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User-Centred Development of Mobile Interfaces to a Pervasive Computing Environment

Karin Leichtenstern
Institute of Computer Science
University of Augsburg
Eichleitnerstr. 30, 86135 Augsburg, Germany
Email: Leichtenstern@informatik.uni-augsburg.de

Elisabeth Andre
Institute of Computer Science
University of Augsburg
Eichleitnerstr. 30, 86135 Augsburg, Germany
Email: Andre@informatik.uni-augsburg.de

***Abstract*—A challenging issue for HCI is the development of usable mobile interfaces for interactions with a complex pervasive environment. We consider a need for interfaces which automatically adapt their interaction and presentation capabilities on the user's situational needs and expectations to decrease the complexity of the environment and increase the usability of the system. Therefore, a rule-set is required which gives knowledge on the mobile interface's adaptations as a consequence on a user's situations within the environment. This rule-set iteratively emerges within a user-centred development process by considering and testing each contextual situation of the user when interacting with the mobile interface. In this paper we describe an approach of a usage model for specifying each context of the user and the environment as well as the user's goals and mental model. Moreover, we describe our used user-centred process to develop the usage model and rule-set, practical experience in development of mobile interfaces, some guidelines and our planned future work.**

I. Introduction and Related Work

Mark Weiser gave a first vision of *Ubiquitous Computing* in [1]. *Pervasive Computing* is often used as synonym. Basic idea of these paradigms is making use of the real world surrounding the user for enabling interactions with everyone and everything at any time and any place. For these interactions an electronic interface between the virtual and real world is required.

Mobile phones seem to be feasible as a pervasive interface. They have successfully become part of our everyday life. Almost everybody owns a mobile phone and primarily uses it as channel for human-human communication, such as exchanging text messages or making phone calls. A growing number of built-in hardware (Camera, Microphone, RFID) and network interfaces (UMTS, Bluetooth, Wifi) enable various numbers of presentation and interaction techniques. Some of these techniques can be used to interact with augmented real-world objects to display their virtual information. Thus, using these novel mobile techniques, mobile phones can become powerful interfaces between the real and virtual world [10] and can close the gab between these two worlds. In pervasive computing the research area addressing mobile phones as interface to a pervasive environment has several names: *physical mobile interaction* [4], *physical browsing* [8] or *internet of things* [9]. All of them base on former work of Kindberg [6] who first described the idea of using mobile phones as interface to people, places and things (pervasive environment).

In this paper we call applications *mobile interfaces* whenever mobile phones and their presentation and interaction capabilities are used as interface to a pervasive computing environment.

Until now research in areas of mobile interfaces to pervasive computing environments has mainly concentrated on the development of new mobile interaction techniques [7] and mobile interfaces [5]. We are investigating the user's preferences for interaction and presentation capabilities of mobile phones. In our former work [4] we found out that users do not prefer a single interaction and presentation capability of a mobile phone when interacting with a pervasive computing environment. Instead of, the user's situation such as a user's location, motivation and activity can create context-sensitive situational goals and influence her preference for a technique.

We suppose an importance to specify a schema giving developers a possibility to describe the concrete usage of a mobile interface in an abstract way including all involved aspects of a pervasive computing environment which can influence a user's situational goals. Having knowledge of all aspects and their interplays, the usage model can be mapped via set of rules to the mobile interface for automatically adapt on a user's requirements. We consider a need to iteratively develop this usage model based on our schema, map it to the mobile interface and evaluate the interface within user tests. Thus, apart from a required usage model we also require an adapted iterative user-centred process to incrementally get closer to the final version of a usable mobile interface which conforms best with a user's real usage in the pervasive computing environment. Based on the formal ISO-13407 [21] specification of the user-centred design, we concreted the process which is also presented in this paper.

Several references motivate our work. Banavar [2] points out that ubiquitous computing leads to several usability issues mainly because of interactions with the physical world in social environments. He mentions that there is a need to specify effective methods for developing ubiquitous applications which is a widely under researched area needing more attention. Henricksen [3] describes the importance to specify models which consists all relevant components including devices, users, software components and user interfaces. Particularly, context data related to users must be considered, including

information describing a user's capabilities, preferences and current activities.

