced at different scales, and as one of the basic interactions with digital maps is zooming, the base map has to be generated on-demand by means of automated generalization according to a scale range related to the zoom level and according to the requirements described in Section 2.1. Additionally these base maps have to be web-accessible through a browser-based client application. The application of base maps for physical plans as described in the DURP ondergronden project serves as a case study to test the approach. In a workshop with planners an investor and an ecologist have been identified as potential users who both consult a physical planning map. They have different requirements towards the base map due to different information requirements. The investor seeks for future commercial areas and the ecologist investigates nature-related areas on the physical plan to identify compensation areas. Consequently, their base maps will be different although they consult the same type of plan (Section 2.1). Based on these two different types of users two user profiles have been created, which describe the same requirement for topology, but a different requirement regarding the level of detail of the base map objects. These two user profiles are used to demonstrate the designed web-based architecture (Section 5.2).

As a result of the DURP ondergronden project, the presented architecture might be integrated into the concept of a physical planning web portal like the Dutch RO-Online portal: www.ruimtelijkeplannen.nl. A conceptual integration has been described by Foerster & Stoter (2009).

5.2 Samples of On-demand Base Maps for the Physical Planning Use Case

The presented approach is applied in the context of physical planning (Section 5.1) with two different user profiles. One profile represents the requirements of an investor, who is interested in commercial planning areas. The other profile represents the requirements of an ecologist, who is interested in nature planning areas (Section 2.1). Subsequently, they have different user profiles for differently generated base maps. As physical plans mostly consist of areal objects, the implemented process focuses only on this type of geometry as a thematic overlay.

The presented work applies large-scale topographic data produced at a scale of 1:1000 in an urban area and 1:2000 in a rural area (*GBKN*) and 1:10 000 (*TOP10NL*) and fixed physical plans. For physical plans, symbolization is prescribed by law. Thereby the generalization system is preconfigured with this information and can apply it, whenever it is necessary throughout the generalization process.

Figure 9 shows sample maps, which are generated by the proposed architecture based on user profiles. In particular, it shows four samples of the same extent (scale 1:5000): the original base map information (GBKN, source scale 1:1000) with the municipal physical plan (Figure 9 a), the municipal physical plan (Figure 9 b), the map (physical plan and generalized base map) as generated for the ecologist (Figure 9 c) and the map (physical plan and generalized base map) as generated for the investor (Figure 9 d). The base map objects are retrieved and generalized from the GBKN according to the supplied user profiles. In the sample of Figure 9, the base map objects for the ecologist's map are more generalized (less detailed) than for the investor's map. In the current example, the preserveBuilding constraint is satisfied by aggregating the building geometries. In the ecologist's map all the buildings inside the commercial area are aggregated to one polygon geometry, whereas in the investor's map the buildings are aggregated to a set of three geometries. The presented example only shows one solution to the preserveBuildings constraint. In a more advanced scenario, the buildings could have also been displaced to satisfy the constraint.

Figure 9: Map example - the original base map information (GBKN, source scale 1:1000) with the municipal physical plan **(a)**, the municipal physical plan **(b)**, the map (physical plan and generalized base map) as generated for the ecologist **(c)** and the map (physical plan and generalized base map) as generated for the investor **(d).**

From applying the designed architecture to our case study, we can conclude that the way we embedded the user profiles in the web-based architecture provides a good way to disseminate on-demand maps via the web. The user profiles are used here to evaluate the implementation. Future research is required to evaluate to what extent user requirements as specified in the user profiles result in usable and acceptable maps. This also includes defining more complete requirements meeting real world cases in the user profiles.

Applying the architecture to a real-world use case resulted in unacceptable waiting time for the client application (acceptable waiting time is below 5 seconds). Tests with generalizing a base map consisting of 100 objects took 30 seconds on a 2.13 GHz dual core processor. Grid Computing is considered to be a solution and has been discussed in Foerster et al. (2009). The physical plan provides a partition of the base map, enabling the generalization process to be split into smaller chunks, which can be then submitted to the grid for further processing. Additional research needs to investigate this possibility in more detail.

Further developments should incorporate the concept of vario-scale maps, as it helps to avoid distracting scale jumps of objects between different map scales. For example the specialized WFS as described by de Vries & van Oosterom (2008) could be included to enable vario-scale maps and progressive transfer.

6 Discussion & Conclusion

Due to the increasing availability of thematic content on the web, which is stored separately from any base information, on-demand base maps become an important resource for improving the communication of the thematic content. In a web-based architecture the requirements towards the base map are higher and more dynamic because of interaction, integration and zooming possibilities of digital maps. Additionally as the thematic content is accessed by different types of users with different requirements, the generalization of on-demand base maps turns out to be a challenge for research (Regnauld & McMaster 2007).

