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## Review

# Context awareness in health care: A review

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### ABSTRACT

**Background:** Health care systems will integrate new computing paradigms in the coming years. Context-awareness computing is a research field which often refers to health care as an interesting and rich area of application.

**Aim:** Through a survey of the research literature, we intended to derive an objective view of the actual dynamism of context awareness in health care, and to identify strengths and weaknesses in this field.

**Methods:** After discussing definitions of context, we proposed a simple framework to analyse and characterize the use of context through three main axes. We then focused on context-awareness computing and reported on the main teams working in this area. We described some of the context-awareness projects in health care. A deeper analysis of the hospital-based projects demonstrated the gap between recommendations expressed for modelling context awareness and the actual use in a prototype. Finally, we identified pitfalls encountered in this area of research.

**Results:** A number of opportunities remain for this evolving field of research. We found relatively few groups with such a specific focus. As yet there is no consensus as to the most appropriate models or attributes to include in context awareness. We conclude that a greater understanding of which aspects of context are important in a health care setting is required; the inherent sociotechnical nature of context-aware applications in health care; and the need to draw on a number of disciplines to conduct this research.

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## 1. Introduction

Health care will evolve as new technologies are adopted. Even if it is difficult to predict what the future hospital will be, aspects such as context awareness will help health care professionals to shift part of their activities to machines. Reinvention of health care [1] is complex. In this paper, we aim to outline difficulties and possible solutions in the area of context awareness in health care.

Even with the ongoing increase in hospitals use of computerized tools (e.g. powerful hospital information systems, connected laboratory results) these tools are not sufficient and new technologies should support a new way of envisaging the future hospital. The future intelligent hospital will be deeply different from the current one. The introduction of future tools leads to challenging research problems [2-9]. First, such an evolution requires new technologies and new architectures to implement secure and reliable systems. It requires the identification and evaluation of what could be done, for what purpose and how this could be implemented. It could also induce new social or political problems in relation to privacy concerns or acceptance of such systems.

Our focus is on identification, evaluation and implementation of new tools or services for the communication and the cooperation of health care professionals.

Communication between health care professionals represents a large part of their activity [10,11]. This communication, direct or indirect, ranging from laboratory results to complex consultation and advice, is important and useful but at the same time induces many interruptions. This complicates the cognitive activity of the health care providers. Cooperation of health care professionals is indispensable to care, but problems with transmission of information between them still induce breakdowns in communication [12,13]. Errors, which sometimes lead to the death of a patient, have been described in US hospitals [14], and obviously exist in all hospitals.

Cooperation between health care professionals can be increasingly mediated through computerized platforms (e.g. hospital-GP intermediation platforms, homecare coordination platforms, etc.). These coordination tools will integrate new mobile tools and propose new communications abilities [15].

In particular, current technologies allow the introduction of context awareness in every day activities.

Context awareness is a concept that has been described for some time, but technologies (e.g. wireless technologies, mobile tools, sensors, wearable instruments, intelligent artifacts, handheld computers) are now available to support the development of applications. Such technologies could help health care professionals to manage their tasks while increasing the quality of patient care. Nevertheless, new technologies impact the communication between agents. In his paper "Interaction design", Coiera [16] presents a framework for the design of interactions between human and computational agents working in organizations. He describes the impact of a new interaction class (in this discussion, a class that would include context-awareness applications) within an organization. The introduction of a new interaction class will impact the level of interaction and communication by agents in terms of costs and benefits to individuals. When designing new interaction classes, one aim is to ensure optimization of benefit versus cost to individuals.

Health care systems could integrate context-awareness computing, not only to explore new tools but to propose useful and acceptable systems.

Intensive care units (ICU's) contain complex health care situations and are a challenging area for such systems. A number of researchers have underlined this context of work as particularly relevant to the evaluation of complex tools assisting the cooperation between workers [17-19]. The medium term perspective of our research is the definition of a set of requirements for the use of context-awareness tools in the ICU.

Our preliminary work consists of the review of context awareness in health care, and is presented in this paper.

### 1.1. Aim of the paper

Through a survey of the existing literature in context-awareness computing, we intend to discuss the most relevant research relating to health care.