However, we see less guidelines, models or specified processes helping developers to consider the user's situational goals during the development process of interfaces. There are some user-centred processes for the development of mobile applications [11], [12] but these processes are mainly GUI-driven approaches which do not include the physical world surrounding the user and the context which has influence on a user's behaviour. A very similar research to our is from Häkkilä. She also addresses issues for mobile users caused by changed context [14]. She describes several guidelines in [15] which might be useful for developers of mobile applications but Häkkilä has not provided these developers with usability engineering tools as we plan to do in our future work and Häkkilä has not focused on adaptations of mobile interface to meet user's real requirements. In context of our planned authoring tool to simplify the development of mobile interface to a pervasive computing environment, there are only just a few other authoring tools such as iCAP from Anind Dey [18] or the Mobile Bristol Application Development Framework from Richard Hull [19]. In both tools context-aware applications can be specified by a GUI. In contrast to our planned authoring tool iCAP and the tool from Hull are mainly used to easily specify a rule-set of situations and actions. We plan to support developers with a GUI to specify the adaptive mobile interface including a rule-set for situational goals but also to support developers with an evaluation tool to verify whether the rule-set and the interface is feasible or not.

In the next section we introduce our schema to specify personas, the user and environmental context, the mobile interface and the interplay between these components. Next to the schema, our adapted user-centred design process is described. 37 user interface designers used the schema and the design process for the development of eleven mobile user interfaces to pervasive computing environments. Thus, the paper describes in a separate section our practical experience and future work. The paper is completed by a conclusion.

II. Usage Model of Mobile Interfaces in Pervasive Computing Environments

In this section we describe a specified schema (see figure 1) which can help software developers to implement a usable mobile interface. A model based on our schema can illustrate a user's current situation in a pervasive computing environment and required adaptations of the mobile interface to always meet a user's requirements. A usage model as our schema consists of all relevant aspects which may have influence on a user's usage behaviour. In the development process of a planned mobile interface a concrete usage model iteratively emerges. The resulted model extends the released mobile interface with a set of rules to give knowledge about required adaptations of interaction and presentation capabilities on each contextual situations of a user. For example the rule set gives knowledge which presentation to display when a user has interacted with the graphical user interface of the mobile phone. Another example might be the rule which interaction to support when the physical environment has changed, e.g. when the noise is currently extremely high. We see four main components in our schema to emerge the set of rules: a model of a persona, a model of the mobile interface, a model of the user context and a model of the environmental context. A model of the persona describes the user and her goals whereas the mobile interface includes a description of the application including supported interaction and presentation capabilities. The user and environmental context can change a user's situations in the pervasive computing environment and can require an adaptation of the mobile interface in forms of an adaptation of the interaction and presentation.

A. Persona

Whenever mobile interfaces have to be developed, the diversity of real users must be considered in forms of different personas [20]. Each persona gives useful input about a group of real users including information about their knowledge, expectations and goals. We split the specification of persona in two parts concerning a user's mental model and a user's goals because we suppose both aspects as relevant when developing a set of rules for an adaptive mobile interface.

1) Mental Model: The mental model describes general information about the user such as information about a user's general knowledge and memories. A user's general attitude and behaviour base on this mental model and influence a user's goals quite intensive. Users having a very negative attitude of our planned application will not use it at all. Thus, mental model must describe a minimum value of open mindedness regarding our planned application. Changing mental models normally require a meaningful positive situational occasion.

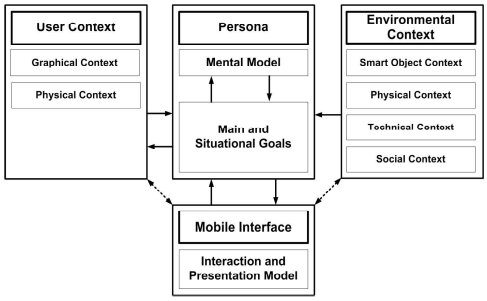

Fig. 1. Usage Model of Mobile Interfaces to Pervasive Computing Environments

2) Main and Situational Goals: We see a user's main goals which can be attained by using the mobile interface and its provided services such as the main goal to load information about a smart object. Apart from the main goals, a user has further goals depending on a user's situation such as a goal to prevent any further cognitive load because the user's activity level is currently high. Situational goals can arise in several ways, such as privacy goals, security goals and goals to prevent cognitive or physical load. The mobile interface has to meet the main goals by supporting right services but

also the situational goals by supporting appropriate interaction and presentation capabilities of the mobile interface. Thus, it is necessary to have knowledge of each main and situational goal.

