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RESEARCH ARTICLE

Personalization in Adaptive and Interactive GIS

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With continuous increase of available on-line spatial data, requirements for the adaptation of spatial content to user's context becomes increasingly important. Location-Based Services (LBS) deliver to the user information specific to a given location preferably using mobile devices. Personalising the information provided to the user to take into account her/his information preferences and current location, the problem of inodating the user with irrelevant information is avoided. The research presented in this paper introduces an approach which implicitly monitors the user's activity and generates a user profile reflecting her/his information preferences based on the interactions of the user with the system, and her/his physical location and movements. The system recognizes the user profile and adapts accordingly both to provide suitable information, and to prioritize the functionality appropriate to the user's current context.

Keywords: Personalisation; Implicit profiling; User recommendation; Adaptive GIS; Context awareness

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1. Introduction

Increasing popularity of spatially aware devices such as current generation mobile phones, PDAs, and in-car satellite navigation systems, along with the growing popularity of mapping systems such as Google Maps, MSN Maps and Directions, and projects such as Open Street Map widely contribute to rapid growth of the availability and pervasiveness of spatial information. By contrast, the devices used to view such information become smaller and more portable. Therefore, it is increasingly necessary to perform content filtering and personalization to suit user requirements. This prevents the user from being swamped with information which may not be relevant to them. Furthermore, steps can be taken to insure that only information suitable to the device in use will be selected for display. For instance, if there is both high definition video and low resolution video available on a given object of interest to the user, the application should be aware of the displaying device's capabilities and provide only the most suitable format for display, unless explicitly stated otherwise by the user. Such information personalization and device adaptation have the capacity to significantly improve the user interaction experience with a GIS.

This paper introduces current research in the area of implicit user profile initialization, and also examines how these techniques have been applied to the geospatial domain. It presents an approach that develops adaptive location-based services which personalize the interface and content depending on user preferences, interests and context in order to reduce information overload for users. The novel approach illustrated in this article combines users mobilities and profiling of their interactions with the interface in order to derive individual profiles that can be used to personalize services (Mac Aoidh *et al.* 2008b, 2007). Profile derivation combines a linear technique described in (Mac Aoidh *et al.* 2008a), with filtering and case-based reasoning (Weakliam *et al.* 2005a,b, Wilson *et al.* 2007), along with user location context (Petit *et al.* 2008b, 2007).

The remainder of the article is organized as follows: Section 2 discusses related work. Section 3 introduces an adaptive LBS architecture applied to a mobile campus navigation assistant. Section 4 develops the methodology and techniques used to generate user profiles. Section 5 describes a GIS personalization approach which relies on users profiles. Finally, section 6 concludes the paper and draws some perspectives.

2. Related Work

Personalization takes place by adjusting the system to suit the needs and preferences of a particular user. The process of identifying and storing information on user interests is known as user profiling. This section introduces principles and related work behind user profiles and their subsequent role in the personalization process.

2.1. *Profiling*

Creating accurate and meaningful user profiles is a key task in providing useful personalization (Montaner *et al.* 2003). There are two primary techniques for collecting user feedback. Information can be obtained explicitly, by directly requesting the user to specify a level of interest in a given piece of data on a specified rating scale, or implicitly, by observing user actions and inferring a level of interest. Implicit interest indication techniques are favoured as they are unobtrusive and do not disrupt the user from completing the task at hand. Claypool *et al.* (2001) discuss implicit interest indicators in the context of Web documents. Techniques employed range from document keyword extraction to event logging such as printing, saving and book-marking Web pages; as well as key-stroke monitoring, including copy and paste, and mouse actions such as text tracing, link pointing, and text selection (Hijikata 2004, Claypool *et al.* 2001). More recently, geovisualisation research has been concerned with investigating user behaviour in order to ascertain why certain types of personalization and interaction tools are useful and beneficial for the user (Wilson *et al.* 2008).

Part of our approach to derive meaningful user profiles involves correlating user mouse movements with their map browsing operations in order to gain an implicit indication of their interests. The use of monitoring user interactions as a means of obtaining user preferences is based on the concept of eye tracking experiments. The research by Cox and Cox and Silva (2006) and Chen *et al.* (2001) show evidence of a strong connection between eye movements and mouse movements while in turn Pan *et al.* (2004) show that there is a link between eye movements and thought processing. There are several examples of non-spatial systems which employ the analysis of user mouse movements as an indication of interest. Curious Browser (Claypool *et al.* 2001), Cheese (Mueller and Lockerd 2002) and MouseTrack (Arroyo *et al.* 2006) are Web browsing applications developed to analyse interest indicators in a Web environment from their mouse interactions.