Section 2 presents a brief state of art on what is context, then proposes a framework for the analyses of the context representation, in order to perform this review of the context-awareness projects in health care. Section

3 briefly proposes a definition of context-awareness computing. Section 4 focuses on context-awareness computing in health care: it presents some of the more relevant teams in this area, then describes the main health care projects developed in such a topic. Section 5 presents the challenges linked to such project: it analyses existing research on hospital context awareness for health care and describes how closely such existing prototypes or applications match the above recommendations, then it mentions the main pitfalls encountered in context-awareness computing area. Section 6 gives a summary and a conclusion of this survey.

## 1.2. Methodology used for developing context-awareness analysis

Major electronic research databases (Medline<sup>1</sup> through PubMed, scientific journals via their own sites or Science Direct) as well as a web search engines (Google predominantly) were used to identify research published in the area of context awareness (and related fields) and health care.

A selection strategy was formulated by the authors focusing on research themes of (i) a proposed general framework for context awareness or (ii) "health care AND context awareness". Main conferences in this domain were identified and reviewed, and related references of the main papers studied. The search was broadened to connected areas of research such as ubiquitous or pervasive computing if used in the context of health care.

## 2. What is context?

The concept of context intersects with a diverse range of research (e.g. artificial intelligence, ontology, knowledge representation, etc.). We do not intend to perform a complete review of what is context in this paper, interested reader might refer to Brezillon's work [20], but we report on definitions, elaborated by people working on context-awareness computing to produce the required framework that could be used for the review of the existing researches on this topic.

### 2.1. Definitions

It is not obvious to define context—Dey et al. [21] proposed a definition of context which is the following: "Any information that can be used to characterize the situation of entities (i.e. whether a person, place or object) that are considered relevant to the interaction between a user and an application, including the user and the application themselves. Context is typically the location identity and state of people, groups and computational and physical objects". But Dourish [22] argued that there is an incompatibility between two views of context. One comes from positivist theory—context can be described independently of the actions done; the definition

proposed by Dey matches this view. Another view can be sustained by phenomenological theory—context emerges from the activity and cannot be described independently. Some similar remarks are made by Winograd: "something is context because of the way it is used in interpretation" [23]. Faced with the complex notion of context, Sato proposes to represent context through "a pattern of behavior or relations among variables that are outside of the subjects of design manipulation and potentially affect user behavior and system performance" [24].

### 2.2. Analysis framework

Using those perspectives, we proposed a simple framework to analyse the use of context in health care applications, choosing three main axes to characterize context. These axes refer, respectively, to the following questions: What context is used for? What are the context items of information? Are the context features invariant and if no, how is it possible to organize them?

- Purpose of use of context:
  - According to Dey et al. [21], context is used in three main cases: (i) presentation of information and services to a user, (ii) execution of a service and (iii) tagging of context to information for later retrieval.
- Items for context representation:
  - Through the analyses of the health care context-awareness projects, it is possible to describe the items of context used. Synthesising our view of the literature we examined, we identified three main classes to split items of context into: (i) people, (ii) environment and (iii) activities.
- Organization of context features:
  - Recent literature highlights the complexity of the features of context. Context representation is not only splitted on the further two axes mentioned above, but should be organized in more sophisticated ways. Different organizations are then proposed. We identified further refinement of the organization through consideration of the following:
    - A hierarchical organization, which draws on from general to local aspects of context, or from generic to specific aspect [25] "activities and the contexts that surrounds them do not exists in isolation, but rather in cascade, following the structure of activities from the general to the specific".
    - An organization according to the dimension of concept [26]: internal aspect of context (mood of the user, state of the device), or external aspect (temperature, time, etc.).
    - An organization according to the focus of the current activity, leading to consider context with different levels of granularity [27].
    - An organization according to the current usefulness of context: manifesting aspect (relevant for current action), or latent (non-relevant for current action) [34].

In our analyses of health care project, we mentioned the existence of such an organization of the context features if it exists.

<sup>1</sup> Medline: National Library of Medicine's premier bibliographic database covering the fields of medicine, nursing, dentistry, veterinary medicine, the health care system and the preclinical sciences.