B. Mobile Interface

Appropriate services must be provided by the mobile interface to complete tasks and attain a user's main goals. A task can be performed by executing a sequence of actions and providing feedback. To also meet situational goals the mobile interface contains an interaction and presentation model which gives information about adaptations.

1) Interaction and Presentation Model: The interaction and presentation model contains rules for adaptations of the interface to meet main and situational goals. The model might contain the rule to support the user with graphical interaction capabilities instead of physical whenever a situational goal is privacy. Thus, the interface can support the user with appropriate interaction and presentation capabilities and avoid unnecessary actions of the user to change the mobile interface because the interface can automatically adapt to a user's needs.

C. User Context

Whenever users change their current situation such as by changing their location, they trigger user context which influences their goals. User context can be triggered in different ways. We consider it useful to differentiate the user context in the graphical and physical user context.

1) Graphical User Context: Users can trigger context by interacting with the graphical user interface presented on the mobile interface which is even textual-based or menu-based. We call this context graphical user context. After a user has triggered a graphical user context the interface can adapt, e.g. by displaying another screen and playing a sound signal.

2) Physical User Context: Physical user context is triggered whenever users physically interact with their pervasive computing environment. Users can even directly interact with their environment, e.g. by touching a smart object via the mobile phone or can indirectly trigger physical user context, e.g. by changing their location. The interface has to adapt on the new situation triggered by the user context to meet changed situational goals.

D. Environmental Context

Normally users do not have any influence on the environmental context but it requires an adaptation of the interface as a consequence of the changed situational goals. Within a pervasive computing environment four kinds of environmental context emerge: smart object, physical, technical and social context.

1) Smart Object Context: An important environmental context can be triggered by the smart objects. Smart objects are all interaction partners within the pervasive computing environment. We define as interaction partner one or more of the following categories: people, sensors and things. Whenever users interact with other users, the other users can also trigger user context and change main and situational goals. In another case, when a user is interacting with sensors such as the sensor to measure the blood pressure, a triggered context of that sensor can also change a user's requirements to the mobile interface. Finally, things can also trigger context because their location, appearance and availability can also change a user's goals.

2) Physical Context: Physical environmental context is triggered whenever physical-based changes happen in a user's pervasive environment. Physical environmental context might be changed noise, lighting conditions or temperature. Changed physical environmental context can have enormous influence on a user because it can preclude some user context.

3) Technical Context: Technical context of the pervasive computing environment can have influence on the user as well. On the one hand the technical support of the mobile phone and its form factor can influence a user's preference. On the other hand technical properties of the pervasive environment such as their technical equipment, e.g. existing large displays can change goals and cause requirements for adaptations of the mobile interface.

4) Social Context: Social environmental context comes up whenever other people have influence on a user's goals, such as the goal for privacy. Once social environmental context has changed a user's goal, the mobile interface requires adaptations on a user's changed situation.

III. Adapted User-Centred Development Process for Mobile Pervasive Interfaces

An adapted iterative user-centred design process is required which basic objective is finding best conforming usage model to create a user-centred mobile interface to a pervasive computing environment. As basis for our adapted process we used the human-centred design process formally specified in ISO-13407 [21]. The main goal of the ISO-specification is setting the user into the centre of the development process. The user is involved as often as possible to optimize applications on a user's goals and needs. This ISO-specification shows several steps of a process to find a user's requirements: understand and specify the context of use, specify the user and organizational requirements, produce a design solution and evaluate the design against requirements. Found issues are used as input to change the context of use and iterate the process as long as a user's requirements have not been correctly matched.

Figure 2 shows our adapted user-centred development process for mobile interfaces to pervasive computing environments. The process consists of a conceptual and analysis phase as well as an iterative design phase. The iterative design phase consists of a specification, implementation, evaluation and analysis.

A. Conceptual Phase

Whenever developers plan to implement a mobile interface to a pervasive computing environment it is recommended to first specify a basic concept to decrease the number of solutions. The result of the conceptual phase should be a basic

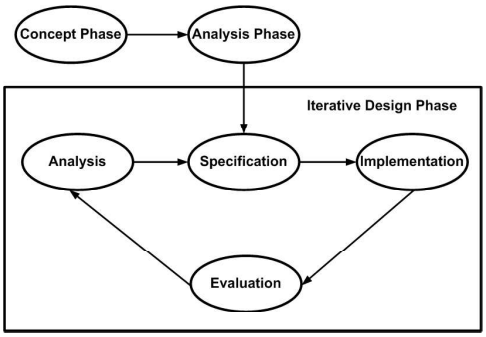

Fig. 2. Adapted User-Centred Development Process for Mobile Pervasive Interfaces

description of the mobile interface, a specification of the target group, the requirements of users and developers as well as a very basic specification of the usage model.