2.2. *Personalization*

Application personalization involves tailoring the application to suit a particular user. Personalization is performed dynamically by the system on behalf of a user, based on their preferences and interests. The user interface and the dataset displayed can be adapted so that both the appearance and contents are personalized and take advantage of contextual factors only known at use time (Fischer 1999). For example, dataset personalization filters out irrelevant content, recommends relevant content, and changes the appearance of relevant features by highlighting them. In contrast, interface personalization removes unnecessary tools from the interface and arranges the tools to give prominence to certain facilities thus altering its appearance. Several systems offering such interface and dataset personalization are described in Fischer (2001, 1999). Proteus (Anderson *et al.* 2001), Mana (Eisenstein *et al.* 2001), and Digestor (Bickmore and Schilit 1997) also document the development of personalized interfaces for mobile systems which re-format Web pages to suit the display of content on a mobile device. In the geospatial domain, location indicators provide an input to query refinement applied to Web services (Yang and Claramunt 2004).

2.3. *Map Profiling and Personalization*

User modelling can determine user interests so that a personalized map content and interface can be provided. This involves inferring *unobservable* information about a user from *observable* information (Zukerman and Albrecht 2001). For example, a user's interests and context *(unobservable)* are inferred based on the mouse movements, on map navigation actions performed, and on their current physical location *(observable).* In the spatial context, extraneous map content downloaded to the display can introduce information overload and thus seriously hinder the user in completing their task. Filtering is therefore important in order to reduce screen clutter and eliminate the needless downloading of features that are not of interest to the user. For example, CoMPASS captures user interactions where map layers are turned on (made visible) or turned off (made invisible) (Weakliam *et al.* 2005a). This concept is used as an indicator of user interest or disinterest to a given type of map feature. The map areas viewed by the user are also considered, so that if the user only views a certain area of the map, then the areas not viewed by the user are deemed not to be of interest to the user. GeminiMap adopts a similar approach, acquiring its knowledge of user intentions by analysing map navigational operations and personalizing the contents to suit the inferred interests (Hiramoto and Sumiya 2006a,b, Hirose *et al.* 2007).

3. Distributed and Mobile GIS

GIS development in mobile contexts imply the need to combine ubiquity, mobility and cartography into user-centred design approaches (Jiang and Yao 2006, Satyanarayanan 1996), and to extend GIS towards a more adaptive notion. GIS should not be considered as an information system specific to a single user, but rather as a collection of geographical location-based services implemented on top of a distributed computing architecture. The following section describes a generic model of a distributed and mobile GIS. This model promotes an integrated approach to user profiling, system personalization and adaptation in GIS. It is applied to the design of an adaptive campus navigation assistant.

3.1. *Case Study Description*

The proposed case study considers university students navigating around a college campus and using a mobile-based GIS for assistance and guidance. This system acts as an aid to students and visitors as they walk around a university campus and discover various facilities and departments. The campus is designed so that several buildings and faculties provide service areas (through hotspots). These services areas permit mobile devices to receive information regarding a building, or group of buildings in the surroundings. When a user is close to a particular building she/he can obtain information on that building. Additionally, users are tracked on the map as they move around the campus, and their locations are reported at the interface level.

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Pictures:

Figure 1. User interface

On the user device the interface is organized into two distinct layers (Fig. 1). The map of the campus highlights a user's current location, and provides zoom and pan functionality. A separate panel on the right provides details and information on the elements of the map. Users can click on specific buildings and objects on the digital map in order to obtain additional information. Similarly, the user may click on the other tabs within the panel to obtain information about other elements of the map.

3.2. *Distributed and Mobile Architecture*

The main concept behind an adaptive GIS relies on its capacity to automatically derive its content and interface from a changing environment. This implies that the environment dimensions that trigger the adaptation process should be clearly identified. Our framework considers an adaptive GIS built upon several service areas that deliver geographical information and processing functionality to a set of users. Such functionality associated with GIS services constitute an adaptable toolbox to provide GIS data handling facilities and analysis tools (Albrecht 1997). In the following sections, several regions of interest are introduced. Together, they describe the system environment at a given time. System states are defined and characterize the set of possible environments the system undergoes at runtime.

3.2.1. Components and Regions of Interest

In the context of a mobile GIS, the set of functionality and data available to the users varies according to the status of the environment. Depending on user location and component distribution, a service may be partly-available at runtime. The proposed model considers several components supporting a tiered system distribution:

- the user interaction components Cu_{usr_j} provide user-oriented views and interaction facilities;
- the data components Cd_x import and export system information subsets;
- the processing components Cp_x host data analysis and transformation functionality.

Each component is related to a region of interest that represents its accessibility area. Depending on the function of a component, several types of regions of interest can be distinguished at a given time instant t_x of system execution[1](Petit *et al.* 2008a):

- processing region(s) P_i, where the tools and functionality for the completion of a given task are available to the user;
- broadcasting region(s) D_i, where the information and data are available to the system;
- user(s) region(s) U_i, where the user(s) is/are located and interacts with the system.

Every region of interest is reported as an element of the set $Regions(t_x) = \{R_1, R_2, ..., R_n\}$. The regions that belong to this set represent the spatial extension of this client-server architecture, with servers components supporting regions D_i and P_i, and client devices to support regions U_i. The servers or clients underneath each region of interest are able to exchange data, relying on wireless transmission capabilities. At the geographic level, the regions are represented by a set of spatial footprints within which the supporting components are accessible.

