Implementing Adaptive Mobile GI Services based on Ontologies
Examples from pedestrian navigation support

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Summary

As we are facing the dawn of ubiquitous computing (UbiComp) by emerging mobile devices and distributed applications, personalization is leaving the desktop domain, because adaptation and context-awareness play a major role in UbiComp in order to realize the user friendliness postulated for UbiComp applications. Adaptation is a relatively new concept for GI services. Therefore we introduce the related research areas. The two most important factors for adaptation are a.) context as the representation of the current situation and b.) the user itself. In particular how to dynamically derive information on the users' properties is a research area applying learning strategies introduced shortly. We see these two concepts not isolated but propose an integrated situation model including several types of context as well as user parameters. After this introduction we present several approaches to realizing adaptive mobile GI services in the domain of pedestrian navigation and tourist information – representing first steps towards UbiGIS. These include context and user aware proactive tips, personalized tour planning and adaptive maps. Implementations and new concepts for extensions of these are presented. The paper closes by an outlook on open research issues related to adaptive GI services.

1. Introduction

We are about to enter an era, where the visions from mobile computing and in particular ubiquitous computing = UbiComp research seem to materialize one by one [41]. This paper will discuss the technical and usability issues related to the combination of GI services and UbiComp – called "UbiGIS" (http://www.geoinform.fh-mainz.de/~zipf/ubigis http://ww.ubigis.org/). One has to consider how to proceed from services "anyplace, anytime, on mobile devices" (LBS promises as we know them) to really ubiquitous personalized GI services adapted to the current situation (context), in order to deliver the right information in the right situation to the right person the right way. One important aspect that needs to be addressed here – apart from personalization - is "Context-Awareness". See also [23]. Context is more than location as used in LBS [37]. We regard the combination of UbiComp and GI services to UbiGIS as a very promising trend for both [35].

Possible application of UbiGIS range from typical LBS, to environmental monitoring by new mini-sensors ("Smart Dust" etc.) to telematics and logistics. The need to manage position of so many objects and persons leads to questions regarding moving objects in spatial DBs. On the other hand the heterogeneity of devices is getting larger - and the issue here is that each may have its own individual "best way" of interaction with spatial applications on these devices – from interactive walls, mobiles, PDAs, to AR or things we wouldn't recognize as computer today at all. This raises questions in Human Computer Interaction (HCI) with GI services.

We consider some of these issues in particular related to personalized and context-aware GI services in this paper. We have developed a range of applications that realize context- and user-aware mobile GI services such as tour guides or car or pedestrian navigation systems. One of the joint aims of the aspired prototypes is to guide and navigate their users through a city.

Most of these systems have been developed using software agents that conform to the specifications of the Foundation for Intelligent Physical Agents (www.fipa.org). Utilizing FIPA- agents requires the use of an Agent Communication Language (ACL) that encodes messages in a layered structure. In order to communicate the agents need to agree on a common data structure for representing the entities and concepts of their "discourse". This structures (sometimes being referred to as "ontology" within the agent community) are defined using XML schema. Later on we will present some examples of this xml encoded ontology.

2. Adaptivity and Context awareness for GI services

Until now personalized information systems are almost only known from classical desktop applications and web based information systems. As Fischer [14] stated one can distinguish personalization approaches in *adaptable* and *adaptive*. Oppermann [31] defines a system as adaptable if the user is in control of the complete adaptation process (initiation, proposal, selection and production of adaptation). Systems are adaptive if these adaptations are done automatically without the direct involvement of the user. Both approaches can coexist in one application with different weighting depending on the type of adaptation.

A critical issue of adaptive and adaptable systems is the complexity be means the directness of the transformation from the user input to the system output. On can argue [27] that the more explicit and direct the transformation is, the more appropriate results are gained. To facilitate personalized and user tailored services adaptable/adaptive systems need to have a clear picture of their users, the interaction with them and the general context both are in. For example, user data can contain various demographic properties of the user, his knowledge of the specific application domain, his skills and capabilities, furthermore his interest and preferences. But it is not only the user a system might adapt to, but also the current situation can be used as an factor for adapting the service. This situation is describable by parameters thus defining the "context" of a specific situation. Possibilities and requirements regarding modeling context information are discussed in the following section.