### 3. What is context-awareness computing?

Context-aware computing can be defined as “an application’s ability to adapt to changing circumstances and respond according to the context of use” [45].

This notion is anything but simple, and implementing such an application will raise challenging issues. We refer to Satyanarayanan’s work [27] to present issues linked to context awareness. We report them, as described in Table 1.

Definitions of models and architectures able to support such applications are still an area of active research and consensus has not been reached. Some problems to be addressed relate to equipment (e.g. networks, captors, artifacts, mobile communication). Others concern security, especially important in the medical domain (e.g. identification, authentication, availability, integrity, confidentiality). Our focus is on context-awareness research relevant to health care.

### 4. The “research context” of “context-awareness computing in health care”

The use of handheld computers has been increasing in many health care applications—Medline, for example, uses “computer handheld”, as a new indexing term of the MeSH thesaurus. This term was introduced in 2003 and retrieves more and more papers on this topic: about 250 papers in May 2004 and more than 400 in January 2005. Many researchers focus on improving the mobility of health care professionals.

Other new computing paradigms also support research in this area. In fact, there are several research themes which share similar concepts: context awareness, ubiquitous computing, embedded computing, pervasive computing, sentient computing and others. Even though these terms are well-known in the field of computer science, their use in medical applications is quite rare. Nevertheless, this research area is attractive enough to have spurred workshops or topics as part of international conferences (e.g. “Pervasive Computing in Health Care”, Pervasive Computing 2002; “Building Bridges: Interdisciplinary Context Sensitive Computing and Mobile Computing in Medical Context”, Glasgow 2002; “Ubiquitous Computing for Pervasive Health Care Applications”, UbiComp 2003; and CFP “Pervasive Health Care” in a special issue of the *IEEE EMBS* journal (end 2003)). A search using Medline on those keywords is an indicator of the current trends: [Medical Informatics] (mesh term) and “mobile” (respectively, “ubiquitous”, then “pervasive”) retrieves 375 (respectively, 135, then

52) papers in January 2005. We must be aware of the weakness of such simple indicators but it highlights the interest in this area of computing in medical informatics.

#### 4.1. Main research teams and their projects

This section presents some of the main research teams working on the topic of context awareness. We summarize different research teams focus in Table 2. For each team, we indicate trends in their main area of research (e.g. computer sciences or social sciences); how much they elucidate a definition of context; their involvement in the definition of an architecture or framework; if they are proposing an application or prototype and their involvement in medical applications.

The reader is referred to Chen and Kotz [28] and Korkea-aho [29] for surveys of context-awareness computing research and for a more detailed description of some applications. A good overview of the issues in this domain can be found in “Context-Aware Services State-of-the-Art” [30] (WASP Dutch project).

Even though most of the general papers on context awareness indicate health care as an important and promising field of research, the majority of laboratories we identified are essentially involved in computer sciences research. Health care, if it exists, appears as one of their interests for a potential testing area of the proposed frameworks or tools.

Only a few laboratories were identified in the literature as being involved in context awareness dedicated to health care research. The Centre for Pervasive Health care, in Denmark, is completely dedicated to this research and The University of Irvine examines social aspects of context awareness in health care.

#### 4.2. Description of health care context-awareness projects

The following section will detail some of the context-aware medical applications proposed in the literature. First, we describe the context-awareness projects, and then we use the main characteristics of context awareness, as identified earlier in this paper, to describe how these projects deal with context.

##### 4.2.1. Application

4.2.1.1. *Vocera communication system—experimentation in St. Vincent hospital, Birmingham, USA* [48]. The Vocera communication system is a communicator badge system for mobile users. It is a wearable badge with a push-to-call button, a small text screen and versatile voice-dialing capabilities based on

**Table 1 – Issues in context awareness from Satyanarayanan [27]**

Implementing a context-aware system requires many issues to be addressed. For example:

- How is context represented internally? How is this information combined with system and application state? Where is context stored? Does it reside locally, in the network, or both? What are the relevant data structures and algorithms?
- How frequently does context information have to be consulted? What is the overhead of taking context into account? What techniques can one use to keep this overhead low?
- What are the minimal services an environment needs to provide to make context awareness feasible? What are reasonable fallback positions if an environment does not provide such services? Is historical context useful?
- What are the relative merits of different location-sensing technologies? Under what circumstances should one be used in preference to another? Should location information be treated just like any other context information, or should it be handled differently?

