

# Toward Context-Aware Computing in Clinical Care

Position Paper

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## Introduction and literature review

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In recent years, new mobile and wireless information technologies (IT) such as personal digital assistants (PDAs), ultra-portable sub-notebooks, smart phones, tablet PCs, Web pads, and wristband computers have become broadly available in the market place. A key driver behind adopting such wearable computers is the hope that they will make important information accessible independently from the user's location. Health care is one of many information-intensive business domains that hope to benefit from mobile, wireless IT. Today, larger health care organizations employ an IT-based infrastructure to maintain clinical information. However, the delivery of services at the point of care (POC) is still largely based on paper records and forms. Our collaborator, the Victoria Hospice, is one of numerous organizations that have conducted trial studies on the viability of adopting mobile IT at the POC. Most of these studies have shown only limited success and few of them have resulted in a permanent adoption of the technology: Carroll et al. conclude with a list of four major advances "needed to make PDAs more usable with an EMR (electronic medical record)", two related to difficulties of data input and output [CST02]. Rodriguez et al. conclude from their formal usability experiment [RBS+04]:

*"The results of this study suggest that limitations of the user interface of the PDA had a significant effect on the performance of the physicians and their user satisfaction. Its small screen and in particular its text input modalities are key elements of the user interface that affect physician performance and user satisfaction. Unless text input modalities are improved, user interfaces on the PDA should be designed in such a way that text entry is minimized."*

In a recent paper, Grasso suggests to make handheld devices location-aware in order to attain the above-stated goal of minimizing data entry at the POC [Gra04]. User needs related to location-aware mobile services are analyzed by Kaasinen [Kaa03], who states "an efficient way of improving the usability of mobile services and applications is to adapt the contents and presentation of the service to each individual user and his/her current context of use". Kaasinen points out that location awareness is merely one form of context-awareness.

Among the various ways of defining the term context we adopt Dey's definition as "any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves" [DSB01].

Bardam et al. explore context-awareness for smart user authentication in health care applications [Bar03]. Their research is motivated by observed usability problems with PDAs and conventional authentication schemes (login/password challenges). Bardam's system architecture involves a central context server that evaluates the usage context of individual users (such as their location) and invokes different authentication schemes. For example, a location inside a restricted area may require a less strict (and more user-friendly) form of authenticating.

Although the term context-aware (CA) computing has been adopted broadly only in the late 90's, research on CA systems has its roots in the discipline of ubiquitous computing (UC), as pioneered by Weiser [Wei91]. Backed by major industrial organizations (e.g., IBM) and professional associations (e.g., IEEE), the term pervasive computing has been introduced more-or-less with a meaning synonymous to UC.

Current research on CA systems falls roughly in four categories: (1) research on CA applications including empirical studies,

(2) research on CA system architectures and frameworks, (3) research on the modeling, storage and retrieval of context information, (4) research on context identification and inference. The following subsections summarize the state of knowledge in these areas.

## CA Applications

An increasing number of papers describing various prototype applications of CA technologies have been published. Many of these applications are in areas of electronic commerce, telecommunication and transportation. They make use of the fact that digital cellular phones have been broadly adopted in many industrial societies and telecommunication companies are able to determine the location of a phone user with great precision (within several feet). Kaasinen discusses and evaluates the use of location-aware, targeted advertisement and other services using cellular phones [Kaa03]. Carrega et al. present a similar application using GPS-based navigation systems in automobiles [DGH01]. Today, location-aware eCommerce technologies are starting to become available for consumers. Research in this area now concentrates on privacy and security issues and on mechanisms to enable users to customize the behavior of CA devices according to their preferences. For example, Quigley et al.'s BlueStar system enables users to control the level of granularity by which location information can be used for CA applications [QWO04]. CA applications in health care mostly focus on specific concerns other than the actual interaction with electronic medical records (EMR), such as caregiver authentication [Bar03] and the guidance and monitoring of patients with disabilities (e.g., vision impairment) or elderly persons [HWL03]. At the Aarhus Centre for Pervasive Healthcare, Bardam is one of the pioneers to explore CA applications integrated at the POC in a hospital-like environment [Bar04]. While his technology has not yet been evaluated in a real hospital setting, he has carried out several workshops with clinicians acting in typical care scenarios and accessing a CA EMR. His results indicate that "*context-awareness is particular useful for user-interface navigation*" [Bar04]. We base our research on the recommendations and principles published by Bardam and others. However, we intend to go one step further by implementing and evaluating CA services within a real health-care environment.

## CA System Architectures and Frameworks

Several research groups have proposed architectures and frameworks for context-aware systems. Dey's Context Toolkit is one of the earliest frameworks introducing reusable Java™ components such as context sensors, aggregators, interpreters, etc. [DSB01]. The Solar framework by Chen and Kotz highlights the description and dissemination of context information in a distributed network [GK02]. Siljee et al. propose a classification of architectural patterns for CA systems based on application requirements [SBN04]. Gu et al. present a middleware infrastructure for CA applications (called SOCAM), including components such as context providers, context interpreters, context databases, CA applications, and service locators [GPZ04]. SOCAM is based on the Open Service Gateway initiative (OSGi) standard. Jahnke et al. investigates Web portal architectures (such as JSR 168 compatible portal servers) as a platform to create CA Web information systems [JBD04].