The research area of "Context Aware Computing" has a strong influence on UbiGIS. Dey and Abowd characterize context as "any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant for the interaction between a user and an application, including the user and the application themselves." Therefore any information that is available at the time of an interaction can be considered as context information. Classical computer systems produce an output dependent on a certain input (black box). But if is it possible to include also further context elements apart from the explicit input of the user to parameterize a request, one can speak of context aware computing. In case more context parameter become available through the use of new sensors, sources of information or inference mechanisms, the development of even more advanced services would be possible. But concerning the notion of context a major problem arise due to its different meaning in the various fields of cognitive science, engineering or geography [4]. A fundamental property for mobile applications is the non-static environment by means of contextual changes. Schilit [36] considers that context in mobile systems consists of computing-context, user-context and environmental-context. There is a context-aware computing cycle with three phases: *Discovery* – learning about entities and their characteristics. *Selection* – deciding which resources to use as the key concern of the context-awareness. The system should be capable to select entities based on the surrounding context. *Use* – employing the available resources.

In the recent years there have been various attempts to build context-aware mobile applications and frameworks. Initial those application had mainly indoor usage scenarios, e.g. ActiveBadge, RemembranceAgent or CyberDesk but rapidly also outdoor scenarios gained attention such as CyberGuide, Guide or commotion. Byun and Cheverst [6] compared context and user models with respect to the data acquisition, their coupling to applications, presentation and period to acquire the data. An overview can be found at Chen (2000) [8].

Table 1: A comparison of Context Models and User Models [6]

Issues	Context Models	User Models
Data Acquisition	Largely from sensors	Largely from interaction with the users
Coupling to Applications	Can be insulated from applications	To be part of an application could be more efficient.
Representation	A data model	A data model, a behavior model, or a combination of the two.
Period required for Data Acquisition	There is no time gap to capture a user's context	Sufficient time and interaction needed for a behavior model to learn a user's behavior.

But in contrast to their proposed separation between context and user model on can argue with Jameson (2001) [22] that it is crucial to model and considerate both in common.

Representing Context through Ontologies for Adaptive GI Services

Ontologies are explicit formal descriptions of concepts or classes in a domain of discourse, properties of each class describing various features and attributes of the class, as well as restrictions on properties which express a shared specification of a conceptualization. Ontologies provide means for sharing such context knowledge, thus minimizing the cost of sensing. This kind of ontologies used in knowledge engineering need to be distinguished from *Ontology* in philosophy, which is referring to the "truth" prior to perception or language [18]. In particular ontologies seem to be very relevant within the area of Ubiquitous Computing (and therefore "Ubiquitous GIS") as they are needed to model the diverse aspects of the context of a situation. Ontologies can therefore be applied as formal descriptions of context information used to parameterize adaptive GI services. In our case they are in particular also necessary for the agent communication [46]. In the domain of spatial information systems ontologies have become an important research area.

Personalization of GI-Services and User Model Acquisition Techniques

In order to acquire, manage and predict profiles of the user, called "user models", personalized applications need to collect general system data such as observable usage of information content, selective actions for a information or the temporal viewing behavior. The most direct way to obtain information about the user is to simply ask them. That counts for initial interviews to get some demographics about the user [13] or for recommender systems

In contrast to these active methods implicit acquisition methods require and initiate no interaction with the user. They try to generate assumptions about the user by specific acquisition rules, i.e. inference rules that refer to observed user actions or a more or less straightforward interpretation of user behavior.

In order to provide personalization and adaptation capabilities, systems need to be able to reason about their users. In general one can distinguish inductive and analogical reasoning. Inductive reasoning approaches try to draw assumptions about individual users, based on their behavior with the system. To do so, they apply methods such as neural networks or general machine learning techniques such as k-Nearest Neighbors, naïve Bayes and TF-IDF algorithms. Another methodology is the analogical reasoning that takes advantage of the rather large user numbers in web-based information systems and applies stereotyping methods [32]. Some more recent approaches try to employ ontology's [16] for personalization.

This shows that there are a number of possible methods to gain information about the user dynamically which of course need to be improved, but which provide a fundament for developing user aware GI services. That is of particular interest in mobile systems, as the situation and environment is changing there rapidly which is for example influencing the user's actual interests and plans.