**Table 2 – Trends in context awareness**

	Some of the projects	Focus area	Definition of Ctxt	Framework	Prototype	Medical application	People
USA—MIT Media Lab [31–33]	Several Media Lab projects: Oxygen, Intelligent Room	Comp. S.	++	++	+++		Selker; Burleson. Intille; Boa. Rondoni
USA—University of California, Irvine [22,34,35,26,8]	Information needs in HealthCare	Comp. S., Social S., Medical Info.	+++	+	+++	+++	Dourish; Fisher; Reddy; Gonzalez
USA—Georgia Institute of Technology [21,36]	Aware Home Ctxt Toolkit	Comp. S.	+++	+++	+++		Dey; Abowd. Mahaney; Pierce
USA—Carnegie Mellon University, Pittsburg [37,27]	AURA: distraction-free ubiquitous computing	Comp. S.	++	+++	+++	+	Fogarty; Smailagic; Siewiorek Satyanarayanan
USA—Institute of Technology, Chicago [24,38]		Design Comp. S.	+++	+++	++	+ (scenario)	Sato; Lim; Swanson; Galvao
USA—Stanford University [23]	Sandford Interactive Workspaces Project	Comp. S.	+++	+++	+++		Winograd; Fox; Johanson; Hanrahan
USA—Palo Alto Research Center [39]		Comp. S.	++	Design principles			Bellotti; Edward
USA—Darmouth College, Hanover [28]	Center for Mobile Computing	Comp. S.	++	+++	++		Chen; Kotz
Australia—University of Sydney [40]	Merino	Comp. S.	++	+++	+		Kummerfeld; Quigley
Australia—DSTO C3 Research Center, Canberra [25]		Comp. S.	++	++			Prekop; Burnett
UK—University of Cambridge [41]	QosDREAM + concept of “intelligent hospital”	Comp. S.	+	+++	+	+ (one/a lot)	Mitchell; Spiteri; Bates; Coulouris
Denmark—Centre for Pervasive Healthcare, Aarhus [42–44]	ISIS: Interactive Hospital; CIT ContextIT project; CfPC pervasive computing for the future hospital.	Medical Info., Comp. S., Social S.	++	+++	+++	+++	Bardram; Christensen; Bossen; Nielsen
Denmark—Aalborg University [45]	MobileWARD	Comp. S.	+	++	++	++ (want to develop that topic)	Skov; Kjedskov
Mexique—CICESE, Mexico [46]	Ensenada, Mexico	Medical Info.	++	++	++	+++	Munoz. Rodrigez. Fevela; Martinez Garcia + Gonzalez from USA
Italia—Applied Technologies for Neuro-Psycho, Milano [47]	European VEPSY project	Medical Info.	+			+	Riva

References and names are those directly cited in this paper. General trends and project name referred to general description of the teams (mainly from their web sites).

speech recognition. It allows hand free conversation: hand free answer to calls, and voice message if there is no answer. It is biometrically secured with speaker verification. It delivers information directly to the users and avoids the need to go to a distant device (phone, PC).

#### 4.2.2. Hospital-based prototypes

4.2.2.1. *Hospital of the future—Centre for Pervasive Health care, Denmark [42,43]*. A context-aware prototype is proposed, including:

- A context-aware hospital bed with a built-in display which can be used by patient for entertainment (e.g. for viewing television) and by clinicians for accessing medical data. The bed “knows” who is using it, and what and who is near it.
- A context-aware pill container that is “aware” of the patient, and reveals itself when near the patient (by lighting the proper container with the name of the patient).
- A context-aware Electronic Patient Record.

The bed “knows” the nurse, the patient and the medicine tray, and displays relevant information according to this context, such as a medicine schema or patient record.

