A user context approach for adaptive and distributed GIS

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Summary. The research presented in this paper introduces a user context approach for collaborative and adaptive Geographical Information System (GIS). The proposed model is part of a framework based on a multi-dimensional contextual approach that combines user, geographical and device contexts. The spatial properties of the GIS components categorize different configurations as a support for the derivation of user groups. The interfaces and functionalities offered by the adaptive GIS are generalized within each group, and derived from the interface usages. The spatial behaviors that reflect user experiences within a group favor collaborative exchanges. A prototype applied to maritime navigation validates the approach and the algorithms developed.

1 Introduction

The research presented in this paper introduces a context-aware mobile GIS that integrates adaptive interaction principles and techniques. We define an adaptive GIS as a GIS that is able to automatically derive its content and interface from a changing environment. An adaptive GIS allows to present relevant information to the user, and improve the usage and usability of the information provided according to the context. The contextual dimensions are of different nature as they involve geographical data, computing processes and interfaces, and user categories. These contexts influence, to a certain degree, the way geographical data and processes are delivered in wireless environments.

Adaptive GIS can be considered as a representative of the emerging trend of personalized software, that has been the object of considerable attention over the recent years [15]. A key issue in developping personalized software and modelling user preferences is the problem of approximating user intentions with a few information inputs. The range of techniques for extracting user preferences and categories varies from explicit user feedbacks [16] where a software agent learns user interests by interacting with her/him, to implicit tracking of user actions where preferences are derived from her/his actions

[18]. Functional approaches categorize users according to their behaviors [10], or the application and interface contexts [11]. These approaches are based on the fact that users are likely to share interests when they belong to a same category.

Previous works in the field of adaptive GIS introduce technology-driven approaches for mobile applications [5][3]. Adaptation of a GIS layer approach to specific user needs and contexts has been also studied [19]. A context-sensitive model for mobile cartography that emphasize different levels of data adaptation and presentation has been proposed [14]. A GIS can be also considered as an interaction and collaborative support between different users [13][9]. Implicit collaboration between users has been used to recommend an interface content for tourism applications [2]. These different contextual dimensions have long been studied individually, but, to the best of our knowledge, rarely considered together in an integrated framework.

In a preliminary work, we introduced and modelled the notions of geographical and user contexts [11][12]. Our approach considers that the way a user acts in a given environment provides a support for a contextual and functional-based characterization of user behaviors and the derivation of users groups. The objective of this paper is to develop and experiment these concepts and to validate the approach in the case of a mobile GIS environment applied to the monitoring of maritime navigation.

The remainder of this paper is organized as follows. Section 2 presents the main dimensions of a contextual based GIS. Section 3 refines the notion of geographical context in a mobile environment. Section 4 introduces the way geographical contexts are used to derive user groups, and develops users collaboration principles. Section 5 describes an implementation of the concepts presented and the details of the algorithms implemented. Finally section 6 concludes the paper and draws some perspectives.

2 Adaptive GIS principles

We define an adaptive GIS as a generic GIS that can be automatically updated according to several contexts defined by (1) properties and location of the geographical data manipulated, (2) underlying categories that reflect different group profiles and (3) characteristics of the computing systems and related web and wireless techniques [4][11].

Our framework considers that an adaptive GIS is built on one-to-many location based services, preferably bounded to a common user interface and that delivers geographical data and querying facilities [11]. The context of a mobile GIS, with respect to a given user acting in the environment, varies according to the respective roles of the different contextual dimensions considered. A service may be available or not regarding the current geographical environment, and when available, a service can be refined by taking into account user preferences and the appliance capabilities. An adaptive GIS offers interaction facilities through a set of services. Geographical data are presented to the user by an adapted view that should reflect common behaviors for a given service. The contextual dimensions that form the core of an adaptive GIS are defined as follows:

- The geographical context identifies to which degree GIS services are available according to the user location and the spatial distribution of the services available.
- The appliance context specifies the interaction interfaces of the computing system available to a given user. These interfaces allow the user to visualize and interact with GIS data. Appliances are organized into classes of similar capabilities.
- The user context categorizes the users sharing a similar geographical context situation into a same group. With respect to a given service, the user context helps to qualify the adaptation process based on common behaviors within a group.

The objective of an adaptation process is to concatenate the constraints associated to each context, and to adapt both the content and the interface of the GIS services, requested for a specific user and appliance. An adaptive GIS forms an intermediate layer between data integration and presentation.