Most personalization approaches depend on machine learning techniques that usually require a large amount of data in order to provide proper results. But in contrast to web-based recommender or information retrieval systems it is rather difficult for mobile applications to get the required amount of data due to the spatial dependability of mobile systems and their location specific content. Due to these difficulties there are only initial attempts to introduce user modeling in mobile application (e.g. [20]).

For our own realizations of adaptive GI services we propose an ontology-based approach that employs different machine learning methods based on stereotype reasoning, domain inference etc.[11]. It was initially developed for web-based information systems. Our latest XML schema definition, presented in figure 1 for a user model consists of some basic user properties such as UserID, first name / last name and the preferred language: Furthermore it includes demographic attributes and some account data. But the most important property is the different interests of the user modeled as "*UMInterest*".

The basic attribute describing an *UMInterest* entity is its name, but attributes like a description and a type definition can characterize it in more depth. Within the *UMConfidence* properties the user model server stores the calculated probabilities (individual and normalized over all users) as well as the used algorithm for this interest and user. This is necessary in order to have some measure for the validity of the calculated interest values, which then can be taken into account when applying the interest values for adapting a service offered to the user.

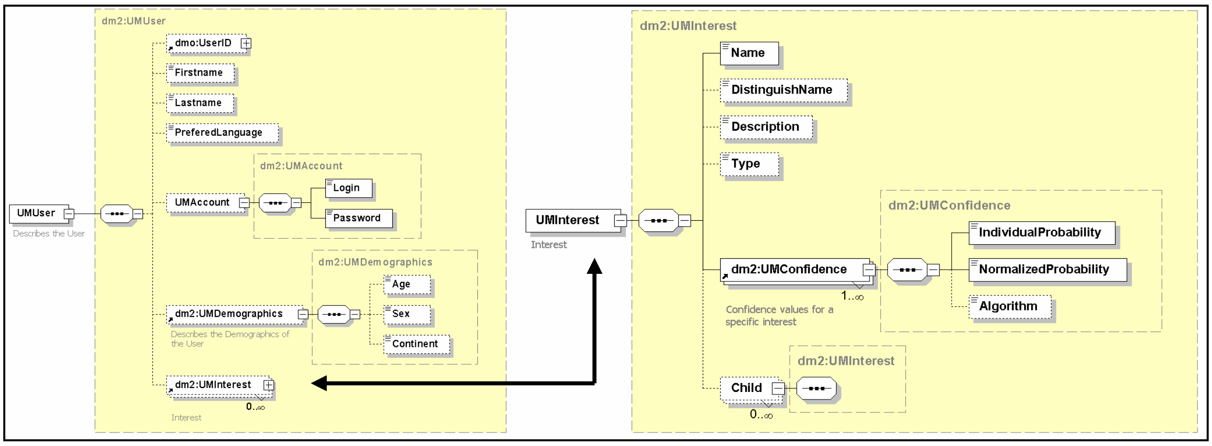


Figure 1: UMUser (User Model User) Schema definition and UMInterest including confidence elements

Combining context and user models

Especially in mobile application scenarios contextual and personal factors involve each other. Personal characteristics determine a humans behavior and the behavior determines the context (and vice versa). In the following a novel approach of a combined user and context model is proposed in order to integrate these effects. This new model consists of three main components namely, the representation of the *user*, the *knowledge* and the *situation* which are explained in turn

