Journal of Network and Computer Applications 35 (2012) 199–210

Contents lists available at ScienceDirect

Journal of Network and Computer Applications

journal homepage: www.elsevier.com/locate/jnca

Review

A framework for awareness maintenance

Amir Talaei-Khoei [a,*], Pradeep Ray [a], Nandan Parameshwaran [a], Lundy Lewis [b]

[a] School of Information Systems, Technology and Management, The University of New South Wales, No. 1039, Quadrangle Building, UNSW, Sydney, NSW 2052, Australia
[b] Southern New Hampshire University, USA

ARTICLE INFO

Article history:
Received 26 February 2011
Received in revised form
9 June 2011
Accepted 23 June 2011
Available online 12 July 2011

Keywords:
Computer supported cooperative work
Awareness maintenance
Systematic review

ABSTRACT

This paper presents a systematic literature review to gain insight into the growing area of awareness maintenance. A systematic review of papers from 1970 to 2010 examines the background and trends of research in this area. The results establish a framework for awareness maintenance and demonstrate trends, gaps, and potentially fruitful areas for future research. In particular, based on 131 papers, the present work proposes a four-phase framework for awareness maintenance that shows promise for real-world applications.

Contents

1. Introduction

People increasingly work and live in cooperative environments, and as such they are often overloaded by irrelevant or loosely relevant information (Leinonen et al., 2005). In addition, cooperative environments have to deal with information uncertainty (Rennecker, 2005), which often requires adaptation as new certain information comes to the fore. Adaptation is important for governments, public agencies, and non-governmental organizations worldwide to overcome the inherent uncertainty in cooperative environments. Research and design practices in Computer Supported Cooperative Work (CSCW) emphasize the role of *awareness* in adaptation where awareness is defined as understanding the relevance of information to one's goal (Daneshgar and Ray, 2000a; Gross et al., 2005). The dominate view in the literature favours the use of information technology to assist individuals in becoming aware and understanding relevant information (Hong et al., 2009), e.g. with machine learning, visualization, and data mining methods.

* Corresponding author.
E-mail addresses: amirtk@kth.se (A. Talaei-Khoei), p.ray@unsw.edu.au (P. Ray), paramesh@cse.unsw.edu.au (N. Parameshwaran), l.lewis@snhu.edu (L. Lewis).

1084-8045/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jnca.2011.06.011

There exist a number of reviews of technology-centric awareness in the literature (Sarma, 2005; Storey et al., 2005; Bricon-Souf and Newman, 2007; Omoronyia et al., 2010), where five types of awareness are defined: (1) workspace awareness (Gutwin et al., 1995), (2) common-sense awareness (Gutwin and Greenberg, 2007), (3) group awareness (Gutwin and Greenberg, 2007), (4) social awareness (Acquisti and Gross, 2006), and (5) context awareness. Context awareness is defined as non-ignorance of an internal or external entity that causes change in a situation (Gross et al., 2005), whereas Dey and Abowd consider context as information about the entity (Dey et al., 2001). Further, Ray et al. (2005a, 2005b) define context awareness as an understanding of relevant information that is required for an individual to carry out tasks. We note that on this view, the notion of context awareness focuses on the relevance of the context rather than knowledge about the context.

The technology-centric view in CSCW has recently evolved to embrace complexity-based paradigm (Zacarias et al., 2010a). This paradigm replaces deterministic perspectives of the internal and external views of systems by agency principles (Magalhães, 2004). Zacarias et al. (2010a, 2010b) define agency relationship as interactions between individuals and software agents to perform tasks on individuals' behalf. Therefore, CSCW tends to agree that the following characteristics of software agents make them useful to assist individuals (Woolridge and Wooldridge, 2001): *Autonomy*: an agent can operate without intervention of individuals. *Social ability*: an agent is able to interact with other agents and individuals. *Reactivity*: computing power of agents makes it possible for them to react on the changes of the environment in a timely fashion (however, this is heavily dependent on the computing power). *Pro-activity*: an agent tries to achieve what it has been initiated for. There are also bodies of work (Ray et al., 2005b; Ulieru and Worthington, 2006) that propose use of software agents to assist individuals achieving context awareness. One of the major questions in CSCW is how to utilize intelligent software agents to maintain contextual awareness (Ray et al., 2005b). *Awareness maintenance* is defined by Riemer and Haines (2008) as a process in which one becomes aware of a context and further shapes one's behavior to know the context and to decrease any contextual uncertainty.

This paper conducts a systematic literature review of current research in awareness maintenance. The present study develops a framework for maintaining awareness that is derived from the methodologies proposed in the literature. The results help us to determine gaps and trends in the existing body of knowledge in awareness maintenance.