To provide such base maps on-demand, these user requirements have to be formalized. This leads to the development of user profiles. The user profile presented in this research formalizes the user requirements regarding the base map and its thematic overlay. The addressed requirements are preserving topological relations between base map and thematic content (concept of topology awareness list) and adjusting the level of detail of base map objects, which are inside a thematic class of interest to the user (concept of generalization matrix). The user profile is applied to generate on-demand base maps for physical plans. In particular, two potential users are identified and their requirements towards the base map are described in such user profiles. The user profiles are embedded in a web-based architecture based on a XML-encoding. The core of the web-based architecture is the generalization-enabled WMS, which consumes such XML-encoded user profiles and performs the generalization of the base map on-demand and thereby delivers the base maps according to the specific user profile. The generalization process incorporated in the generalization-enabled WMS is implemented using agent-based generalization.

From our research, we can draw several conclusions. Firstly, the proposed approach is an important contribution in the context of on-demand web mapping applications. The proposed user profile allows the service provider to generate on-demand base maps based on generalization constraints and optimization goals. Addressing the need for on-demand base maps is a new contribution to generalization and web research. Additionally, it goes beyond the currently available approaches for specifying maps on-demand, such as SLD and WMC documents, as it provides direct input for automated generalization (e.g. described in the map specification). Also it goes beyond the selection of features and feature classes for the personalization of maps as described in Wilson et al. (2010). This is also true for the focus on a web-based architecture applied in this research. The aspect of a web-based architecture stresses the need for user profiles to generate on-demand base maps. This research demonstrates that user profiles can be used as a complement to these two documents. Regarding the categories as specified by the ETSI (Section 2.4), the proposed user profile specifically addresses human centered preferences. This type of preference is most essential for the automated generalization process and the desired application of a web portal for thematic maps. Additionally, the proposed architecture is promising, as it demonstrates how such user profiles can be exposed to the architecture (i.e. generalization-enabled WMS). Moreover, the architecture enables the client application to integrate several map layers from different sources.

Several topics can be outlined for further research. Firstly, the presented approach provides the technical basis for future usability research on base maps, which will complete the user profiles for various types of users. Independent from the usability research, the produced base maps might be evaluated according to the readability measures of Stigmar & Harrie (2008). Furthermore, the proposed architecture might also be tested with other types of thematic maps such as soil maps. Or stated even more generally: the architecture with user profiles might be tested for the general case of multi-source web-based maps. What is foreground/background depends on the user/application. Also one could imagine that there is no strict separation between foreground/background objects, but a gradual change from objects that should be changed minimally (or not at all) to objects where more flexibility is allowed with respect to changing their representation. Van Oosterom et al. (2001) proposed to characterize this aspect of a user profile by ordering the different object classes in the legend according to their relative importance. Regarding the performance of the architecture (Section 5.2), Grid Computing might be an applicable solution, which needs to be verified in the future. Another alternative is to replace the agent-based generalization approach with a batch-oriented approach, which scales better in terms of performance, but might produce maps with less cartographic quality. A last topic that can be identified for further research is the integration of ontologies into the user profiles. This enables the potential of an open web-based architecture, which involves loosely coupled data services. In particular, the application of a geo-ontology (Duckham & Worboys 2005; Agarwal 2005) is promising to not link the user profiles to known feature classes but to link concepts specified by ontologies. This will enable on-the-fly selection and automated generalization of appropriate maps on the web.

Acknowledgements

The presented work has been financially supported by Dutch national research programme Ruimte for Geoinformatie (RGI). The authors acknowledge the support of the research group at Ordnance Survey, GB for their support on 1Spatial Clarity and the company 1Spatial for providing the software. Moreover, the authors appreciate the effort of the Dutch Kadaster for providing the data.

References

Agarwal, P., 2005. Ontological considerations in GIScience. *International Journal Of Geographical Information Science*, 19(5), pp.501-536.

Barrault, M. et al., 2001. Integrating multi-agent, object-oriented and algorithmic techniques for improved automated map generalization. In *20th International Cartographic Conference - ICC*. Bejing, China, pp. 2110-2116.

Beard, K.M., 1991. Constraints on rule formation. In B. Buttenfield & R. B. McMaster, eds. *Map Generalization: Making Rules for Knowledge Representation*. London: Longman, pp. 121-135.

Booch, G. et al., 2007. *Object-Oriented Analysis and Design with Applications* 3. ed., Addison-Wesley Professional.

Burghardt, D., Edwardes, A. & Mannes, J., 2004. An architecture for automatic generalisation of mobile maps. In G. Gartner, ed. *2nd Symposion on Location based service and telecartography*. Vienna, Austria.

Cecconi, A., 2003. *Integration of Cartographic Generalization and Multi-Scale Databases for Enhanced Web Mapping*. PhD thesis. University of Zurich.