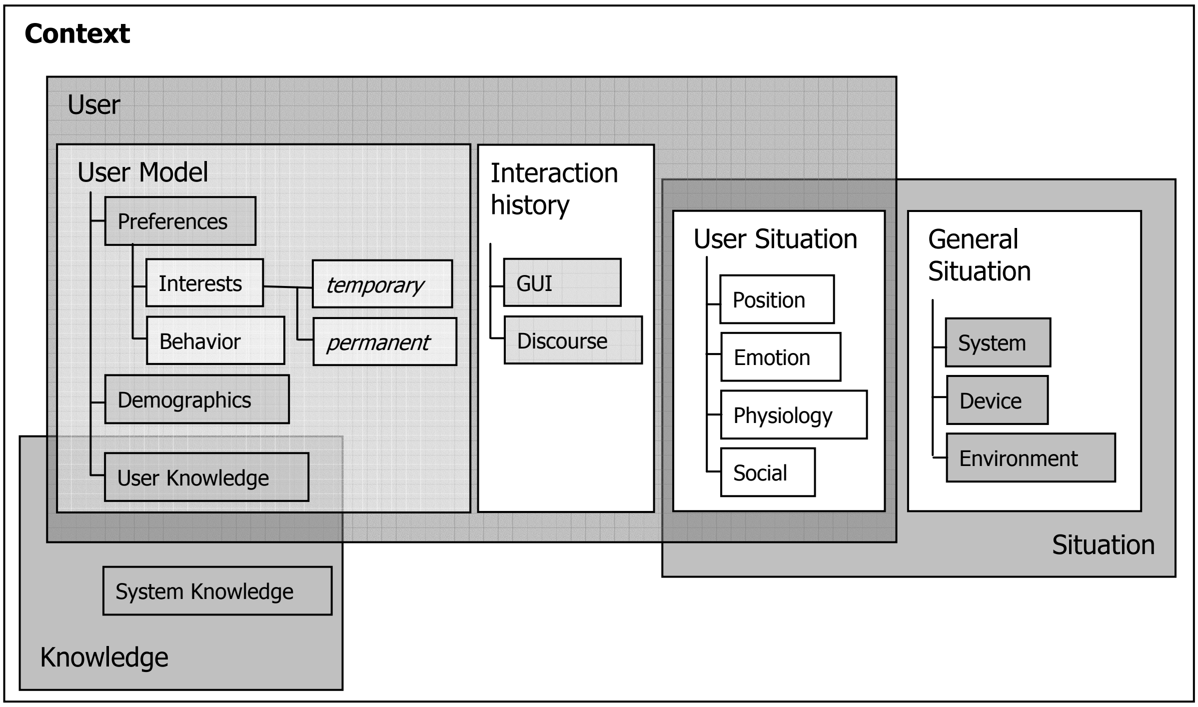
User

The system's representation of the user incorporates a user model. It describes the user with assumptions about his knowledge and preferences, the interaction history and a description of his current situation.

For dealing with preference a distinction between interests and behavioral preferences is proposed. Interest preferences depict the user's interest in certain topics, for example buildings of a specific architectural style or an historical event. One can distinguish such interests as of only a short duration or as a general long-term interest in order to reflect the concept of interest shift during the use of the system.

Behavioral preferences should represent some aspects of the user's general demeanor. An example might be if the user usually does not like to wait in line at an entrance to a sight or if he likes to have a tea break in the afternoon.

Figure 2: Context model including strong user model enhancements.



The interaction history comprises the different interactions between the user and the system either via natural language or a graphical user interface.

Situation

The user's situation is part of the general situation. It is the attempt to describe the user's current situation with its various characteristics in the real world. Some of these occurrences can be gathered more or less directly through the use of external sensors like the user's current position, whereas others can only be inferred through indirect indicators derived from the context model. An example for the latter might be the emotional or social state or the physiological condition of the user. The context model distinguishes three different aspects of the general situation as user independent situation information. First the overall status of the system (e.g. whether some services are temporarily unavailable), second the device situation (e.g. battery or memory status of the device) and third the environmental situation (e.g. whether it is raining or some museums are closed).

Knowledge

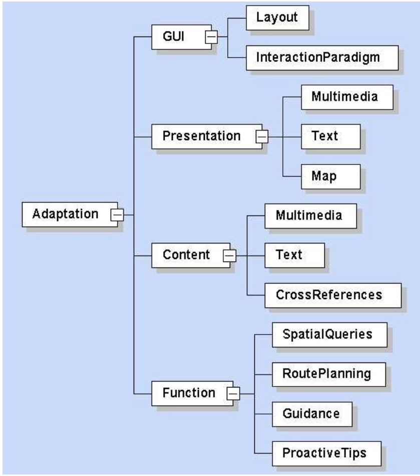
The third main component is a representation of the user's and the system's knowledge. The user knowledge provides references to information, which was already given by the system in order to allow an adequate interaction and to refine the user preferences. The system knowledge should represent the system's overall knowledge about the world. This is a complicated issue on it's own and ontology's for representing spatial and common world knowledge are researched by increasingly by GI Science.

