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Characterising Context for Mobile User Interfaces in Health Care Applications

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Abstract

Mobile technology has been piloted in a variety of domains. We investigate the use of smart phones in the hospital environment, as they can play an important role in the recording and exchanging of information. This paper examines how context can be characterised for developing context sensitive user interfaces for smart phone application in a hospital environment. We introduce a new characterisation of the notion of context, based on the principle of separation of the concerns that are relevant to the application domain. We coin the term *context descriptor*, which captures the notion of context at the end-user level, while the characterisation of the context incorporates the user model via the user stereotype. We use a sub-domain of health care, nursing services, the tasks of the nurses serving as a living example to illustrate the ideas presented.

Keywords: Context; Mobile; User Interface; User Stereotype; Context Descriptor; Health Services

1. Introduction

Mobile technology has been piloted in a range of health-related areas, and has been used to improve the dissemination of public health information (e.g. messages about disease outbreaks and prevention). It has also facilitated remote consultation, diagnosis and treatment, the distribution of health information to doctors and nurses, patient management, public health monitoring and the increased efficiency of administrative systems. Research suggests that mobile phones can play a significant role in all these areas [1]. However, the role of these devices, as with other information and communication technologies (ICT), is subject to increasing scrutiny in the health care area, precisely because the stakes are so high and the potential gains from technology development in this area are so significant [1].

A dynamic user environment which must respond to fast-changing contexts can benefit from the use of a context-aware device. The hospital is an example of such an environment. Currently, mobile

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computing is a supplemental service in hospitals, which complements existing clinical information systems; for instance, it provides an alternative means to access medical information [2], and supports interpersonal communication [3].

Our contribution in this paper is to address the idea of characterising the hospital context as a foundation for designing and developing a context-sensitive mobile medical application. Computer systems for health care present a number of usability challenges [4], among them the considerable number of medical errors that occur related to entering and retrieving patient information, which can be caused by: (1) human-computer interfaces unsuited for the highly disruptive use context of hospital work; and (2) cognitive excess resulting from the number of steps required to retrieve correct information. We call the UI developed for mobile devices a Mobile User Interface, or MUI. The designer of an MUI can incorporate context-based modifications into the appearance or the behaviour of the interface, either at design time or at run time.

It is important for us to point out that our proposed model is based on separating how context is acquired from how it is used, by adapting MUI features to the user's context. The adaptation of MUI sources, like features, widgets and sensors, in the recording and accessing of information is based on both our context model and the User Stereotype. We provide a brief exposé, along with an example, of an approach for developing an MUI based on that notion of context. The research reported in this paper builds on our previous work [5], which focused on the design of a desktop UI in the health care domain based on adaptation of the principles of human-computer interaction (HCI). Our present research, in the same domain, moves into the area of mobile design, focusing on human-mobile interaction. We hope that this paper will improve human-human interaction with the aid of an MUI that responds intelligently to contextual changes. The cognitive ability of the user will be matched in certain instances by the cognitive responses of the MUI, and the mobile device, serving as an extension of the user, will be able to adapt through an interface model that accommodates change. As it interacts with the user, keeping in mind the User Stereotype, the mobile interface will change, depending on the situation or the location for instance, and respond intuitively.

The paper is organised as follows: In section 2, we provide a summary of the literature on context characterisation. At the end of this section, we demonstrate how our views are similar to those of others and how they are different. In section 3, we present our model, which will provide a clear understanding of context in our application. In section 4, we introduce the application context, which is the hospital domain, and, for the sake of brevity, we present a summary overview of a representative example from a sub-domain of the health care application. Note that we do not address the important issues of security, privacy and reliability with regard to health care applications in this section. Section 5 constitutes a proposed approach for MUI development. Here, we explain how we apply our model and provide an example. Section 6 concludes our paper and outlines the directions of our ongoing research.

2. Context: Related Work

The commonly used English word *context* can be intuitively understood, but its formal or technical meaning in the area of context-aware computing or in the design of adaptive software systems is quite an elusive one. However, a clear and unambiguous understanding of the term will help software engineers to achieve their development goals more efficiently and effectively. A thorough review of the extensive literature in this area would be challenging. In this section, we consider some critical issues, but we do not claim this review to be comprehensive.