In the campus navigation system, several processing components generate user views and interaction layers $\big(\text{Fig. } 2(Cp_{1\rightarrow3})\big)$. These components rely on raw information on

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[1] Let T be the set of time instants $\{t_0, t_1, ..., t_n\}$ defined as real. As $T \subseteq \mathbb{R}$, T is associated to a total order relation $\leq$: $\forall\ (t_x, t_y \in T),\ (x \leq y)$ implies $(t_x \leq t_y)$

groups of buildings managed by dedicated data components $\big($Fig. $2(Cd_{1\to3})\big)$. For example, the component Cd_3 handles data on Scientific Departments. At the infrastructure level, hardware hotspots combine data management and processing facilities $\big($Fig. 2(⊠✱)$\big)$. These hotspots broadcast information within an area derived from their wireless capabilities.

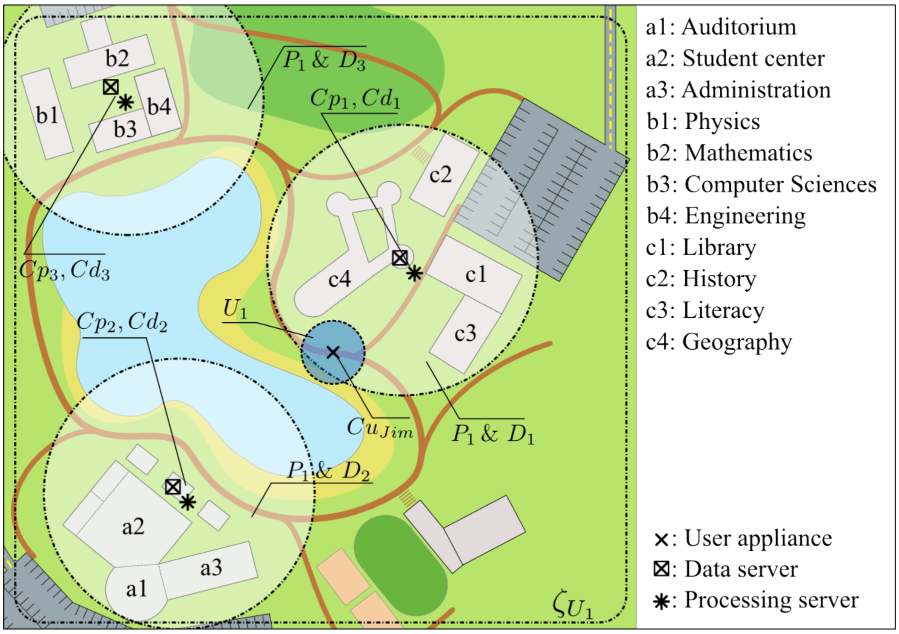

Figure 2. Campus view and geographic environment of the campus information system at t_7

This set of components supporting the system gives rise to several regions of interest within the campus information system space, and $Regions(t_7) = \{U_1, P_1, D_1, D_2, D_3\}$. The user component, for the first user in our case study, Jim, Cu_{jim} generates a region centred on Jim's device, and within which he interacts with the system. The components Cp_2 and Cd_2 share a same hardware hotspot layer and might be accessed within the same region of interest. Their associated spatial footprints overlap ($D_2 \in P_1$), and users within this region are provided with information on Administrative Departments. The processing facilities at $Cp_{1\to3}$ component levels derive identical functionality (i.e., generate user views and interaction layers from raw data). As the processing facilities and user tasks remain the same whatever the processing component considered is, their spatial footprints belong to a same processing region $\big($Fig. $2(P_1)\big)$.

3.2.2. System State

The regions of interest constitute a multi-layered space whose different configurations impact the availability of a given service, and the levels of interaction offered to the user. In particular, the regions share their components mobility. With several mobile components at the infrastructure level, spatial footprints are likely to differ over time. For example, when a user region leaves a processing region, their related components cannot share information anymore. Moreover, functionality and tools are not available anymore at the user level. During runtime, the system encompasses several contextual configurations wherein the spatial footprints distribution constitutes a distinctive feature. These different system states offer many functional levels at the user side which derive an appropriate system behaviour. Let us consider a geographic approach to systems configurations that 1) defines regions of interest mobility areas, 2) analyses possible region footprints motions at runtime, and 3) generates a set of distinct system states.