B. Analysis Phase

After having a conceptual specification of the mobile interface there is a need to evaluate it before starting to consider its explicit modelling and implementation. People of the target group must be asked for their attitude about the concept. Moreover, there is a need to find out users' abilities. A result of the analysis phase is the reviewed specification of the concept. In addition, a specification of the personas and the scenarios for later user tests should be the outcome of the analysis phase. These different personas base on the resulted user's abilities and attitudes.

C. Iterative Design Phase

The objective of the iterative design phase is to find a usage model and a set of rules for required adaptations of the planned mobile interface to always meet a user's needs best. For each persona identified in the analysis phase a set of rule has to be defined.

1) Specification: During the specification phase the usage model and the set of rules are specified and adapted for the planned mobile interface to a pervasive computing environment.

2) Implementation: The set of rules from the specification phase is used for the implementation of different versions of the mobile interface.

3) Evaluation: After a new version of the planned mobile interface has been developed, the interface and its set of rules must be evaluated within experts and real users test. For the real user tests, the specified scenarios of the analysis phase are used. These scenarios should include all testing situations to investigate relevant user and environmental context.

4) Analysis: The results of the evaluation can be analyzed to find out whether the usage model and rule-set conforms a user's needs and expectations or not. Resulted issues give valuable input for modifications of the specification.

IV. Practical Experience and Future Work

Until now, we have used our introduced schema and the adapted user-centred design process for the development of eleven different mobile interfaces. In total 37 software developers were involved in the development of these interfaces which only adapt on graphical and physical user context. Environmental context is considered in the usage model but we have not included adaptations into the implementation yet. One example of an interface is called *Mobile Movie Guide*. Using this interface in a video store, users can download information about smart DVDs such as a trailer or a critic which can help to make a decision which DVD to choose. In the following we describe our overall practical experience and resulted guidelines. We use the *Mobile Movie Guide* as example to brief describe some practical steps in the different phases.

A. Conceptual Phase

In the conceptual phase of the *Mobile Movie Guide*'s development, we specified the concept and the target group. Moreover, we specified the user and environmental context. For example, we considered smart object context as relevant in a video store because the location of the smart DVD can change a user's situational goal for an interaction technique. As physical context, noise might play a role because it can cause an decreased attentiveness of the user which can have an influence on a user's behaviour and situational goals. Furthermore, we specified social context in form of other people within the video store because we see privacy issues. For the physical user context we specified RFID-based interaction and for the graphical user context we specified a text-based search system and a menu-based Top5-list to select a DVD.

As a result of our practical experience in the conceptual phase, we recommend the following guidelines.

- **Collect information about other interfaces:** Read related work describing the development of other mobile interfaces or analyze similar products from your competitors to achieve useful information such as guidelines for your own interface.
- **Collect information about the users and the environment:** Use marketing research data of the target group which gives information about their behaviour and requirements. Moreover, be aware of the environmental context in the pervasive computing environment. Best recommendation is to use video observations to detect context but also to get information about users and their behaviour in the environment. Afterwards, use our schema to specify all found relevant environmental and user context.
- **Find a useful mobile interface concept:** Consider the existence of an added-value and a reduction of the user's cognitive and physical load.

B. Analysis Phase

In this phase we conducted interviews for our mobile interface *Mobile Movie Guide* in a video store. We asked 20

people for their attitude about our concept. As a result we found a user's main goals and changed services supported by the mobile interface. For example users want to read official critic and feedback of other users but do not like other planned services such as a forum. Moreover, we asked users for situational goals as a consequence of a context situation. We found some important input to our usage model such as users prefer to use RFID-based physical user context, when being close to DVDs.

The following aspects should be considered in the analysis phase.

- **Interview real users:** Try to conduct interviews in the pervasive computing environment and only ask users which are within the target group. Moreover, address all open issues and assumptions of the development team. As a result of the analysis phase adapt the concept and the usage model.
- **Mediate the concept:** Use storyboards to introduce and illustrate the concept.