3. Example Applications of Adaptation to GI Services

In the next sections we will discuss examples of adaptive GI services for mobile applications that use user and/or context information relevant in a navigation scenario – e.g. for pedestrians. The first one is the standard example for LBS – proactive tips, but in our case these do not only use location as a parameter but further user and context information. The second one is the personalization of tour planning to context and user and the third one include several examples of adaptation of mobile maps to a range of factors.

Most adaptive systems focus only on the adaptation of database contents or Web-contents like Yellow Page Servers, but we also want to deliver adaptive GIS services. When developing personalized mobile GI services we distinguish several types of "personalization", as an enhancement of the adaptive hypermedia model by Brusilovsky (1996) [5]:

Figure 3: Different types of adaptation

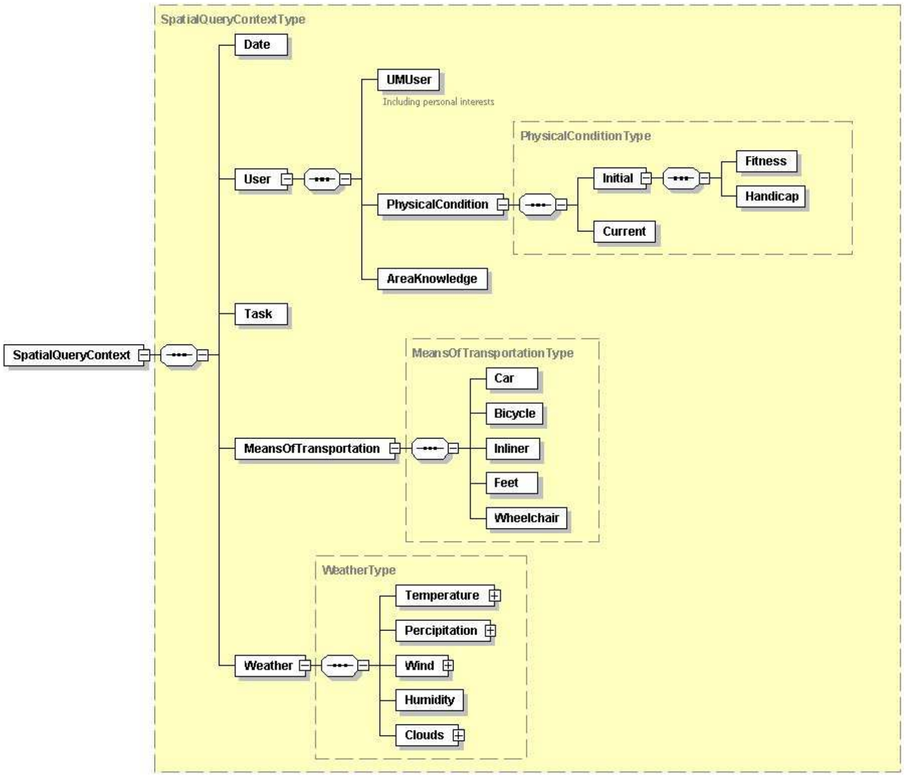


Within this paper we concentrate on adaptive routing and map adaptation.

Context triggered and parameterized spatial queries

Context information can be used to trigger or parameterize spatial queries [46]. There a “proactive spatial-context agent” presents tips to the user based on the user’s location and interests regarding nearby objects of interest. The system takes not only the position of the user and surrounding objects into account in order to deliver suggestions, but also the user’s current interests which are learned dynamically through a user modeling component. But even resolving what “nearby” means to the user in a specific situation would involve a wide range of personal parameters and contextual information. While we researched the factors that might influence this [47], the results are not yet included in the current implementation. This is currently under development. Li gives some initial results on the information needs while using LBS for wayfinding [29]. A first new result is an new and improved model of a context and user-aware *SpatialQueryContext* as illustrated in figure 4.

Figure 4: Context and user-aware spatial query schema



In future research it would be useful to have a more sophisticated domain model in order to specify what means “near” in the current situation. Among the possible parameters that might influence that decision and that need to be weighted against each other are for example the following. These need to be modeled in a domain or application ontology for that purpose.