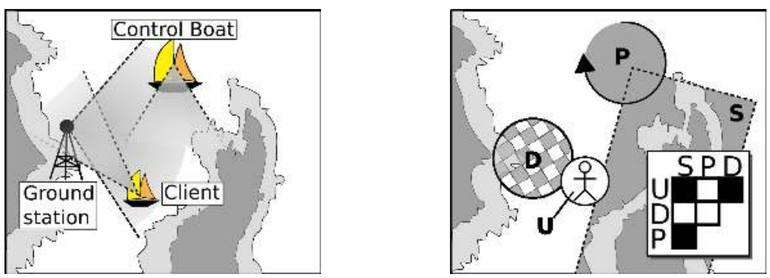
3 Geographical context

A GIS is usually integrated within the user desktop. In a distributed and mobile environment, an adaptive GIS is highly dependent on the services availability, that is, the ones that provide the geographical data views. Moreover, the components constituting a service are distributed over space. Several regions of significance characterize the geographical context for a given service [8]:

- S denotes the region where geographical data are collected from and centralized.
- D denotes the region where the geographical data of the region S is accessible to the service considered.
- P denotes the region where the data from D can be processed and broadcasted into a geographical data view, allowing the user to interact with the data.
- U denotes the location where the user is interacting with GIS services.

These regions form a spatially-related client-server architecture, ideally with servers acting for regions D and P, a client appliance for U and a geographical database for S. The servers or clients underneath each regions of significance are able to exchange data, relying on wireless transmission capabilities. These regions constitute a multi-layered space whose different configurations impact the availability of a given service, and the levels of interaction offered to the users. The way these regions overlaps generates a set of elementary geographical configurations [11]. A member of this set is denoted as a geographical context configuration [12]. Note that U and S can be disjoint as the location of the user can be outside of the region of data collection.

The way a service is available to a mobile user at a given time is derived from the geographical context configuration available at that time. A service is fully available at a given location when a data source is accessible and can be processed, that is, when regions P and D spatially intersect and are able to exchange data. The other geographical context configurations, that do not fullfill this constraint and do not denote a context rich enough for the delivery of an acceptable service, restrict the range of functionalities available to the user. As the contextual regions vary over time, the functionalities at disposal are also likely to change.



(a) Communication infrastructure view

(b) Service components distribution for a given user

Fig. 1. Geographical context example

Let us consider the example of a geographical environment where a ground station collects and broadcasts geographical data to a client ship (Fig. 1). These data provide basic topographic information on the island coastline hereafter denoted as the region S. The control boat that processes geographical data and defines the extent of region P is not able to communicate with either the ground station that broadcasts data in the region D, or the client interacting in the region U. However, communication between the client and the station is available (Fig. 1(a)). Regarding the geographical context (Fig. 1(b)), an intersection occurs when a wireless transmission can be established between the clients or servers that underneath two given regions. This geographical context configuration is denoted as $\{\{U, D\}, \{U, S\}, \{P, S\}\}$ where every pair denotes a non empty intersection between the two regions of the pair. As the processing region P does not intersect neither D nor U, no view can be made available to the user located at U. When U intersects D, coastal information is provided to the user appliance for further manipulation whenever U intersects the processing region P. Fig. 1(b) also introduces a tabular notation to summarize the relationships that constitute the geographical context configuration. A black cell denotes a non empty intersection between two regions of significance, whereas a white cell denotes an empty one.

The successive geographical context configurations, encountered by a user regarding a service, generate a sequence dynamically updated over time. Every geographical configuration in a sequence is time-stamped by the time spent by the user in that given contextual configuration. These sequences are considered as parts of the user profile, and are stored on the user appliance.

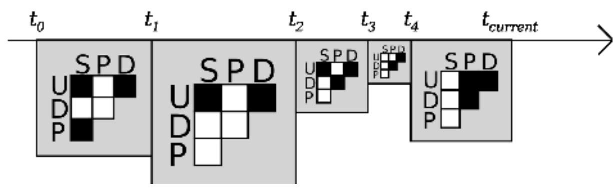
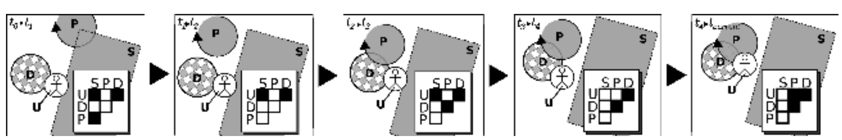
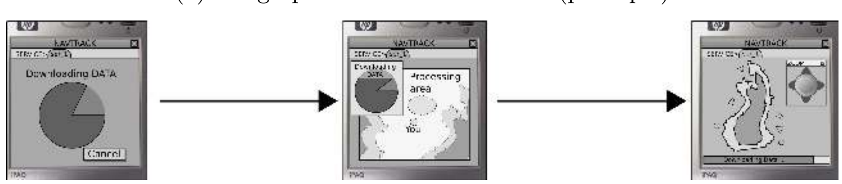