The paper is organized as follows: Section 2 presents the research method used in our study. Section 3 presents the results of the review, including an awareness maintenance framework, a trend analysis and a gap identification. Section 4 supports the findings of this paper by existing theories in CSCW for awareness maintenance. discusses the contributions of the paper and recommends a direction for further research.

2. Research method

The study was undertaken as a systematic literature review based on the original guidelines proposed by Kitchenham (2004) and Kitchenham et al. (2009) and applied in several systematic reviews such as Ghapanchi and Aurum (2011). In this case, the goal of the review is to come up with a framework for awareness maintenance by reviewing the work in this field. The steps for this study are as follows: (1) identification of resources, (2) selection, (3) data extraction and synthesis, and (4) data analysis.

2.1. Identification of resources

In order to identify the resources, the first step is to recognize the relevant keywords. For this purpose, we adapted an experimental strategy given by Dieste et al. (2008). In this strategy, an optimum search is performed by keywords that retrieve articles in which 20–25% (i.e. precision rate) of them are related to the topic. Taking the objective of this review for investigating the literature of awareness maintenance, the term "awareness" was searched in Google scholar for publications between 1970 and 2010 in the field of "Engineering, Computer Science, and Mathematics". The first 100 papers found in the search were considered and in each of the related terms to "awareness" were identified. Therefore, "context" with a precision rate of 23.7% and "situation" with a precision rate of 20.9% were decided to be considered. Subsequently, "maintenance" was searched in combination with each of these terms, that is, "awareness maintenance", "context maintenance", and "situation maintenance". Additionally, "create" with a precision rate of 22.6%, "sensitive" with a precision rate of 20.6%, "obtain" with a precision rate of 23.3%, "identify" with a precision rate of 24.1%, and "develop" with a precision rate of 24.8% were also being recognized. However, the limitation of systematic reviews is that they are heavily dependent on the chosen keywords that have been admitted in the literature of this research method (Kitchenham et al., 2009).

The articles were searched using eight online databases. Depending on the search services offered by the databases, the titles, keywords, and the abstracts were searched for papers that have been published during (including) years from 1970 to 2010. In each database, the search was repeated three times by the following phrases:

- AND [(awareness) (OR (create sensitive obtain identify develop))][1]
- AND [(context) (OR (create sensitive obtain identify develop))]
- AND [(situation) (OR (create sensitive obtain identify develop))]

For example, the first phrase means all the articles that have the keyword "awareness" and any of the keywords "create", "sensitive", "obtain", "identify", and "develop" in their titles, abstracts or keywords. For each search result, Google scholar and Citeseer were searched to see the papers that have cited the found paper. For the papers indexed by these two search engines, those with less than five citing papers, were not included into the list.

The articles were searched in a comprehensive list of subjects. The names of the databases, the subjects, the number of the found articles, and the number of repeated papers are listed in Table 1. 14,699 articles were found in total while 5692 papers were repeated. The selection process excluded the repeated articles from the archive and came up with 9073 papers.

2.2. Selection

The objective of this step is to find the articles and exclude the papers that are not relevant to the topic of "awareness maintenance". Fig. 1 depicts the selection process. This process had two iterations.

In the first iteration, aforementioned keywords were searched in the 8 databases. Then, steps 1.2, 1.3, and 1.4 excluded 8511

[1] Operators come prior to keywords.

Table 1
The online databases and research fields.

Name of database	Subjects	Number of found articles	Number of repeated articles
SpringerLink	Computer Science, Engineering	1385	–
Wiley InterScience	Computer Science and Information Technology	1013	–
ScienceDirect	Business Management and Accounting, Computer Science, Decision Science, Engineering, Mathematics, Psychology, Social Sciences	1503	–
Scirus[a]	Computer Science, Economics, Business and Management, Mathematics, Psychology, Social and Behavioral Sciences	291	49 articles from the above databases.
IEEE Xplore	Computing and Processing, Communication Networking and Broadcasting, General Topics for Engineers (Math, Science and Engineering), Robotics and Control Systems	6023	3007 articles from the above databases.
ACM Digital Library	Computer Science, Mathematics, Engineering, Social Sciences	1287	892 articles from the above databases.
CiteSeer	Computer and information science	1089	379 articles from the above databases.
Google Scholar	Engineering Computer Science and Mathematics	2108	1365 articles from the above databases.
Total		14,699	5692

[a] This database does not provide any service for search abstracts. Therefore, we only searched the titles and keywords.