Deoliveira, J., 2008. GeoServer: Uniting the GeoWeb and Spatial Data Infrastrucutures. In *Proceedings of the 10th International Conference for Spatial Data Infrastructure*. GSDI 10. St. Augustine, Trinidad. Available at: http://www.gsdi.org/gsdi10/papers/TS26.4paper.pdf [Accessed November 2, 2010].

Duchene, C. & Gaffuri, J., 2008. Combining three Multi-agent based Generalization Models: AGENT, CartACom and GAEL. In A. Ruas & C. Gold, eds. *Headway in Spatial Data Handling*. Lecture Notes in Geoinformation and Cartography. Springer, pp. 277-296.

Duckham, M. & Worboys, M., 2005. An algebraic approach to automated geospatial information fusion. *International Journal Of Geographical Information Science*, 19(5), pp.537-557.

van Elzakker, C. & van de Berg, W.P.E., 2009. Topografische ondergronden voor plankaarten: een gebruikersonderzoek. *Geo-Info: tijdschrift voor geo-informatie Nederland*, 6(3), pp.64-69.

ETSI, 2009a. *Human Factors (HF): Personalization and User Profile Management: Architectural Framework*, ETSI.

ETSI, 2009b. *Human Factors (HF); Personalization and User Profile Management; User Profile Preferences and Information*, ETSI.

ETSI, 2005. *Human factors (HF); User profile management*, ETSI.

Fink, J. & Kobsa, A., 2002. User Modeling in Personalized City Tours. *Artificial Intelligence Review*, 18(1), pp.33-74.

Foerster, T., Stoter, J. & Morales, J., 2009. Enhancing Cartographic Generalization Processing with Grid Computing Power and Beyond. *GIS.Science*, 2009(3), pp.98-101.

Foerster, T. & Stoter, J.E., 2009. Providing customized base maps in a SDI for physical planning. In *GSDI 11*. Rotterdam, the Netherlands.

Foerster, T., Stoter, J.E. & Lemmens, R., 2008. An interoperable Web Service Architecture to Provide Base Maps Empowered by Automated Generalization. In A. Ruas & C. Gold, eds. *Headway in Spatial Data Handling*. Lecture Notes in Geoinformation and Cartography. Montpellier, France: Springer, pp. 255-76.

Forrest, D., 2005. Automated Selection of Topographic Base Information from the Global Map Database for Thematic Maps. In *From Pharaohs to Geoinformatics*. FIG working week and GSDI-8. Cairo, Egypt. Available at: http://www.fig.net/pub/cairo/abstracts/ts_48/ts48_03_forrest_abs.pdf [Accessed November 2, 2010].

Gottschalk, K. et al., 2002. Introduction to Web service architecture. *IBM Journal*, 41(2), pp.170-177.

Gruenreich, D., 1992. ATKIS - a topographic information system as a basis for GIS and digital cartography in Germany. *From digital map series to geo-information systems*, Geologisches Jahrbuch Reihe A(Heft 122), pp.207 - 216.

Hardy, P., Hayles, M. & Revell, P., 2003. Clarity - a new environment for generalisation using agents, Java, XML and topology. In *Fifth Workshop on Progress in Automated Map Generalization*. Paris, France.

Harrie, L., Sarjakoski, L.T. & Lehto, L., 2002. A variable-scale map for small-display cartography. In *Proceedings of the Joint International Symposium on "GeoSpatial Theory, Processing and Applications" (ISPRS/Commission IV, SDH2002)*. Ottawa, Canada, p. 6.

ISO/TC 211, 2005. *Geographic information - Services*, International Organization for Standardization.

Kuipers, B., 1982. The "map in the head" metaphor. *Environment and Behavior*, pp.202-220.

Lecordix, F. et al., 2007. Development of a new generalization flowline for topographic maps. In *10th ICA workshop on Generalisation and Multiple Representation*. Moscow, Russia. Available at: http://aci.ign.fr/BDpubli/moscow2007/Lecordix_ICAWorkshop.pdf [Accessed September 19, 2008].

Mackaness, W.A., Ruas, A. & Sarjakoski, L.T., 2007. Observations and Research Challenges in Map Generalization and Multiple Representation. In W. A. Mackaness, A. Ruas, & L. T. Sarjakoski, eds. *Generalization of Geographic Information: Cartographic Modelling and Applications*. Elsevier, pp. 315-323.

McMaster, R.B. & Shea, K.S., 1992. *Generalization in Digital Cartography*, American Association of Geographers.

Network Services Drafting Team, 2008. *Technical Guidance to implement INSPIRE View Services*, INSPIRE. Available at: http://inspire.jrc.ec.europa.eu/reports/ImplementingRules/network/Draft_Technical_Guidance_View_Services_v1.0.pdf [Accessed April 20, 2009].