## Modeling, Storage and Retrieval of Context

Early CA systems used simple type-value relations to represent context information, e.g., [DSB01]. Current approaches suggest using formal ontologies as a common schema for representing context information. Gu et al., Jahnke et al. and others have adopted the standardized Ontology Web Language (OWL) as formalism for specifying context schemas [GPZ04, JBD05]. They also point out there is an application-specific and an application-independent part to a context ontology. The application-independent part comprises concepts such as actors, locations, time and spatio-temporal relationships among them. The domain-dependent part varies from one application domain to the next. Jahnke et al. adopt concepts from the HL7 Reference Information Model (RIM) for this part of his ontology. Efficiency of storage and retrieval of context information is key to many real-time applications. Mokbel et al. investigate the complexity of retrieval operations on context databases, including spatio-temporal queries, queries on transient objects and queries on stationary objects [MAH03]. They propose a concept of sharing to achieve greater scalability. Jahnke et al. propose a garbage collection scheme to remove context information from a database that is no longer needed [JBD05].

Vajirkar et al. describe a data-mining approach to uncovering patterns based on a predefined context ontology in the area of health care [VSL03]. They distinguish between four different types of context: (1) the domain context, which is centered on patient profiles, (2) the location context, centered on the region patients live in, (3) the data context, centered on a particular type of data (e.g., cancer), and (4) the user context, centered on the clinician entering and querying the data. The focus on particular contexts help to reduce the complexity of multidimensional data mining and guides the data analysis process. In their paper on metarule-guided mining of multi-dimensional association rules, Kamber et al. point out the importance of such guidance, in order to produce sensible association rules [KHC97].

## Context Identification and Inference

The majority of research in context identification is concentrated around localization. Wide-area localization mechanisms (e.g., using cellular networks or GPS) is out of scope of our project and will not be discussed here for reasons of conciseness. Local-area localization can be based on various technologies, such as triangulating the signal strengths of wireless access points [LBM02]. The difficulty with these approaches is that the wireless signal strengths tend to fluctuate significantly based on the positioning of furniture (e.g., hospital beds), the state of doors (open vs. closed) and the presence of human bodies in the building. Ladd et al. point out that efforts in constructing mathematically precise radio frequency propagation models for the purpose of localization have thus been largely unsuccessful so far [LBM02]. Instead, they propose a machine learning technique based on Bayesian networks. The main advantage of localization based on WiFi infrastructure is that this solution does not require additional sensor infrastructure. Niculescu and Nath suggest that the accuracy of WiFi-based localization can be improved by equipping wireless base stations with directional antennas in order to compute an angle of arrival (AOA) for roaming users [NN04]. Even more accurate localization can be achieved by deploying additional active or passive wireless sensors [AS04]. Sensors can also be used for identifying relative locations, e.g., the proximity to another entity.

Context inference algorithms are used to combine the various low-level contextual facts and to infer composite contextual situations. Mokbel uses relational database queries to retrieve composite contexts [MAH03]. Gu uses a first-order logic-based query calculus [GPZ04], while Jahnke uses programmed graph rewriting systems [JBD05, SWZ95].

## The envisioned target application in End-of-Life-Care

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The target application for our research is developed in close cooperation with the School of Health Information Science at the University of Victoria and the Victoria Hospice Society (VHS). Funding for the research initiative has been granted by Telus Inc. and the National Science and Engineering Research Council. The Victoria Hospice is currently installing a wireless information infrastructure that will enable clinicians to use PDAs and tablet PCs at the POC for the purpose of data entry, decision support and reporting.

Previous experiments with electronic data capturing at the POC conducted within VHS have been abandoned largely due to the limited usability of PDAs. Cumbersome data I/O and difficulties in navigating small screens have slowed down the care process to an unacceptable rate. Moreover, clinicians criticised that they did not see an immediate benefit from the data collected, i.e., there was no easy and fast way to access reports from the mobile device. Our objective is to develop and evaluate an infrastructure that compensates for these limitations by minimizing the necessity for information input and

navigation. Figure 1 gives a conceptual overview on the architecture of this infrastructure. It shows the (pre-existing) VHS database on the left-hand side. The PDAs/tablets and their Web server is shown on the right-hand side.