We mention only two examples:

- *task/purpose* - near means something different to me when I am asking for a closet or for a good outlook or famous sight
- *knowledge of the region* - how good is the users mental map? Research on mental maps has shown that perceived distances shrink when the user learns to know the region better the more often the user traveled the path.

The actual area that represents the "near region" is also dependent from the walking and viewing direction. The definition of the user-specific region will obviously become a more complex task. Thus the reasoning on this parameters will face a trade-off between region optimization and fast processing/reply.

Personalized Tour Planning and Sightseeing Proposals

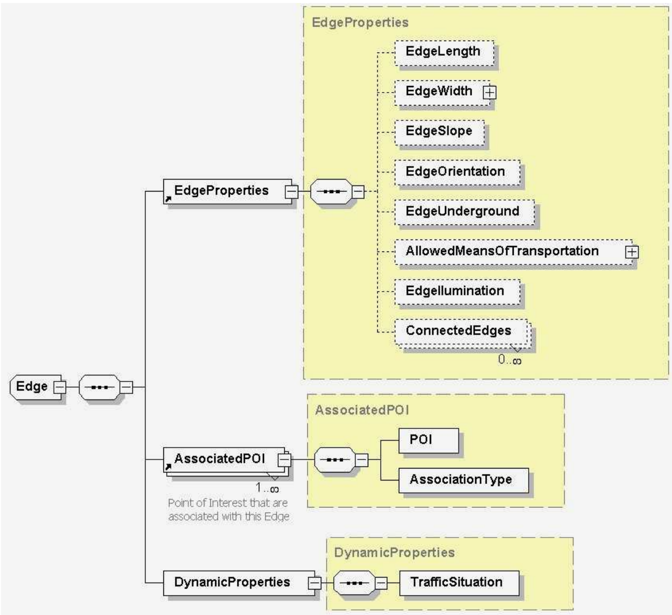
The general idea for adaptive personalized tour proposals is as follows [44]: "The tour shall consider personal interests and needs, social and cultural backgrounds (age, education, gender) as well as other circumstances (from season, weather, traffic conditions to time and financial resources). For every location on the tour individualized information should be presented to the user."

Gryl and Ligozat (1995) [17] divide the relevant tasks for this into three steps:

- ***WTM***: determine **W**here **T**o **M**ove: This is an important aspect dealing with the actual tour planning algorithms.
- ***WTU*****:** **W**hat **T**o **U**se as a landmark: Landmarks are an important issue in presenting route description both graphically or using natural language.
- ***HTSI*****:** **H**ow **T**o **S**ay it: The last aspect is how to present the route.

Several possibilities exist for including user interests in tour-planning and proposing individual sight-seeing tours [2][24]. The data structure on which a tour planning can be modeled is a graph composed on nodes and arcs. To solve the mathematical problem of finding a shortest route on such graphs various approaches have been published. But in contrast to the rather "simple" standard problem of finding the shortest path from one location to another, the problem on reaching multiple (or all) nodes on a graph is much more complex (be means NP Complete). This problem can be summarized as the Traveling Salesman Problem. A further extension on these problems are the profitable TSP's. Such heuristics do not try to combine all nodes in a graph to an optimal tour but furthermore they select nodes and edges according to associated price values.

Figure 5: Schema for network edges



In recent years there have been initial approaches to apply personalization techniques in order to enhance tour planning systems [2]. It is suggested that profitable TSP's are well suitable for the provision of personalized and context-aware tour proposal by means of dynamically calculate prices of nodes and arcs in a given network topology [24]. The following schema for network edges serves as a basis for the dynamic personalization of the graph. It includes default spatial properties such as length, slope etc. derived from GIS computations, as well as aspects on the path continuation problem [42] and travel demand analysis. It combines therefore spatial and user attributes in new and unique way.