Fig. 2. Graphical representation of a sequence

Let us consider the example presented in Fig. 1 where a specific service is delivered from a control boat to a region P. Successive movements of the control boat give different contextual configurations, the last one being a configuration where the regions U and D intersect P, allowing then full availability of the service functionalities (Fig. 3(a)). Fig. 2 proposes a graphical view of this sequence that represents the evolution of context configurations from the time t_0 when the sequence is created, to a current time $t_{current}$. This sequence shows that the user spent most of its time in the configuration $\big\{\{U, D\}, \{U, S\}\big\}$ and that the current context configuration is $\big\{\{U, P\}, \{U, D\}, \{P, D\}\big\}$. The context configuration changes from t_0 to $t_{current}$ passing through different geographical contexts. This implies to reflect these changes in terms of the



(a) Geographical context evolution (principle)



(b) Adaptive interface changes (interface level)

Fig. 3. Example of geographical context evolution

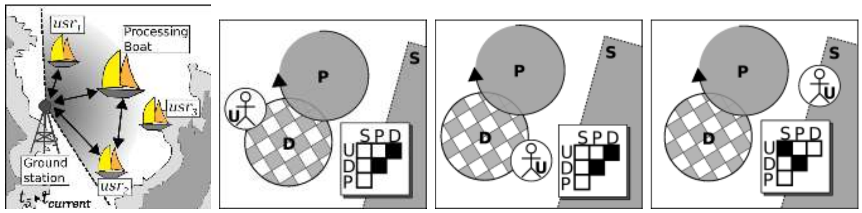
functionalities available. From t_0, the user usr_1 located at U can receive and store data delivered in the region D. From t_2, the regions D and P overlap and the user is then aware of the location of the processing region. Finally, at t_4, the user reaches the processing area and the view associated to the service is displayed on her/his appliance. In order to reflect the functionalities at disposal, the user interface is updated after each change of the geographical context (Fig. 3(b)).

4 User context

The geographical context allows for the characterization of the service functionalities that can be made available to the user. The objective of the user context is to derive and provide adaptation rules to select the most appropriate geographical content for a given user. Categorizing user contexts also allows to identify the main users behaviors at the interface level. As an adaptive GIS allows for multiple users to simultaneously access the functionalities of a given service, user interactions are considered as a way to define these user contexts and derive the properties of a given service. By implicitly tracking the user interface interactions, and without annoying her/him with unsolicited actions, common usages within a group of users are derived. This allows the system to adapt service functionalities according to users behaviors at the interface level. Collaboration between the users is not explicit as it can be in a peer-shared software, but instead works as a background process for the user benefits.

4.1 User group modelling

The derivation of the users groups leads us to examine different semantic and implementation issues. The first one is the identification of the range of actions that constitute the input of the categorization process. The second one relies on the definition of the extent of the users groups, or in other words the number of users groups that makes sense from an application point of view. Finally, the developed system should integrate an algorithm that binds the users to a given group according to their behaviors. A specific characteristic of the adaptive system developed so far is that the user actions on the geographical space are modelled according to sequences of geographical contexts as introduced in section 3. As a sequence denotes the evolution of the geographical context of a service for a given user, sequences constitute a potential candidate to act as the primitives that define the input of the users categorization processes. Due to the communication infrastructure, the fact that two users share a given service can only be established when their underlying regions U intersect with at least one common region of interest D, P or S. When this constraint is fullfilled, the server behind a region D, P or S shared by these two users



(a) Communication infrastructure (b) usr_1 context (c) usr_2 context (d) usr_3 context

Fig. 4. Geographical context of multiple users

serve as an indirect bridge for information transmission from a user to the other.