Some researchers define context as the user's physical, social, emotional or informational state, or as the subset of physical and conceptual states of interest to a particular entity [6]. The authors in [6] have presented the definition or interpretation of the term by various researchers, including Schilit and Theimer [7], Brown *et al.* [8], Ryan *et al.* [9], Dey [10], Franklin & Flaschbart [11], Ward *et al.*[12], Rodden *et al.* [13], Hull *et al.* [14] and Pascoe [15]. In Dey and Abowd [6], the authors are interested in context-aware systems, and so they focus on characterising the term itself. In Pascoe [15], the author's interest is wearable computers, and so his view of context is based on environmental parameters as perceived by the senses. He also studies the difficulties encountered in building context-aware systems, and introduces the notion of the Context Information Service (CIS). In Pascoe *et al.* [16], the authors introduce the notion of a universal context model which can enable applications to sense the environment surrounding them, so that they can react or adapt. In Gwizdka [17], the author considers what is internal (to the user) in a context and what is external, in dealing with contextual information. In Winograd [18], the author introduces the term from a linguistic point of view, and explains how context plays a role in communication or dialogue between people. In Flanagan *et al.* [19], the authors are interested in the recognition of context based on the features of multi-dimensional data from different sensors. Schmidt [20] suggests that an implicit HCI model based on a situational context needs to be created for both input and output information. In his work, basic mechanisms of perception for acquiring context are discussed, such as context based on external sensors. Our work depends on the internal sensors of a mobile device, and adaptation of MUI features for both entering and accessing data, such as widgets. Dourish [21] considered context as both a representational problem and an interaction problem. He argues that context arises from the activity, instead of taking context and content (activity) to be two individual entities. He considered context to be indivisible, while our model is based on separating how context is acquired from how it is used, by adapting MUI features to the user's context. Tools like those proposed by Damask [22] are intended to simplify the process of designing user interfaces for several platforms, but he does not take into account user categories. MIContext [23] is a context model for mobile interaction that stays at the conceptual level, and details on characterising spheres of interaction are not provided. The Supple system [24], which is concerned with the automatic generation of customised UIs, takes a different approach, treating interface generation as an optimisation problem: the rendition of UI widgets is optimised under the device's constraints, while the estimated cost of the user activity is minimised. The Supple study focuses on creating specific algorithms and locating user patterns, but does not take into account the characterisation of the context related to a mobile device. It only explores mechanisms that would allow users to customise the functionality of the interface, rather than the presence and placement of pre-specified UI widgets. By contrast, Korpipää *et al.*, in their ontology for mobile device sensor-based context awareness (SBCA) [25] propose an interface capable of adapting to the user's current activity. SBCA focuses on modelling at the sensor level, but does not take into consideration adaptation of the input, such as user interactions involving voice or touch. The authors bring up another important issue in the sensing of context, namely the confidence level. CAMob [26] is a mobile handheld system designed for communication and collaboration between health care professionals in a hospital environment, in which user roles facilitate the communication and collaboration process. However, contextual elements, such as User Category and MUI elements, are not considered. Project TEA [27] developed a sensor board equipped with 8 sensors which supplies contextual information. The application described is a mobile phone that recognises its context (in a user's hand, on the table, in a suitcase, outdoors). However, this work did not consider MUI features or the User Stereotype, focusing on completely sensor-based context awareness, and adaptation was only addressed for the output mechanisms (ringing mode) and not the input mechanisms. Finally, in [28], adaptability is examined in terms of a user's continuously moving state as a necessary component of MUI design, although the number of MUI parameters this research considers is limited.

Most of the research in this area has been based on analysing context-aware computing that uses sensing and situational information to automate services, such as location, time, identity and action. More detailed adaptation has been generally ignored, input data based on context, for instance. In this paper, we focus on categories such as location, time, environment, user, task and object. These abstract notions of context need to be incorporated into MUI design, so that mobile context-aware tools can be provided to health care personnel in a hospital environment. One of the ways of achieving this is to consider what context means in this application domain.

3. Our Model of Context

In this section, we characterise the term *context* from the MUI designer's perspective, with a view to implementing an adaptable MUI. Let us look at a nursing scenario in a hospital ward, in which a task is performed by an actor using different objects. We define the vector <L, M, E> as the *basic context (BC), where L indicates a location, M indicates the time when the task was performed and E characterises the physical environment.* Zero or more of the basic context parameters might be relevant to the set of tasks performed in the domain of application considered. Each of these parameters in the basic context can be characterised by one or more features at a varying level of granularity. For example: the location can be a patient's room; the patient's bed; the emergency room; a transplant ward, etc.