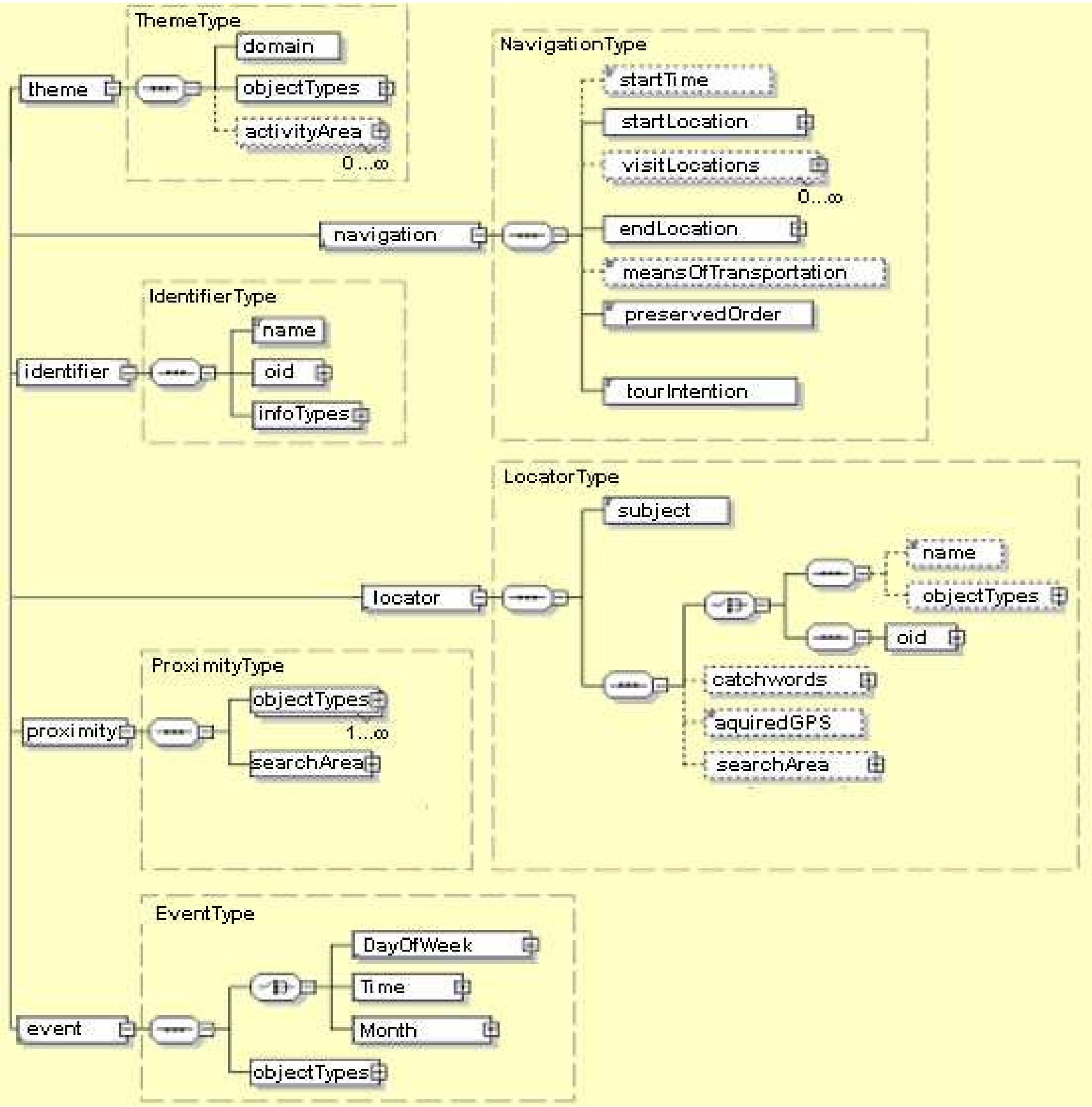
The main focus within this schema lies on the associated Points of Interest (POI). A POI such as sights, shops or public facilities is spatially located and can be associated with additional explanatory descriptions. Those descriptions serve as the basic entities to apply personalization techniques from the domain of information retrieval or recommender system [11][24].

For that reason it is possible to connect preferences or interest values from the textual to the spatial level. But furthermore the opposite way is also applicable. A interaction of a user with his physical environment can serve as indicator for some thematic interest, as there is a link to the thematic properties of the spatial entity he is dealing with. An example is when a user is standing in front of a building of a certain kind, e.g. shoe shop, in repeated manner. This might serve as indicator that he has currently some interest in buying shoes. While the current realization already takes into account spatial and thematic aspects future versions of the personalization module shall also address issues like spatio-temporal behavior and time-geography.