Given a region $R_i \in Regions(t_x)$, let the *mobility area* ζ_{R_i} denote the set of possible spatial footprints of R_i during the system up-time. When $R_i \subsetneq \zeta_{R_i}$, the region R_i is *mobile*. Conversely, this region is *fixed* when $\zeta_{R_i} = R_i$ during system runtime. At the functional level, the system behaviours rely on inter-tier communication, from the data source to the client side. As components communication vary over time, several *system states* distinguish, and enable different sets of functionality and data at the user level. At a given time of execution, the *system state* felt by the user is characterized by the set of intersecting regions of interest at t_x:

$$State(usr_j, t_x) = \Big\{ (R_i, R_j),\ R_i \cap R_j \neq \emptyset\ \wedge \left(\substack{R_i, R_j \in Regions(t_x) \\ \wedge R_i \neq R_j} \right) \Big\}$$

For example, the system state at t_7 characterizes a situation where the user Jim accesses information on Humanities Departments. In that case, $State(Jim, t_7) = \big\{ {\scriptstyle (P_1,D_1),(P_1,D_2),(P_1,D_3),(P_1,U_1),(D_1,U_1)} \big\}$. The functionality and data delivered are restricted to this system state, and enable an adapted user-interface to be displayed. For example, no mention is made of Scientific Departments at the user device level. This information remains outside user scope, within D_3 as a region of interest (Fig. 1).

Any system described by its evolving regions generates a countable set of system states: $States(t_x) = \{s_1, s_2, ..., s_n\}$. This set gives the boundaries of the whole range of spatial configurations. In the proposed case study, users are *mobile* inside the campus. Their region of mobility ζ_{U_1} covers the entire campus space (Fig. 2). On the other hand, and due to hotspot hardware, the regions P_1 and $D_{1\to3}$ are *fixed* at any given time t_x. The spatial footprints of their mobility areas ζ_{P_1} and $\zeta_{D_{1\to3}}$ equal regions P_1 and $D_{1\to3}$ own footprints. Depending on user location, the campus information system state at t_x for a given user is one element of the set $States(t_x)^1$:

$$States(t_x) = \left\{ \substack{ s_1 = \{(P_1,D_1),(P_1,D_2),(P_1,D_3),(P_1,U_1),(D_1,U_1)\}, \\ s_2 = \{(P_1,D_1),(P_1,D_2),(P_1,D_3),(P_1,U_1),(D_2,U_1)\}, \\ s_3 = \{(P_1,D_1),(P_1,D_2),(P_1,D_3),(P_1,U_1),(D_3,U_1)\}, \\ s_4 = \{(P_1,D_1),(P_1,D_2),(P_1,D_3)\} } \right\}$$

These states represent situations where a user usr_j accesses the system through one of the hotspots at t_x (when $State(usr_j, t_x)$ equals s_1, s_2 or s_3), or the situation where the user stands outside the hotspots broadcasting regions (when $State(Usr_j, t_x) = s_4$). Each system state gives rise to an appropriate content and container. For instance, the data provided when bearing in state s_1 or s_2 are different, and the content displayed at the interface level is adapted (Fig. 3(a) and 3(c)). When the user is out of scope and enters the state s_4, a generic map of the campus is displayed, and the location of the user is regularly reported. In that case, the user device is in charge of data display and interaction, as no other active component is accessible (Fig. 3(b)).

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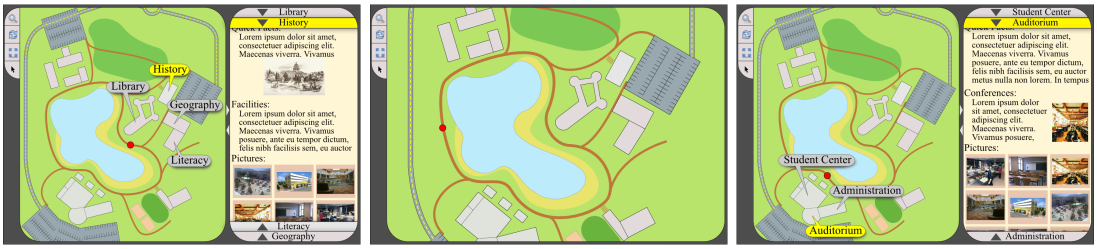
[1] In the remainder of this article, $s_{1\to4}$ are constants that shorten the full-length notation of systems states.



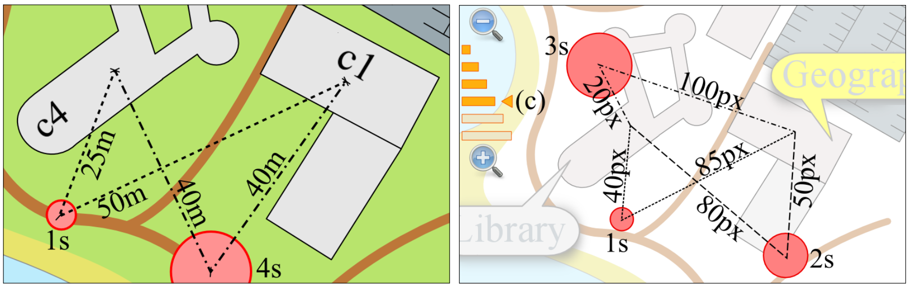
(a) $State(Jim,t7)=s_1$: the user region intersects $D_1(t_x)$ (b) $State(Jim,t8)=s_4$: the user region is unreachable (c) $State(Jim,t9)=s_2$: the user region intersects $D_2(t_x)$

Figure 3. Examples of system state dependency at the interface level

4. Scoring User Interests

Ordering the users objects of interest by attributing scores to elements makes personalizing the geospatial map possible by highlighting content relevant to the current user and eliding content which is not of interest to them. On the user device, located content subject to filtering is displayed at the interface level (e.g. buildings placed on an electronic map). Our objective is to determine the users' level of interest, not just in particular areas or types of features in the map, but regarding the specific objects contained in the map and in users' surroundings. Hereafter, scorable elements are defined and mobile users interests related to these objects are determined through either map-interactions, or proximity to these elements. These scores are combined to form a personal profile.