With respect to the example of the service presented in Fig. 4(a), communication between usr_1 and usr_2, who are sharing at $t_{current}$ the same geographical context (Fig. 4(b) and Fig. 4(c)), is possible through the server associated to the data diffusion at D. Conversely, the user usr_3 has a different configuration (Fig. 4(d)) and is not able to share information with the other users. As the server-mediated data communication between the users in a group is a low-level pre-requisite to a collaborative adaptation, the groups are derived from the users of a service that are sharing a geographical context at a given time. The notion of group is thus dynamic and temporally dependent. With respect to the example illustrated by Fig. 4, two groups of users are present at $t_{current}$:

- usr_1 and usr_2, with the associated geographical context $\big\{\{U,D\},\{P,D\}\big\}$,
- usr_3, only member of its group, with the associated geographical context $\big\{\{U,S\},\{P,D\}\big\}$.

A property of this approach is that a given user always belongs to no more than one group at a given time. The association or removal of a user to/from a group denotes a change of user geographical context. This may be triggered by a displacement of the user if she/he is moving to another geographical configuration, or by the system if the regions of significance intersect in a different way.

Group characteristics are stored on the server D, P or S that support data transmission to the members of that group. With respect to the example presented in figure Fig. 4, the characteristics of the first group described are stored on the server underneath D as usr_1 and usr_2, members of that group, exchange data through D. As groups need to contain at least one user, a group is deleted from a server whenever its last registered user leaves it.

4.2 Collaborative adaptation

The objective of the collaborative adaptation is to refine the functionalities and the user interface of a given service regarding the common behaviors and usages of group members. Mobility and contextual changes of the geographical environment are used to spread the adaptation processes in a peer-shared network made of the servers behind the active regions of interest and the users appliances.

We consider that a user is likely to spend time in a given context configuration and to improve her/his usage experience of the functionalities offered. After a learning period, the user derives a deeper knowledge of the proposed user interface and preferences regarding the geographical data she/he may request and manipulate [17]. Adaptive systems usually store user characteristics within a profile that reflect her/his experience of that system. Regarding the proposed framework, where groups are derived from geographical contexts, personal profiles are not considered as basic components of the adaptation process. Every group generated supports a collaborative definition of its profile, regarding the service functionalities and interfaces offered. Thus, adaptation rules in a given group profile reflects the actions of the users within that group. A new user coming in an existing group have at disposal the rules derived by the other users already members of the group. This may be seen as a an effective response to the cold start problem [1]. Actually, no learning of the new member's behavior as to be done before applying the group profile.

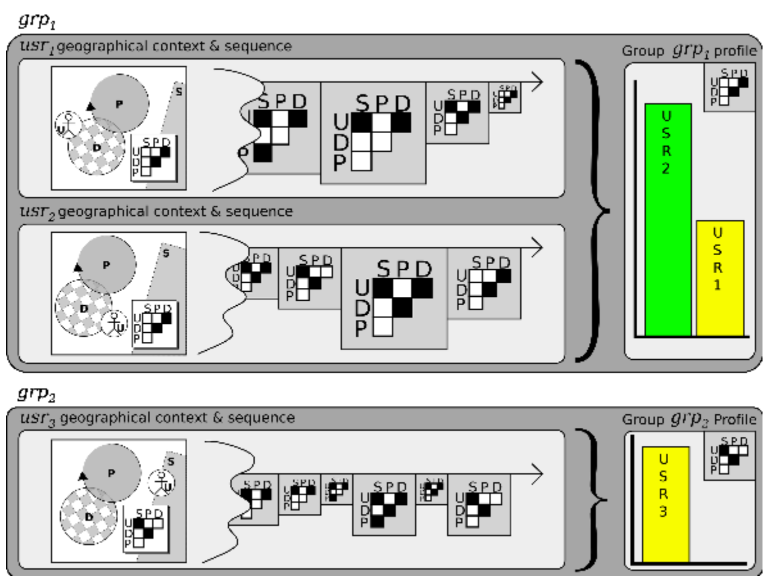


Fig. 5. Group profiles initialization

Let us consider the two groups derived at $t_{current}$ in the example illustrated by Fig. 4. usr_1 and usr_2 are members of the group grp_1. They contribute together to the enrichment of their group profile, while usr_3 derives group grp_2 profile based on her/his single experience. When the profile of group grp_1

is derived, participation of a user to the group profile is moderated by the time he/she spent in the group. Assuming the sequences illustrated by Fig. 5, the usr_2 spend approximately twice the time of usr_1 in the group grp_1. Therefore, the contribution of the usr_2's behavior to the group profile is higher than the one of usr_1. Whenever two or more users collaborate to create a group profile, an operator that aggregates and merges each of these user experience and behavior to the group profile needs to be defined. The way this aggregation is done directly depends on the data structure implemented to qualify the user experience level. Such structures are currently available but are closely tied to a particular field of interest like web content recommending [7] or tourism activities [2]. Within an adaptive GIS, such aggregation mechanisms and structures should be defined according to the specific properties of a given service, particularly with respect to the spatial dimension.