4.2.2.2. *Intelligent hospital software—University of Cambridge, UK [41]*. Following a study of the needs at the Accident & Emergency Department of the Royal London Hospital, the authors proposed scenarios of use (remote consultation, tracking of patients and equipment, notification of awareness and patient data) and have implemented an experimental prototype. The prototype allows localisation of a team member and the ability to initiate an audio–video conference from the nearest point. Clinicians are localised, are notified of the call and can acknowledge the call through their active badge. This prototype is presented as a demonstrator of the middleware platform QoS DREAM, for reconfigurable multimedia streaming and event-based programming.

4.2.2.3. *Context-aware mobile communication—CICESE, Mexico [46]*. The idea of this project is to empower mobile devices to recognize the context in which hospital workers perform their tasks. In particular the authors propose an extension of instant messaging to add context awareness as part of the message such as circumstances that must be satisfied before the system delivers the message. Contextual elements used include location, delivery timing, role reliance, artifact (particularly the device) location and state. A prototype is proposed, which is able to provide contextual messaging, for example, “a message for room 226 to any physician, delivery time for the message today after 2 p.m.”.

4.2.2.4. *MobileWARD—Mobile Electronic Patient Record, Aalborg University, Denmark [45]*. MobileWARD is a prototype designed to support morning procedure tasks in a hospital ward, and is able to display patients lists and patient information. The device presents information and functionality according to the location of the nurse and the time of the day. This project simulates the context events linked to the location of the staff member. Patients are chosen through a patient-list or an activation of a barcode at the bed-side.

#### 4.2.3. Other prototypes

The above projects are hospital based. Other specific projects exist, more in the domain of pervasive health care.

*Some deal with medication consumption:*

Fishkin and Wang [49] propose to assist medication given at home: a pad is designed to detect when a bottle of medication is lifted off and put back, which bottles are moved and how many pills are removed. Information such as how many pills to take, and post-medication suggestions are displayed behind the pad. Floerkemeir and Siegemund [50] propose smart blister packs: equipped with sensors, they are able to detect the removal of the pills. The patient will receive a reminder on his mobile phone if it is detected that he has not taking the prescribed medication.

*Some deal with distant monitoring:*

Korhonen et al. [51] propose a social alarm for elderly based on wearable sensors (a wrist unit—detection of movement) and intelligent monitoring (IST Vivago System®).

*Some are new assistants:*

Helal et al. [52] propose to combine Java smart phones and smart home to provide assistance for elderly patients (mobile patient care giving assistant, general reminder system, augmented awareness: notification of events such mail delivery, water leak, etc.). Mihailidis et al. [53] present an assistant during hand washing for adults with dementia.

#### 4.2.4. Scenario

4.2.4.1. *Representation of context for a hospital information system that uses PDAs to deliver patient information to doctors—Institute of Design, Chicago [38]*. The team presents a simple example in a medical setting to show how context could be described by combining contextual information from the hierarchy of environment (hospital room), person (patient) and activity (doctor–patient status discussion).

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## 5. What are the challenges?

Context-awareness computing is still challenging. In this section, we focus on three major aspects of such challenges:

The first one is that we did not find any recommendations about the functional needs of the context. The second one concerns the gap which still exists between fundamental researches on context representation and actual context-awareness prototypes. We present these points through a deeper analysis of the hospital-based projects mentioned above.

The last point deals with the difficulties in building efficient computerized systems for a mediation of human perspectives. We develop that point through a presentation of some pitfalls mentioned in literature and encountered in context-awareness computing.