Within a given system state s_k, the score of a geographic element elm_i is derived from the software interactions and location indicators of a given user usr_j. Let $Elems(s_k, t_x)$ denote a function that returns the set $\{elm_1, elm_2, ..., elm_n\}$ of scorable elements in the system state s_k at t_x. When the state $s_k \notin States(t_x)$, $Elems(s_k, t_x)$ returns an empty set.



(a) $Jim's$ monitored locations and breaks at the physical level (b) Pointer hesitations and views at the device level

Figure 4. Scoring *Jim* location-based and interaction-based interests

Let us consider two buildings from the Literacy Department, scorable within the system state experienced at *Jim* Level: $Elems\big(State(Jim, t_7), t_7\big) = Elems(s_4, t_7) = \{c1, c4\}$ (Fig. 4). *Jim*'s interactions and moves have been implicitly tracked prior to t_7. The scores of the elements $c1$ and $c4$ (reported as “Geography” and “Library” on the device) are derived at t_7 and reflect $Jim's$ assumed preferences[1].

4.1. *Interaction-Based Scoring*

Monitoring mouse activity and interactions gives an indication of user thougts and interests. It is also the foundation of our approach to user preferences elicitation (Cox and Silva 2006, Pan *et al.* 2004, Chen *et al.* 2001). In particular, the measured mouse positions and pauses bring user interests to light. According to these implicitly denoted preferences, interaction scores are allocated to the elements displayed at the interface level and combined with the user context and location scores in order to build complete elements (map objects) scores and form a user profile.

Every interaction a user makes during a session creates a new view or occurs within a view. For example, a user can zoom and pan to create a new view whereas interactions such as mouse movements and distance measuring occur within an existing view. Sequential views form a logical framework of chunks within which to analyze user behaviour. Each view is weighted according to its scale and duration. Views where the user is zoomed in furthest and viewed longest receive the greatest weights. A weighting function reports this relative view at the interaction score derivation level. Let $\omega_{view}(usr_j, t_x)$ be the function that returns the weight granted to the view a user usr_j created at time t_x. When usr_1 zooms-in between t_1 and t_2, the view displayed at t_2 narrows t_1 view, and $\omega_{view}(usr_1, t_2)$ is higher than $\omega_{view}(usr_1, t_1)$. The interaction score of an element combines $\omega_{view}(..)$ to a mouse-based assessment of users current and past interests. In a given system state, we examine when and where a user's mouse pointer hesitates in order to reveal their interests. Let $MouseHes(usr_j, s_k, t_x)$ return the screen-locations set $\{mh_1, mh_2, ..., mh_n\}$ denoting usr_j pointer hesitations within the system state s_k. When t_x denotes the current time, the derivation of $MouseHes\big(usr_j, State(usr_j, t_x), t_x\big)$ returns usr_j set of monitored hesitations within her/his current system state. Having $mh_l \in MouseHes(usr_j, s_k, t_x)$, let the function $HesTmp(mh_l, usr_j, t_x)$ return the time spent hesitating at mh_k screen position. The user interaction score $UIScore(elm_i, usr_j, t_x)$ of a scorable element elm_i is given by:

$$\begin{array}{c} UIScore \\ (elm_i, usr_j, t_x) \end{array} = \omega_{view}(usr_j, t_x) \times \sum_{k=1}^{\left|\begin{array}{c} \scriptstyle MouseHes(usr_j, \\ \scriptstyle State(usr_j, t_x), t_x) \end{array}\right|} \frac{HesTmp(mh_k, usr_j, t_x)}{d(elm_i, mh_k)}$$

$$\text{with } d(elm_i, mh_k), \text{ the screen distance from displayed element } elm_i \text{ to } mh_k$$

The formula described above takes map object proximity to a logged mouse pointer position as a reflection of the importance of the object to the user, in the context of the view in which the object and accompanying interactions appeared. The longer a mouse hesitation is, the more salient its location is deemed to be, thus it receives a larger weight. Accordingly, elements closest to the longest mouse hesitations are awarded the greatest importance. Additionally, based on our observations of a user's map browsing habits, fundamental and generic behaviour patterns are identified which can also contribute to

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[1] Although four elements might be scorable at t_7, in this example, and to remain illustrative, the calculus runs on a limited set of elements

the user profile (Hiramoto and Sumiya 2006a, Hirose *et al.* 2007, Weakliam *et al.* 2005a, Wilson *et al.* 2007).