C. Iterative Design Phase

As basis for the iterative design phase the usage model is used. In the usage model the following aspects are specified: the environmental and user context detected in the conceptual phase as well as the user's main and situational goals and the definition of the mental model of the personas detected in the analysis phase. Having this usage model, the rule-set can be specified for the mobile interface. It defines the interplay between the aspects defined in the usage model and gives the mobile phone interface the knowledge which interaction and presentation to use as adaptation on user and environmental context to meet the user's goal.

We implemented the rule-set of the *Mobile Movie Guide* in two iterations. In the first iteration we implemented a low-fidelity prototype in form of a paper prototype and in the second iteration we implemented a high-fidelity prototype in J2ME. We used the paper prototype for a user test with five subjectives and the high-fidelity prototype for a test with ten users. In these tests we reviewed supported interactions and presentations on a user's needs. Figure 3 shows the final task flow of the mobile interface.

We see the following recommendations in the iterative design phase.

- **Consider principles and official guidelines:** Comply general usability principles [17] and mobile phone guidelines [22].
- **Run as many iterations as possible:** In each iteration always change only minor aspects of the specification and verify the changed specification within evaluations. Try to start with a very basic specification and extend and alter it in each iteration.
- **Use experts and real users for evaluations:** Always first start with expert tests to verify basic aspects such as whether guidelines and principles are still complied. In the followed iteration run real user tests to verify the usability of the specification whether it fits on the user's requirements in each contextual situation or not.
- **Capture users:** Capture users and the pervasive computing environment during the usage of the mobile interface and use the method called *thinking aloud*. *Thinking aloud* asks users to verbalize their thoughts which gives important knowledge of a user's mental model as well as a user's main and situational goals.

Fig. 3. Application Flow as Rule Set of the *Mobile Movie Guide*

As design iterations are a very time-consuming and expensive step within the development process and reduction of costs is one of the most important aspects in the development process [16], we came up with the idea to automate the design phase by providing developers with an appropriate engineering tool. This tool is expected to make iterations more efficient and to reduce costs. The planned authoring tool is split in three different components: the specification component, the implementation component and the evaluation & analysis component.

1) Specification Component: The specification component supports developers with a graphical user interface (GUI) to easily specify the rule-set via a task-flow of the application. Within the task flow, interaction and presentation adaptations of the mobile interface can be modelled to meet a user's main and situational goals on different user and environmental context. The resulted rule-set is represented in a XML-based description which is used by the other two components.

2) Implementation Component: The planned implementation component is also a GUI. Developers can select a visual

presentation of the mobile interface and generate program code (e.g. J2ME) based on the XML-description of the rule-set. During the code generation, the implementation component automatically checks the compliance of the GUI-driven mobile phone guidelines and the HCI-principles.

Each of the generated versions of the mobile interface is a high-fidelity prototype and can be uploaded to a mobile phone for the evaluation. We consider no further need to use low-fidelity prototypes because the benefit of a quick and cheap production of prototypes is also supported via our engineering tool. Moreover, by using high-fidelity prototypes we also consider that the number of iterations can be reduced because user tests become more realistic and results more reliable.

3) Evaluation & Analysis Component: The evaluation & analysis component can be used to conduct user tests to verify the rule-set of the mobile interface. The component is also a graphical user interface which gives control to a video capturing tool to record the users as well as the pervasive computing environment. We decided to automatically log each user and environmental context as well as the adaptation of the mobile interface's interaction and presentation capabilities to enable automatic annotations of our captured videos. Having these automatically annotated videos and the information about a user's goals through the method *thinking aloud*, problems can be easily detected and the task flow of the specification component can be adapted to develop a new prototype.

V. Conclusion

In this paper we introduced a usage model and an adapted user-centred process for development of usable mobile interfaces to a pervasive computing environment. Our usage model enables the description of the user and environmental context as well as the user's goals and mental model. The user's goals can change and require an adaptation in terms of an adaptation of the mobile phone's presentation and interaction capabilities. Having knowledge of these aspects a rule-set of adaptations can be used for a released mobile interface to always meet a user's needs in different contextual situations within the pervasive computing environment.

As a result of the development of eleven mobile interfaces based on our process and on the usage model, we found some guidelines and came up with the plan to develop an engineering tool in our future work. The engineering tool can help to make development of mobile interfaces more efficient by decreasing development time. The tool is expected to easily help the specification of a rule-set for the mobile interface. Moreover, the engineering tool enables an efficient evaluation and analysis of the user tests to quick and easy run iterations in the design phase.

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