### 5.1. Actual characteristics of context-awareness application at the hospital

Table 3 summarizes the characteristics of the hospital-based projects described above. The second column describes the

**Table 3 – Analyses of the hospital context-awareness projects**

	Type a	Use b	Settings	Activity features	People features	Environment features	Is context organized	Description of the project
Pervasive Healthcare Project (Bardram)	M P S	Pi	Hospital PDA artefacts PC	Yes (on physical artifact)	Patient ID, professional ID/role	Medication, location artefacts	No	Context-aware pills container, context-aware bed
MobileWARD (Kjeldskov, Skov)	P	Pi	Hospital mobility PDA	No	Professional ID/role status of patient	Simulated location time	No	Mobile EPR
Context-aware mobile communication in hospital (Mexico)	M P S	Pi	Hospital mobility PDA, PC, printer, artifact instant messaging	Artifact state	Role reliance, identity recipient	Location timing artifact—location	No	Handheld with alerts, information on clinical patient record, alert instant messaging with contextual delivery
Follow Me video application, QosDream FmWk Accident & Emergency Department (UK, Mitchell)	M P S	Pi	Hospital active badge micro speaker, video touch sensitive screen	Idea of what people are doing	Professional ID	Staff patient and artifact location	No	Location through active badge, audio–video conference
Context-influence framework (Swanson, Chicago)	M S			Doctor–patient status discussion	Patient attending physician	Hospital room	Yes but only a scenario	Combination of contextual information generates list of influences which affect the use of the sub-system
Vocera Communicating System (Vince, 2003)	A	Pi	Hospital mobile device		Professional ID/role	Location	No	Communication system with speech recognition (dialing), speaker identification

type of work done (proposed model (M), prototype (P), application (A) or scenario (S)). The third column describes the use of context according to the first axe of categorization presented in Section 2.2 (presentation of information (Pi), execution of services (ES), storage of contextual information (SI)). Columns 5–7 are used to describe the different features of context manipulated by the system, in the three main classes described for the second axe of Section 2.2, i.e. activity, people and environment. The eighth column refers to the third axe of Section 2.2 and describes if the context is organized through a categorization. The last column describes briefly the objectives of use of context awareness.

Most of these projects are prototypes and real applications are still difficult to find. This is obviously due to the difficulty of managing a distributed and complex system for context awareness. If we look more precisely at the context, we can remark that:

- We can find explanations on how the situations are managed, but it is more difficult to know “why” such settings have been chosen and how it meets functional needs. Considering medical work in hospital, papers give some general recommendations (for example, Bardram mentions that context awareness is particular useful for user-interface navigation, communication systems are also underlined by different teams).
- The features used are often very simple—time, location and identity of health care staff member and patient are the most common attributes described.
- No organization of context is used even if recommended in the more fundamental studies of context awareness.
- Activity knowledge is used infrequently.

One of the most advanced projects is the hospital of the future proposed by Bardram [43], in which activity is treated by using the artifact (bed, pill containers) to inform about the current actions of medical staff.

## 5.2. Identified pitfalls with the use of context-awareness computing

Acceptance of a system at the individual, social, political or economic level will strongly influence its future use. Different studies illustrate that even if context awareness is an attractive proposition, one must be careful when using such applications. We identified in our literature review problems which could occur and difficulties linked with human perspectives:

### 5.2.1. The system must remain intelligible

Belloti and Edward [39] argue that humans have complex motivations which lead to unpredictable behaviors. The presence of context-aware systems, inferring human intent and mediating between people, without intelligibility and accountability, could be problematic. The prototype proposed by Kjeldskov and Skov [45], which only takes into account location for the display of Electronic Patient Record on nurses' PDA, strengthens this point “some nurses became confused or even annoyed by the automatic adaptation of information on the screen to their physical location”. Barkhuus and Dey [36] describe three levels of interactivity with context-awareness computing: per-

sonalization, passive context awareness and active context awareness. They study how participants evaluate these three levels of interaction and conclude: “users are willing to accept a large degree of autonomy from applications as long as the application's usefulness is greater than the cost of limited control”.

### 5.2.2. People invent new conventions through new tools

Brown and Randell [54] analysed how people, “dwelling” with technology, use a phone ring or medical alerts. First, they show that suggesting correct behavior using context (even for such simple tools) is incredibly complex. It is perhaps more useful to use context defensively, to avoid incorrect behavior. Secondly, they show that people use technology to communicate context to users, for example, ringing another person twice indicates that the call is urgent; a very recent call means that the caller is still next to his phone, and should reply when called back. Their recommendation is to provide simple structures so that users could adopt and use technology.