In the proposed example, Jim has already spent some time within system state $State(Jim, t_7) = s_1$, and three mouse hesitations have been monitored at the interaction level $\big($Fig 4(b)$\big)$. Besides these mouse hesitations, Jim has zoomed inside the view to refine building location $\big($Fig 4(c)$\big)$. This view weights $\omega_{View}(Jim, t_7) = 4$ and $UIScore(c4, Jim, t_7) = 4 \times \left(\frac{3}{20} + \frac{1}{40} + \frac{2}{80}\right) = 0.8$. Conversely, the score of the second element is given by $UIScore(c1, Jim, t_7) = 0.32$.

4.2. *Location-Based Scoring*

User interaction scoring can be extended for use in situations where the user is interacting with a mobile device and their location is being monitored. For example, the concept that frequent mouse proximity to a map item indicates a user is interested in that item can translate to continuous proximity to an entity indicates the user is interested in the entity and therefore should be incorporated into the user profile. Users likely break their walks to interact with their handheld devices and fetch information. These resting places might be considered as interest indicators for surrounding elements. In particular, during a campus visit, newcomers might first walk towards a building, and then pause nearby to use the system and document the building. In such a case, the locations of the user's breaks provide a valuable input to preference elicitation and complete the interaction-based scoring. The location scoring principles are formalized and exemplified by our case study. Location sensitive profiles are generated and used to personalize the map content and interface.

Let $BreakPos(usr_j, s_k, t_x)$ be the function that returns the set $\{bp_1, bp_2, ..., bp_n\}$ of usr_j break places in her/his walk through the environment, screened out by the system state s_k; and let $BreakTmp(bp_l, usr_j, t_x)$ return usr_j break duration at $bp_l \in BreakPos(usr_j, s_k, t_x)$. These functions allow location-based score derivation for a given element and user at t_x:

$$LocScore(elm_i, usr_j, t_x) = \sum_{k=1}^{\left|\substack{BreakPos(usr_j,\\ State(usr_j, t_x), t_x)}\right|} \frac{BreakTmp(bp_k, usr_j, t_x)}{d(elm_i, bp_k)}$$

$$\text{with } d(elm_i, bp_k), \text{ the metric distance from element } elm_i \text{ to } bp_k$$

The geographic score of an element grows with user proximity and break duration. For instance if scorable elements $Elems(t_x)$ contain edifices, the longer a user faces a building, the more salient this building should be. Similarly, the nearer the user stands to the building, the higher the location-based score is. In the proposed example, Jim has made two breaks of one and four seconds $\big($Fig. 4(a)$\big)$. The location scores are derived from the distance between Jim's break locations and the considered element, weighted by the duration of each break. For instance, $LocScore(c4, Jim, t_7) = \frac{1}{25} + \frac{4}{40} = 0.14$. Conversely, the score of the second element is given by $UIScore(c1, Jim, t_7) = 0.12$.

4.3. *User Profiles*

After the user interactions have been monitored, session scores for each individual localized element are combined. Scores are made dimensionless and are averaged to provide a combined score. A weighting function is defined at the design stage, and allows system developers to match the elements scoring algorithm to situations where mobility is either less or more relevant than interaction. The users profiles combine the scores of all the elements available.

Let the function $Score(elm_i, usr_j, t_x)$ return an averaged combination of location score and interaction score for a given element elm_i at time instant t_x. This combined element score is given by:

$$Score(elm_i, usr_j, t_x) =$$

$$\begin{cases} \left(\begin{array}{c} \omega_{Score}(elm_i, usr_j, t_x) \times \dfrac{UIScore(elm_i, usr_j, t_x)}{Sum_{UIScore}(usr_j, t_x)} + \\ \left(1 - \underset{(elm_i, usr_j, t_x)}{\omega_{Score}}\right) \times \dfrac{LocScore(elm_i, usr_j, t_x)}{Sum_{LocScore}(usr_j, t_x)} \end{array} \right) & \begin{array}{c} \text{iff } elm_i \in \\ Elems\big(SysState \\ (usr_j, t_x), t_x\big) \end{array} \\ 0 & \text{otherwise} \end{cases}$$

$$\text{with } \underset{(usr_j,t_x)}{Sum_{UIScore}} = \begin{cases} \sum\limits_{k=1}^{\left|\substack{Elems(SysSta \\ te(usr_j,t_x),t_x)}\right|} \underset{(elm_k, usr_j, t_x)}{UIScore} & \text{iff} \left(\begin{array}{c} \exists\ elm_l \in Elems\left(\substack{SysState \\ (usr_j,t_x),t_x}\right), \\ UIScore(elm_l, usr_j, t_x) \neq 0 \end{array} \right) \\ 1 & \text{otherwise} \end{cases}$$

$$\text{and } \underset{(usr_j,t_x)}{Sum_{LocScore}} = \begin{cases} \sum\limits_{k=1}^{\left|\substack{Elems(SysSta \\ te(usr_j,t_x),t_x)}\right|} \underset{(elm_k, usr_j, t_x)}{LocScore} & \text{iff} \left(\begin{array}{c} \exists\ elm_m \in Elems\left(\substack{SysState \\ (usr_j,t_x),t_x}\right), \\ LocScore(elm_m, usr_j, t_x) \neq 0 \end{array} \right) \\ 1 & \text{otherwise} \end{cases}$$