5 User context model implementation

5.1 Algorithm principles

The algorithm principles are based on the fact that the time spent by a user in a contextual configuration reflects her/his interest for the functionalities available, and that the machine learning process that derives this user model is also time dependent [6]. Therefore, regarding a given user and service, the geographical context configuration where the user spend most of time denotes what we assume as her/his "best known" context. The functionalities at disposal in this particular context contribute to the usage experience, either from the user point of view or for the adaptive GIS that integrates these behaviors to derive her/his contribution to the group profiles. In order to reflect this learning process, a copy of the group profile to which a given user collaborate the most is stored on her/his appliance. This profile becomes user predominant profile along the different geographical contexts she/he may encounter during the usage of the services delivered by the adaptive GIS.

Let us consider the example presented in Fig. 6 of a user passing through different geographical contexts (Fig. 6(c)). Fig. 6(b) shows the evolution of the groups profiles related to the geographical configurations encountered by the user. The interface and data presented are adapted according to these groups profiles. Fig. 6(a) illustrates the predominant profile, which is stored on the user appliance. Within a group, users shared experience increase over time. When the experience of the current group profile is greater than the user predominant profile experience, this group profile replaces the predominant profile on the user appliance.

The predominant profile being the one associated to the context where a user spent most of her/his time, this does not presume the quality and quantity of interaction actions made by the user. The predominant profile may be associated to a context of minor interest for the user. In that case, lack of user

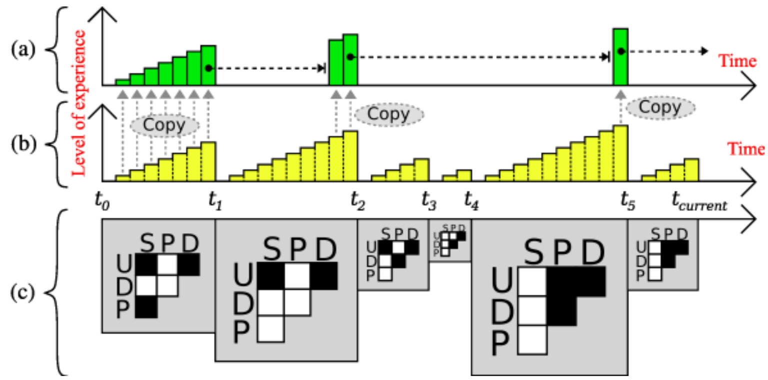


Fig. 6. Step-by-step enrichment of the group profiles, and evolution of the predominant profile stored on the user appliance

interaction leads to an undetermined profile which may not be seen as meaningless for adaptivity. For example, in such a context, a possible adaptation is to deactivate energy-consuming processes in the mobile appliance.

In order to share the benefits of a user predominant profile, a user gives her/his predominant profile to the group. This implies to consider two cases:

- The user creates a new group or joins a group where her/his predominant profile is not already present. Therefore, the predominant profile is copied from the user appliance to the group (Fig. 7(b)).
- The user joins a group where a profile similar to her/his predominant profile is present in the group. A fusion between the two profiles is done (Fig. 7(a)).

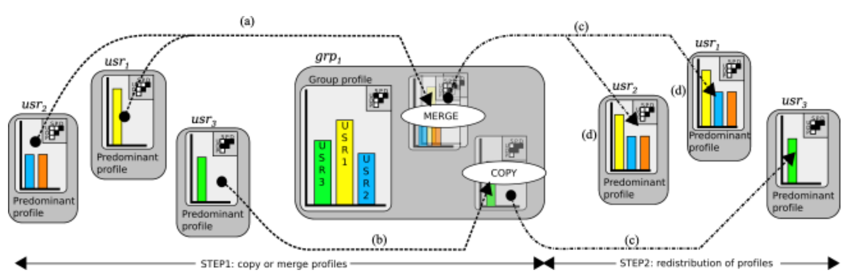


Fig. 7. Predominant profiles fusion and distribution (example)

A consequence of this algorithm approach is that each group hosts a set of profiles that may contains from one (i.e. current group profile) to many different distinct profiles. A group is progressively enriched by new profiles or fusion of existing profiles. When profiles are updated within a group, they are distributed to the members of the group (Fig. 7(c)). For example, when a predominant profile stored on the user appliance is the result of a fusion process, it integrates implicitly other members usage preferences (Fig. 7(d)).