Adaptive Map Generation

Widespread examples for mobile GI services are interactive maps. These still are quite simple in terms of adaptation to the user or context. Mobile maps need special considerations [30]. We propose that it is not enough to focus on adaptations to technical parameters (device characteristics, QoS,…), but argue that maps need to be generated according to a wide range of variables from user preferences and interests, his cognitive abilities, the given task and purpose of use, cultural aspects actual context and location [45].

Figure 6: Extract of XML schema of the "MapTask" model based on an extension of work by [34]



This results in a large number of factors influencing the design of a map. To automate this is a challenge for smart systems, as map design is a complex task involving not only technical[50] but rather cognitive and psychological aspects [3].

For each task it is crucial to think about what is to be displayed and what can be omitted or generalized [48]. Combining information from user or context models in particular with the demands emerging from the given task [49], leads to a huge number of possible requirements for the design of the map. First work on process models for generating individualized maps have been presented [45].

One of the dominant factors for adaptation is the task the user wants to perform - what does the user want to do at all. As all parameters relevant for adaptation the relevant factors need to be represented formally within the system. Therefore we present shortly an example of an ontology for tasks the user wants to perform with a mobile map. Here the work on ontologies for way finding [39] and in support for activities in geographic space is of particular interest. The idea is that user activities can be described in an ontology. An recent example of a task ontology we have newly developed based on the ideas of [34] is presented in Figure 6.

For the scenario presented *route maps* are very important. There has been quite some research in route maps [1], especially to generate geometrical distorted representations, but in general without the aim to generate user specific maps. Here we can also distinguish different types dependent on the task: different information is needed when the task is to navigate on the fastest path from A to B but different again if it is a tour from sights to sights, as also "interesting" information on the side can be displayed.

4. Summary and Outlook

In this paper we have presented several novel realizations of adaptive GI services for mobile applications using dynamic personalization as well as context factors. Further possibilities for future enhancements have been discussed. It is an innovative approach of applying adaptation techniques like learning of user models in the domain of geographic information services that opens a new area of research within GIScience. While the development of personalized GI services has been argued for recently more often – e.g. in the plenary of Geoinformatics 2004 conference on the future issues in GIScience, the “Münsteraner GI Tage” or in research agendas for GIScience proposed earlier (e.g. by UCGIS 2002 [40]), only very little work has actually been carried out in that direction within GIScience so far and even less has been implemented in real prototypes. Earlier approaches in general computer science have mainly focused on we-based or even mobile systems that adapt textual information according to a range of user and context factors (one of which is of course location) but nearly no work has been done on adapting real GI services (like spatial queries, tour planning or map generating) as presented in our examples. Only recently a few approaches have been suggested – mainly in the domain of map making [30] – but mostly lacking real dynamic features like for examples user learning components but rather using hard-coded adaptations (which is of course also true for some of our examples presented).

In addition we have presented ontologies for representing user and context information needed for adaptation purposes explicitly. This represents another application domain for ontologies within GI services in addition to the typical examples for spatial ontologies for semantic interoperability.

A lot of further work is necessary to develop a solid theory for this kind of adaptation to GI services. While we have shown that it is possible to adapt GI services dynamically to context and user properties in general - how to actually do this (what parameters to choose, ho to weight them and what types of adaptation to realize) the best way in order to achieve optimal results is not known at all. This requires empirical tests and evaluations and a further integration of work from cognitive science e.g. spatial cognition as well as usability research about how to present what in order to achieve a best result. Measures in order to specify how well an adaptation performs in a real setting need to be developed. Such a measurement will be not always easy to obtain, but is needed in order to built optimizing strategies into the adaptation process.

Another topic we have not tackled in this paper is that of privacy concerns associated with localisation technologies, as well as context sensing technologies or those related to user related information. The issue of spatial privacy is being discussed recently more often, e.g. see Dobson and Fisher (2003) [10]. A range of further social issues should be discussed (from acceptance to social consequences), but within this paper we had to stick to technical issues that demonstrate the positive potentials of the technologies mentioned.

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