The subfunction $UIScore(elm_l, usr_j, t_x)$ allows the overall scoring between the interaction and location scores to be balanced. This function is provided at design stage, or might be dynamically modified according to user behaviour. In particular, when $\omega_{Score}(..) = 0$, a given element overall score derives only from location scoring. Conversely, if $\omega_{Score}(..) = 1$, the interaction score contributes alone to the final scoring. This weighted approach allows designers to adapt scoring to different case studies. For example, when using the system on a desktop, scoring user mobility is not as relevant as scoring the interaction, and $\omega_{Score}(..)$ should approximately be set to one. Another possible definition of this function dynamically increases the location score in relation to user mobility.

The collection of averaged elements scores constitutes the user profile at a given time instant:

$$UsrProf(usr_j, t_x) = \Big\{ Score(elm_i, usr_j, t_x),\ \forall\ elm_i \in Elems\left(\substack{SysState \\ (usr_j,t_x),t_x}\right) \Big\}$$

Such user profile provides an initial input to interface and data personalization.

In the proposed example, the designers put location and interaction on an equal footing, and define $\omega_{Score}(c4, Jim, t_1) = 0.5$. At the overall score level, Jim's final score for element $c4$ is given by:

$$Score(c4, Jim, t_7) = 0.5 \times \frac{0.14}{0.14 + 0.12} + (1 - 0.5) \times \frac{0.8}{0.8 + 0.32} = 0.62$$

Conversely, $Score(c1, Jim, t_7) = 0,37$. At t_7, Jim's break locations and interface usage highlight his interest for element $c4$ over $c1$. Jim's profile is made of $c4$ and $c1$ scores at t_7: $UsrProf(Jim, t_7) = \{0.62, 0.37\}$.

5. Personalizing an Adaptive GIS

Personalization of GIS data and interface is achieved using profiles. Adaptation in the campus navigation system implies relieving the user from the burden of information overload. The contents of the dataset along with the interface used to display information are personalized. Users are given the choice to use the suggested personalization, or to remain with the application's default settings. This is beneficial when the user profile may be inaccurate. Often, an improper personalization irritates the user, and can be more harmful than beneficial. Giving the option of discarding the personalization reduces the risk of irritating the user.

5.1. *User Interactions*

Figure 5 highlights the functionality available to the users as they interact with the system. The user can manipulate the interface in a number of ways in order to alter its appearance based on their current task. In addition to the usual zoom, pan and rotate map interactions, the user can alter the appearance of the interface to suit their current requirements. For example, the screen portion devoted to displaying the map can be increased while that occupied by the information panel is decreased and vice versa $\big($Fig. 5(b)&(c)$\big)$. When viewing the content in the information panel, the user may be offered