OGC, 2004. *OGC Web Map Service interface*, Available at: http://www.opengeospatial.org/standards/wms [Accessed November 2, 2010].

OGC, 2007. *Styled Layer Descriptor profile of the Web Map Service Implementation specification*, Available at: http://www.opengeospatial.org/standards/sld [Accessed November 2, 2010].

OGC, 2005. *Web Map Context documents*, Available at: http://www.opengeospatial.org/standards/wmc [Accessed November 2, 2010].

van Oosterom, P., 2005. Variable-scale Topological Data Structures Suitable for Progressive Data Transfer: The GAP-face Tree and GAP-edge Forest. *Cartography and Geographic Information Science*, 32(4), pp.331-346.

van Oosterom, P. et al., 2001. Multi-source Cartography in Internet GIS. In Milan

Konecny, ed. *Proceedings of the 4th AGILE Conference*. Brno, Czech Republic, pp. 562-573. Available at: http://www.gdmc.nl/publications/2001/Multi-source_cartography_internet.pdf.

Ottens, H., 2004. An Information Model for Strategic Spatial Policy Documents. In *7th AGILE Conference on Geographic Information Science*. Heraklion, Greece, pp. 605-611.

Poppe, E., van Elzakker, C.P.J.M. & Stoter, J.E., 2006. Towards a Method For Automated task-driven Generalisation of Base Maps. In *UDMS 2006 - 25th Urban Data Management Symposium*. Denmark, Aalborg, pp. 3.51-3.64.

Regnauld, N., 2007. Evolving from automating existing map production systems to producing maps on demand automatically. In *10th ICA Workshop on Generalisation and Multiple Representation*. Moscow, Russia.

Regnauld, N. & McMaster, R.B., 2007. A synoptic view of generalisation operators. In W. A. Mackaness, A. Ruas, & L. T. Sarjakoski, eds. *Generalization of Geographic Information: Cartographic Modelling and Applications*. Elsevier, pp. 37-66.

Ruas, A., 1998. OO-constraint modelling to automate urban generalization process. In *Spatial Data Handling '98 Conference Proceedings*. 8th International Symposium on Spatial Data Handling. Vancouver, Canada, pp. 225-235.

Ruas, A., 2000. The Roles of Meso Objects for Generalization. In *Proceedings of the 9th International Symposium on Spatial Data Handling*. Beijing, China, pp. 3b50-3b63.

Sabo, M.N. et al., 2008. Toward Self-Generalizing Objects and On-the-Fly Map Generalization. *Cartographica*, 43(3), pp.155-173.

Sarjakoski, T. et al., 2005. Web generalisation services in GiMoDig - towards a standardised service for real-time generalisation. In F. Toppen & M. Painho, eds. *AGILE 2005*. Estoril, Portugal, pp. 509-18.

Sester, M., 2005. Optimization approaches for generalization and data abstraction. *International Journal Of Geographical Information Science*, 19(8-9), pp.871-897.

Sivasubramanian, S. et al., 2007. Analysis of Caching and Replication Strategies for Web Applications. *IEEE Internet Computing*, 11(1), pp.60-66.

Slocum, T., 1999. *Thematic Cartography and visualization*, Prentice Hall.

Sparx Systems, 2009. *Introduction to Enterprise Architect*, Available at: http://www.sparxsystems.com/uml_tool_guide/ [Accessed November 2, 2010].

Steiniger, S. & Weibel, R., 2007. Relations among map objects in cartographic generalization. *Cartography and Geographic Information Science*, 34, pp.175-197.

Stigmar, H. & Harrie, L., 2008. Usability testing of legibility constraints. In *Proceedings of the 11th ICA workshop on Generalization and Multiple representation*. Montpellier, France. Available at: http://aci.ign.fr/montpellier2008/papers/03_Stigmar_Harrie.pdf [Accessed November 2, 2010].

de Vries, M. & van Oosterom, P., 2008. Model Generalization and Methods for Effective Query Processing and Visualization in a Web Service/Client Architecture. In A. Belussi et al., eds. *Spatial data on the web*. pp. 85-106.

Weibel, R. & Dutton, G., 1999. Generalising spatial data and dealing with multiple representations. In P. Longley et al., eds. *Geographic Information Systems - Principles and Technical Issues*. John Wiley & Sons, pp. 125-155.

Wilson, D., Bertolotto, M. & Weakliam, J., 2010. Personalizing map content to improve task completion efficiency. *International Journal Of Geographical Information Science*, iFirst.

Wooldridge, M., 2002. *An Introduction to MultiAgent Systems*, Liverpool, UK: John Wiley & sons.

Yang, C. & Tao, C.V., 2006. Distributed Geospatial Information Services. In S. Rana & J. Sharma, eds. *Frontiers of geographic information technology*. Springer, pp. 103-120.