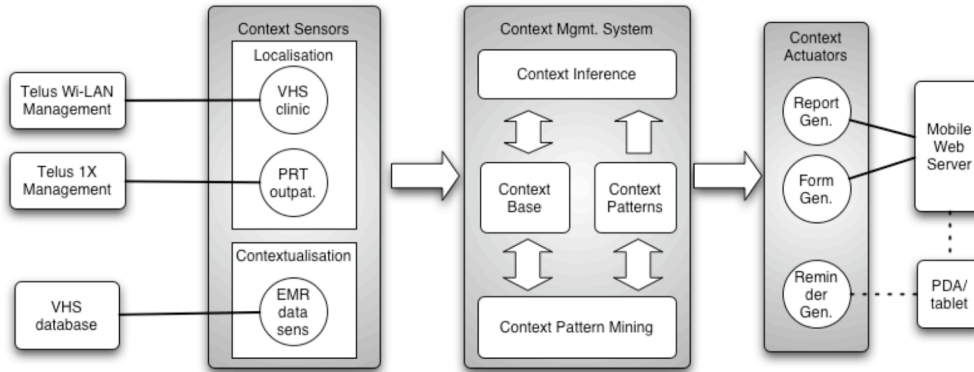


Figure 1. Architecture

The three core components to be developed and evaluated are rendered in grey and entitled *Context Sensors*, *Context Management System*, and *Context Actuators*.

## Context Sensors

This component is composed of three subordinate software components with the task of importing context information from the VHS database and information about the localization of mobile users. Two different localization sensors are envisioned to support inpatient care, as well as outpatient care. Inpatients are patients residing at the hospice while outpatients are palliative patients still living with their families and in their homes. The VHS has a mobile Palliative Response Team (PRT) and nurses that visit outpatients regularly and in case of an emergency. Wireless access information access inside the hospice will be based on a 802.11g network of base stations that are centrally managed by a Telus WiFi LAN management server. Telus has recently conducted signal distribution measurements at the VHS facilities to map out the distribution of access points. The VHS clinic localization sensor will use information from this Telus server to infer indoor localization information. We will implement and compare existing adaptive localization algorithms (e.g., [LBM02]). If the resolution achieved will turn out to be too coarse, we will augment the localization system with wireless Bluetooth beacons. This augmentation can be done fairly inexpensively, since modern PDAs and tablet PCs have Bluetooth capabilities built-in. There exists a body of research results on localization algorithms based on triangulating WiFi signals, or by using sensor beacons, respectively. A combination of both approaches to augment and enhance existing wireless infrastructure with precise localization capabilities has received little attention so far. We believe that we can break new ground in this area by creating algorithms to compute the distribution of beacons to maximize the precision of localization at locations that need a fine resolution (e.g., patient rooms) vs. other locations that do not need this level of precision (e.g., the cantina).

The localization sensor for outpatients simply accesses the geographical localization information delivered from the Telus 1X mobile network and maps it to an address database of outpatients.

The contextualization sensor queries data from the VHS database(s) about patient EMRs, their care history, guidelines, medication and other related information.

## Context Management System

The context management system consists of four components, (1) a context base as a repository of context information, (2) a set of context patterns representing rules that govern the delivery of information dialogues in particular contexts, (3) a context inference engine that matches context patterns against the data contained in the context base, and (4) a context pattern mining tool that analyzes the context data collected during device usage in order to elicit usage patterns. Not shown in the infrastructure diagram (Figure 2) but important for the realization of the context manager is the context ontology, a formal model describing the concepts considered in the context manager [VSL03]. We will model the domain-specific part of our context ontology after the HL7 Reference Information Model (RIM) [DAB01]. The domain-independent part of the context ontology covers spatio-temporal concepts of the physical world related to space and time.

We have already implemented our context ontology within a relational DBMS, which will serve as the context base. The context-pattern mining tool will be implemented as an adaptation of Kamber's algorithm on mining data cubes [KHC97]. Context patterns will then be described as spatio-temporal queries against the relational schema. If necessary for scalability reasons, we will implement shared object optimization strategies as proposed by Mokbel et al. [MAS03]. We believe that mining patterns for context-aware user-interfaces based on recorded usage data has great potential for providing more intelligent, user-centric Web information systems.

## Context Actuators

The purpose of context actuators in our infrastructure is to present mobile device users with the right information dialogues in the right context. The actual rendering and serving of information dialogues is performed by a mobile Web portal server, which we will use as an off-the-shelf product. Web portal servers are advanced Web servers that use portlets to render information dialogues. We will use a Web portal server based on the JSR 168 portlet standard, such as Sun Microsystems Web Portal Server or LifeRay. Portlets are customizable information dialogues defined with Java. We will define portlets for data input and reporting forms as developed by health information scientists (CPS, PPS, PPI, PaP, and ECOG-PS) [Lau05]. The Report Gen. and Form Gen. context actuators will use the context manager to determine in which situation to present which portlet. Moreover, the actuators will automatically fill in context facts such as the current patient's identity, the current location, time, the nature of the encounter etc. In addition, the actuators will adapt the user interface to the specific device used. This can be done by using the Web portal server's ability to render portlets in minimized or maximized view, utilizing different real estate on the screen. The third actuator (Reminder Gen.) has the ability to send instant messages to mobile devices in order to remind caregivers of particular concerns, e.g., when a patient has not yet received her medication.

While context actuators will attempt to generate the user dialogues that are most appropriate in any given situation, the user will still have the ability to override this selection in order to access other dialogues. These "overriding" actions will be recorded in the context base in order to evaluate the existing patterns and refine them.

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