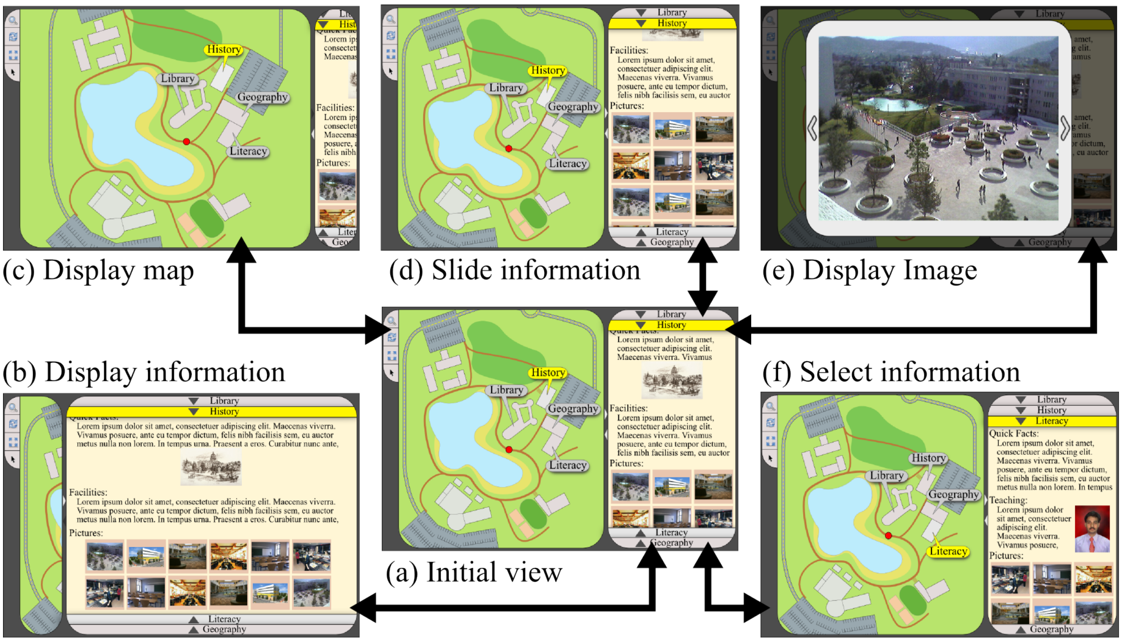
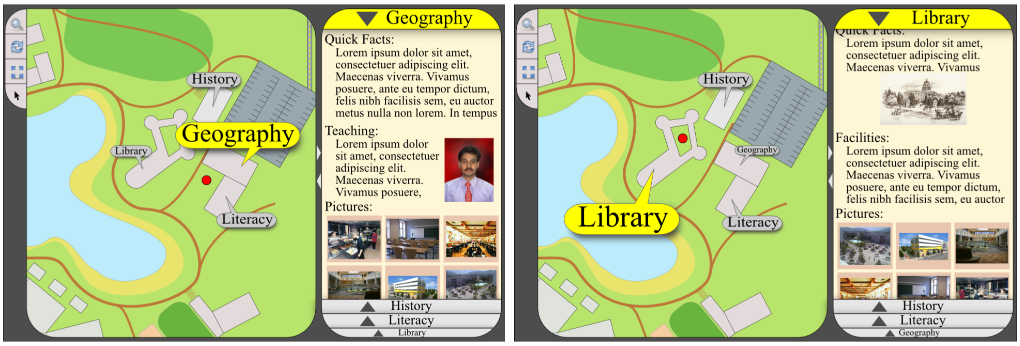


Figure 5. User interaction diagram

relevant photos which can then be enlarged in order to provide a clearer view (Fig. 5(e)). Information selection occurs by clicking on the appropriate label at the map level, or by selecting an item at the information pane level (Fig. 5(f)). Users may slide up/down an entry within the tabbed pane to get access to hidden information (Fig. 5(d)). Each time the user interacts with the interface, the system implicitly collects information about her/his usage which is computed based on the interaction with the map (e.g. zoom, pan and stylus interactions). This information is combined with her/his location context and used to continually build and maintain a profile of that user.

5.2. *Content and Interface Adaptation*

The application described above becomes adaptive when user context, location and profile interests are integrated to the design to provide a personalized experience to the user by adapting the interface, spatial content and information levels. In our prototype, data and user interface adaptations are triggered by changes at the profile level. These profiles maintain a ranked list of the user's interests among the elements displayed at a given time and system state. The various elements displayed at the user interface level can be given higher or lower priority according to the associated scores within the profile.



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Pictures:

(a) *Jim*'s display at t_2 (b) *Jim*'s display at t_5

Figure 6. Examples of profile adaptation

For example, as *Jim* approaches the geography building, his profile indicates a strong interest in geography. This is highlighted at the user interface level by making the label larger. Additionally, the content provided in the information panel changes so that preferences are taken into account. For example, the labels on the tabbed panes change so that those which are deemed more appropriate to the user are highlighted with a larger font and preferential ordering (Fig. 6(a)). From t_3, as *Jim* comes near the library, the label of the corresponding building is increased in size and the library tab on the information panel is given greater prominence. For instance, at t_5, the library building becomes the focus of *Jim* attention. His client interface emphasizes the library label and re-orders the tabs to push the library entry to the top (Fig. 6(b)).

6. Conclusion

The development of adaptive and personalized software is an area that is becoming crucial for the successful development of many multi-user and location-based applications. Implicit profiling, personalization and adaptation have been recently integrated with conventional information systems, but to the best of our knwoledge not so far applied to the context of geographical information and location-based services. However, it appears clearly that software personalization when applied to mobile applications should consider contextual location usage to provide adapted content to the users.

The research presented in this paper introduces a methodology oriented to the design and maintenance of user profiles based on their location and device interactions, as well as their subsequent use of the mobile system. This personalization process is based on an unobtrusive approach through implicit user profiling. The details behind the construction of users profiles, including interaction and location-based perspectives have been presented. These profiles produce different levels of data and interface personalization. A user profile is continually updated with information gleaned during user interaction with the system. Several weighting functions enable fine-tuning of personal score derivations. By providing an effective personalization solution, the user experience is improved as irrelevant content for users' current context is subject to filtering and elision. Providing such personalization decreases information overload at the user level.

Current work concerns a prototype development of the navigation system, and validation of the personal adaptation algorithms. We plan to orientate future work towards human-computer interaction and ergonomics issues. User mobility might also be seen as a medium to propagate profiles and preferences in the system environment as it should allow users outside a given state to share their preferences and interests.

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