We define the vector <A, T, O> as the *domain-based context (DBC) where A is an actor, T is the task performed and O indicates the target object.* Each of these parameters in the DBC can be characterised by one or more features. For example, the actor belongs to a user stereotype (a young nurse or a senior nurse, for example), and is characterised as such because we are interested in adapting the MUI to User Stereotypes. The actor (a nurse in this case) is playing a role (nursing, in this case), but that role may involve several tasks. The task *T* is obtained from the task model, where different methods could exist to perform the same task in a context with different context descriptors. The *informational object set* is made up of all the data objects on the MUI, e.g. patient recorded data. To narrow the domain in this paper, we have taken one task performed by one actor, and considered that as the domain for discussion.

Separating the basic context parameters from the rest of the context-defining parameters creates the possibility of creating a CIS (Pascoe [15]) to facilitate the sharing of context recognition among multiple applications running in different places in a large hospital. With our definition of context, we can create many levels of application (Figure 1). Level 1 is the BC, which is independent of the DBC, because it includes similar applications, whether or not they are mobile, that run in a particular location, at a particular time and under particular environmental conditions, light and audio, for example. The BC is acquired from the sensors installed in the smart phone. Level 2 is the DBC, which is dependent on the BC, clearly meaning the adaptation of mobile-based data entry rather than computer-based data entry, because the BC changes when the application is executed in the mobile , while in stationary case the BC does not. For example, when the user performs a task using a mobile device, the MUI will adapt the features based on the available BC, which is the handling context. Level 3 is the User Stereotype, and represents the user preferences and profile. The MUI will also adapt the features to the User Stereotype, as well as to the BC.

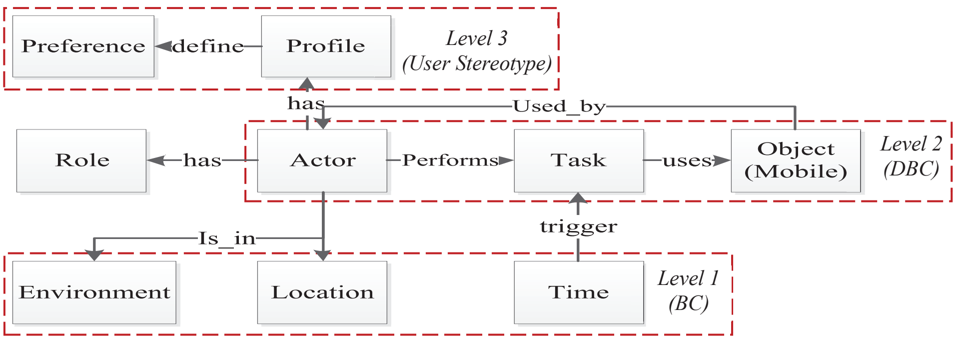

Figure 1 Characterisation of Context

4. Hospital Domain

A hospital is a sub unit of a larger health care system which can have an emergency unit, several hospital wards, specialised diagnostic or service divisions, and outpatient clinics. It can be viewed as a coordinated set of services, including physician consultation, examination, imaging, testing (blood, pulmonary function, etc.) and nursing, among others. Owing to the large volume of information and operations to be handled in hospital automation processes, the control and data management procedures that support information classification for decision-making purposes can become quite complex. In our research, we are focusing on the particular area of the hospital ward that involves **nursing services**. The relevant actors are: nurses, patients, physicians, pharmacists, orderlies, nutritionists and PCAs (personal care assistants). An actor can play many different roles, and so the relationship between roles and actors is many-to-many. All role-playing in hospitals involves both information-based actions (e.g. record-keeping) and skill-oriented physical actions (e.g. checking blood pressure).

Nurses spend considerable time at the bedside monitoring patients' vital signs. However, many of today's hospital applications are designed based on little empirical knowledge of nursing activities [29]. In a recent study, nurses had many physical demands made on them by having to use a COW (Computer on Wheels). This device weighed 67 pounds, and created issues with nurses' backs and hips [30]. Nurses have the most physically intensive contact with patients and need to be able to meet the demands of those patients in any situation**.** A mobile smart phone has been shown to be of significant benefit to these workers (at no cost to the user for extra sensors or devices), considering both their context and User Stereotype, and the ability to use the device anytime and anywhere in the hospital as a recording and display medium for patient information.