When a user geographical context becomes the one related to her/his predominant profile, then this profile is taken into account when the adaptation rules are computed. Either her/his profile is merged to the current group profile, or when she/he is alone in that context, a group is created and her/his predominant profile is considered as the group profile. In both cases, the user appliance derives its adaptation rules from the current group profile. That is, at least parts (if not all) of the adaptation rules derived from her/his previous experience of the same context are again applied.

5.2 Experimentation

A prototype has been developed in order to validate the approach. This prototype simulates an evolving geographical context (Fig. 8). Users present in a

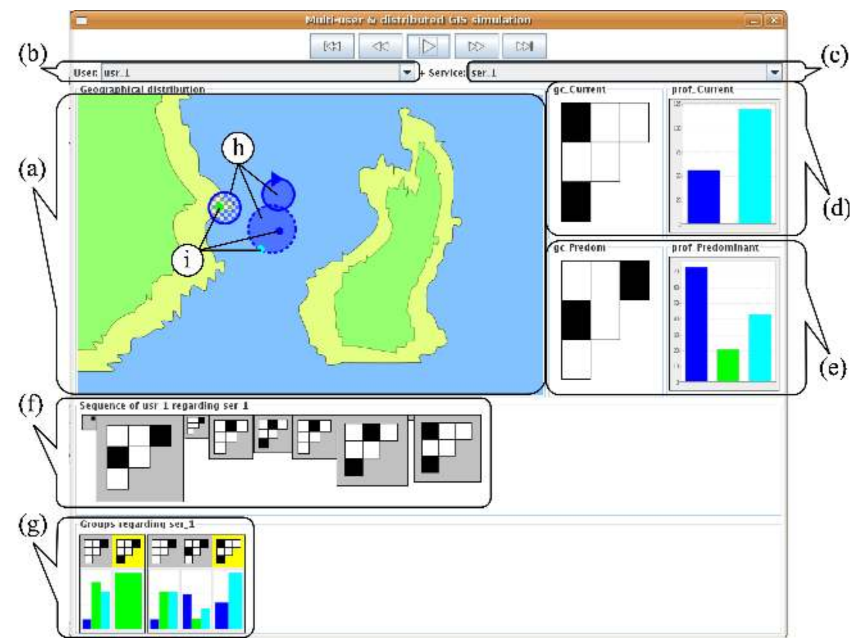


Fig. 8. Simulation prototype interface

given geographical environment (Fig. 8(i)) and service components D, P and S (Fig. 8(h)) can be tracked in the environment (Fig. 8(a)). Fig. 8(d) illustrates an example of geographical context, and the group profile related to this context. The interface of the user appliance applies adaptation rules derived from this profile. Fig. 8(e) shows the predominant context and the associated predominant profile that is stored on the user appliance. A sequence is dynamically derived when the user or service components are changing (Fig. 8(f)). Fig. 8(g) shows the active groups at a current time and their set of profiles, including the current group profile. Currently represented user and services are changed at Fig. 8(b) and Fig. 8(c), respectively. The experience level reflected in the group profiles shows the time a user spend in a given group. The merging profile algorithm merges both experience level values into a new profile.

Preliminary experiments concern the simulation of the example illustrated in Fig. 1. The adaptive GIS is made of a service that can be accessed by several users. Group generation and profile diffusion have been tested in the case of a relative proximity of the regions U, D, P and S. Users and regions intersect and users sharing a similar context allows profiles to be enriched and diffused. Fig. 8(g) shows that the second group contains different profiles, one being the current group profile, and the others coming from predominant experience of the group members. Further development of the prototype concern validation of the robustness and efficiency of the algorithm, and integration of additional users and services in the environment.

6 Conclusion

Users, appliances and geographical contexts are essential components of an adaptive GIS. Although these components are generally considered separately, the research presented in this paper proposes a contextual approach that integrates them in a common adaptive framework. Considering an adaptive GIS as a set of services derives from different regions of significance allows for the characterization of the notion of geographical context. User groups are derived from geographical contexts. Profiles reflecting users usages are associated to these groups. A prototype validates the approach and supports collaborative derivation and diffusion of predominant experiences of the users. Future work concerns the definition of group profiles and extension of the approach to multiple services. The appliance context should also provide a specific refinement of the user interface.

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