### 5.2.3. The purpose of the tool could be deviated

From a human perspective, designing tools which are able to achieve good communication is not an obvious task. Fogarty et al. [37] have designed a context-aware system which is able to indicate the availability of an individual, taking into account their location, computer and calendar information, in the hope it could help people avoid disruptions through interruptions. They report that in testing, participants do not experience a reduction in interruptions, rather they use the context provided to identify the presence of the person they want to speak to, not to check his/her availability.

## 6. Discussion

Cooperation of actors in health care requires a large amount of diverse information types. Of the potential set of candidates for context feature, there is room for more complete exploration (e.g. elements from the patient record, global activities, etc.). The authors agree that there are specific features unique to the “rhythm” of health care work (particularly in a hospital) that while considered by some authors [35] have yet to be explored to a sufficient level of granularity. Many researchers discuss the importance of location as an important attribute in context-aware systems, but it is the author's view that this may not have the same priority as a requirement of such systems in a health care setting. In contrast activity is felt by the authors to be a crucial component of communication but even if cited, it is rarely used with the importance afforded location.

This review illustrates the reality that there remain many questions in the field of context awareness in health care, with few answers as yet to the questions/issues described in the research of Satyanarayanan [27].

It is apparent to the authors that developing context-aware applications is not a problem of access to technologies (sensors, networks, etc.) as these exist. One difficulty is, as yet, the research community has not reached a consensus as to



the best way to model context and architectures to support its use.

Also no preferred direction for the use of context awareness has emerged, with at present a range of potential uses (instant messaging, video conferencing, etc.) evident in the literature. It is likely that the evaluation of such systems in health care settings will guide the focus of future research, as some candidate applications are found to have negative impact such as increased communication load on health care workers or an increase in errors.

Despite the often cited claim that health care is an ideal candidate for context-awareness applications there seems to be a paucity of actual systems development and implementation in this area. Even if one considers prototypes, a large gap exists between the requirements expressed in the literature we reviewed and the prototypes developed to date. This is not surprising however given that this is a new area of research in an early stage of its evolution.

## 7. Conclusion

In this paper we have tried to provide an overview of the new area of context awareness in health care. While we have not covered all aspects of research in this area, or all projects, we have attempted to provide an overview of this evolving area, identify which areas of research are more dynamic and to highlight the gaps that exist. In order to classify the research reviewed, we developed a matrix to illustrate our key conclusions. Bear in mind that the conclusions we drew were based on the author's opinion and are not meant to be a quantitative assessment of the various research groups' strengths in different areas.

It seems that this area remains a fertile area for research. Despite the opinion by many research groups that health care would be an ideal focus area for context-aware applications there are relatively few medical informatics research groups actively involved in such research. In order to develop this research area a greater understanding of which aspects of context are most important in the health care domain is required. Assumptions about the relative importance of an attribute such as location are yet to be validated by the evaluation of systems beyond limited clinical trials. It is when such applications are integrated into the complex network of interactions within a hospital that the value (or otherwise) of a design will become evident. Given that error is such a concern in the health care setting [14], we also need to be mindful of the potential for new applications areas to introduce a new set of errors.

As a final point, Coiera [1] argues that since health systems are sociotechnical systems, where outcomes emerge from the interaction of people and technologies, we cannot design organizational or technical systems independently of each other. Lorenzi [57] articulates a number of non-technical issues that can act as barriers to a new systems success.

The development of such systems will need to draw on expertise from a number of disciplines including (but not limited to) computer science, social sciences, design and evaluation. Our hope is that this review will stimulate discussion and aid research in this area.

### Summary points

“What was already known before the study was done”

- Papers mentioned the complexity of context.
- Papers mentioned the usefulness of context-awareness computing.
- Papers mentioned “health care” as interesting settings for context-awareness computing.
- But no requirements about:
  - which interesting health care settings can use context-awareness computing;
  - which interesting context features can be used to implement health care applications.

“What this study has added to our knowledge”

- An overview of the existing systems for health care.
- An overview of the features of context actually used.
- An analysis of the gap between actual context-awareness prototypes in health care and the modelling of contextual applications proposed in the literature.
- The fact that no preferred contextual needs emerge yet.

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