It is important to provide hospital workers with point-of-care access to information by bridging the gap between caregivers and the information they need using computer and network technologies. The EU-funded Ward-In-Hand project [31] was one of the early research efforts to investigate the use of mobile computers and wireless access to medical information at the point of care. More recent work has focused on the use of contextual features, like hospital workers' physical locations, to provide point-of-care access to relevant medical information, such as the MobileWard prototype [32]. In addition, there are many hospital scenarios in which UbiComp technology may prove helpful, such as [2], where the author focuses on designing a context-aware pill container and hospital bed, both of which react to what is happening in medical terms at the hospital, and adapt to it. The paper concludes that clinical work requires context aware clinical applications. However, that paper's focus on the context of patient beds in a defined zone, which constitutes the location entity, is limited, because the display of patient information will only function in the presence of a nurse within the zone. Our work, by contrast, will move beyond examining the infrastructure of a single zone by making it possible to adapt MUI features to the various input and output contexts of a nurse.

A 'sub-domain' scenario from a hospital ward

Consider one of the many roles played by a nurse, namely taking and recording vital signs, such as temperature, blood sugar, blood pressure, pulse, oxygen saturation, pain level, fluid in and fluid out, weight, and the healing status of a wound. The frequency of such recording in a single day depends on the patient's status. In a traditional system, the nurse notes down all the vital sign values on a piece of paper that she keeps in her pocket at all times, and later enters on a *nursing chart.* This chart serves as a medium of communication with other actors who need to share that patient information. Typically, a nurse on duty in a hospital ward looks after between two and six patients in a shift. Noting and copying the data of multiple patients can be a possible source of error, and sharing a paper document can be less reliable than sharing information electronically. In a modern hospital ward, there is usually a nursing station, along with a desktop computer accessible to all nurses for entering vital signs into shareable electronic records. An improved method would be to give a mobile device to every nurse on duty, which would allow them to enter the vital signs immediately, ideally at the point of care. This mobile device can also be used by a nurse to communicate instantly with other actors and to verify specific details about medications and medical care protocols in complex situations.

As we can safely assume that not all nurses are alike in a hospital setting, we have developed a number of *user models* to which they may belong. For example, a young graduate of a modern nursing programme might be very computer savvy and find it easy to learn a new application on a mobile device.

An experienced nurse who has some familiarity with computers might be willing to be trained and adapt to new methods of performing mundane record-keeping. A senior nurse with years of experience might be reluctant to change, and even be afraid of using mobile phone-based applications. It is important that developers take these models into consideration when developing MUI or context-aware applications for a hospital environment. It has been found that when they do not, user experiences are very mixed, and, as a result, this real-world technology may not be readily accepted [33].

5. Proposed approach for MUI Development

We propose a top-down approach in the beginning stages of analysis and development of a context model. In this section, we illustrate our proposed approach with an example.

Step 1: Establish the goal or sub goal G_{ij} of the MUI in a suitably bounded domain D_i. The simple, but non-trivial example we have chosen is that of nursing services provided in a hospital ward. Staying in the hospital domain, we include the user characteristics (through traditional user models, or User Stereotypes) as part of the MUI. The design goal is to develop an MUI for the nursing application (gathering vital signs) that is adaptable to the User Stereotype and to the context of the work.

Step 2: Conduct a task analysis and develop the set of tasks $\{T_i\}$ that each role will require in the selected domain of application. For example, $\{T_i\}$ could be: {enter the vital signs one at a time; upload the data; correct any mistakes that have occurred; send a Twitter message related to the work}.

Step 3: Perform a thorough requirement analysis and gather a set of *context descriptors*, denoted S_i, in the form of sentences or sentence fragments, that will form the basis for MUI adaptations. For example, S_i could be: {I am in an isolation ward; on the way to pick up something; my hands are not free; ambient light is too low; etc.}. In general, context descriptors can arise from a variety of sources, namely constraints to be satisfied, the physical state of an individual, etc. The user model can add context descriptors to the set S_i. For example, the stereotype U_j may add {I need large letters; I don't like being disturbed when my hands are not free; etc.}

Step 4: Determine, based on a clear understanding of the UI architecture, a set of adaptable features F_i. We include in the UI architecture such artifacts as: the UI's objects or widgets, the way individual screens are laid out, and the navigation sequence required to accomplish each of the Tasks $\{T_i\}$.

Step 5: Capture and formally represent the knowledge required for the MUI to self-adapt at run time, or to implement the adaptations at design time. Any suitable knowledge representation method known in the literature can be used for this purpose. Rule-based representation is one possibility.

Step 6: Enhance the user experience by establishing a trade-off between the costs and benefits of MUI adaptations. A UI is the link between the software system and the human user, and the software is a tool that helps a nurse perform her nursing tasks. He or she will become used to the particular way in which the UI performs. Any change in the form or behaviour of the MUI as a result of adaptation is a transitional inconsistency, and will represent a change in the nurse's routine. The following example explains how the adaptation of the MUI affects the context using our approach.

Example: Suppose a <u>nurse U_i</u> (a user belonging to the User Stereotype 1 class), performs <u>task (T_j):</u> enter the blood pressure (BP) of a patient, using an <u>MUI</u> on his or her smart phone which is always carried in the nurse's pocket. Our approach starts with the general goal: gather vital signs. Then, one task is defined, which is to enter the BP on the smart phone. This task can be performed using various methods, depending on our context model. Finally, determine the MUI features required for each method.

Context descriptor S_i is an instance of the context that allows the MUI to adapt directly based on recognition of the run time context. These descriptors are obtained at the requirements analysis stage.

For example, S_i could be: "I am in a patient ward containing a number of beds, taking BPs on the morning shift"; "I am in a patient ward containing a number of beds, taking BPs on the evening shift"; or "I am in a patient ward containing a number of beds, taking BPs on the night shift" (see Table 1).

In Table 1, each column represents a method, which is the way the user will perform the task based on his or her context, and, since we have more than one method for performing the same task and bearing in mind that the user belongs to the User Stereotype 1 class, the selection rules for these methods will be based on the match *Context value*. For example,

IF [C1] is a match, Then ADAPT MUI features which belong to Method 1
ELSE IF [C2] is a match, Then ADAPT MUI features which belong to Method 2
ELSE [C3] is a match, Then ADAPT MUI features which belong to Method 3

Table 1. Description of our example

Method	1	2	3
Task= Enter the BP	Step 1. Tap the patient's name Step 2. Tap BP Step 3. Enter the BP value by typing on the virtual keyboard Step 4. Tap Save	Step 1. Say the patient's name Step 2. Listen to the name Step 3. Confirm by tapping Yes or No Step 4. Listen to the choices Step 5. Say the choice number selected Step 6. Listen to the question: Enter the BP value Step 7. Say the BP value Step 8. Listen to the BP value Step 9. Confirm BP value by voice	Step 1. Tap the patient's name Step 2. Tap BP Step 3. Enter the BP value by typing on the virtual keyboard Step 4. Tap Save
Context (C)= ***<L, M, E, A, T, O>***	C1=*<L=Patient_Room, M=10:00AM,E=Bright_room, A=Nurse, T=Enter_BP, O=type_ by_ touch >*	C2=*<L=Patient_Room, M=8:00PM,:E=Low_Light_room, A=Nurse ,T=Enter_BP, O=say_by_voice>*	C3=*<L=Patient_Room, M=3:00AM,:E=Dark_room, A=Nurse ,T=Enter_BP, O=type_by_touch >*
MUI Adaptable features	Accept the data by typing on the virtual keyboard and Sound Control=On, Light=Normal Font size= Normal	Accept the data entered by voice	Accept the data by typing on the virtual keyboard and Sound Control=Off, Light=On, Font size=Large

It is important to remember, however, that we have to consider the user preferences in the adaptation of the MUI, if there is another User Stereotype class involved.

6. Conclusions and Future Work

A universal definition of context would not be viable. Consequently, every software engineer needs to clearly understand and characterise the context in question, and the goal of its development. We have introduced a new characterisation of context for MUIs in the health care domain, based on identification of the principles of concern that are relevant to MUI designers. The adaptations built into an MUI can enhance the acceptability of the technology in the health care domain, where diversity is inherent. We have analysed the benefits of context-based MUI adaptation, and find that they are the following:

- Increased usability, e.g. if the MUI only supports one interaction model, such as typing or voice input/sound output, the usability of the service would be drastically decreased.
- Increased awareness of social ethics, e.g. in a quiet, multi-bed unit after midnight, when the patients are asleep and the nurse needs to enter vital signs, sound based interaction, such as voice input and sound output for call notification, could be an obstacle and disturb other patients. In this case, the sound could be turned off automatically.
- Improved workflow productivity, by reducing redundancy and repetitive tasks, like noting data on paper to be entered later onto a PC. Enabling nurses to enter vital signs immediately, preferably at the point of care, would allow them to be more efficient and productive.
- Improved level of attention, e.g. if the patient's result is outside of the normal range, this would be recognised by the MUI adaptation and the nurse notified based on his or her context.

Architectures and field-testable prototypes are currently under development as part of the ongoing doctoral work of the first author. The proposed approach for designing UI for mobile applications based on our context model will be validated using a controlled experiment.

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