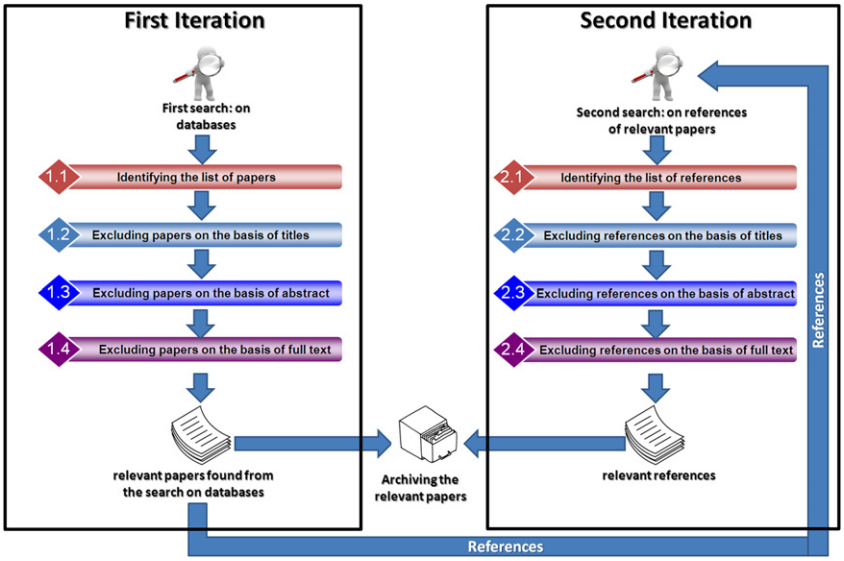

Fig. 1. Selection process.

articles based on their titles, keywords, and full texts. These steps excluded articles that:

- did not focus on maintenance of awareness.
- did not focus on methodological aspects of awareness maintenance.
- focused only on applications of awareness maintenance.
- were not in the relevant fields or could not be used in the relevant fields.
- were in languages other than English.
- were not peer reviewed.

After the exclusion steps, the 91 remained articles went to an archive in Zotero Research Tool (Zotero Co., 2010) for storage and organization.

In the second iteration, the references were retrieved from the papers that had come out of the exclusion process in the first iteration. In step 2.1, the keywords were searched on the list of references and those references that are matched with the keywords were chosen. Step 2.2, 2.3, and 2.4 examined the references against the above exclusion criteria and based on their title, keywords, and full text. Then, the 40 remaining references were added into the archive.

Finally, the systematic review resulted in 131 relevant papers (91 from iteration 1 and 40 from iteration 2).

2.3. Data extraction and synthesis

The data extraction and synthesis process aims to extract the key details from the 131 papers. Two types of data were extracted from the studies: (1) methods, where data is synthesized to recognize the different methodological aspects of awareness maintenance and (2) demographics, such as year of publication.

2.4. Data analysis

Fig. 2 shows the analysis process for the final list of the publications. The terms and definitions in the articles formed a primary list of categories for the methods. At this stage the different problems that the different methods in the articles were trying to solve were discovered (see Table 2).

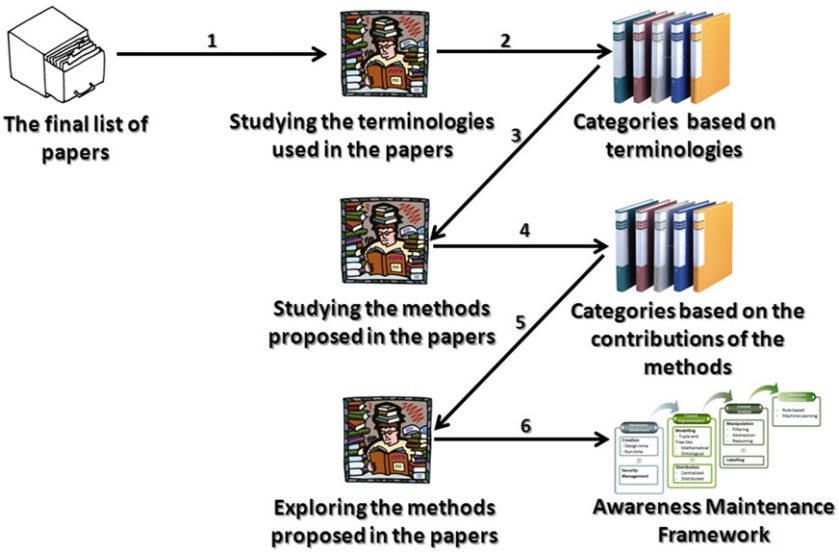

Fig. 2. Data analysis procedure.

Table 2
Problems identified by exploring the terminologies and methods in the articles.

Categories identified by exploring the terminologies used in the articles	Categories identified by exploring the methods proposed in the articles
• Awareness Creation • Context Modeling • Context Distribution • Inference • Labeling	• Awareness Creation (in design time, in run-time) • Security Management • Context Modeling (tuple and tree-like, mathematical, ontological) • Context Distribution (Centralized, Distributed) • Context Filtering • Context Abstracting • Context Reasoning • Context Labeling • Awareness Utilization (Rule-based, Machine Learning)

Having put the methods in the different categories identified by exploring the terminologies used in the articles, the following points were discovered (see Table 2):

- Awareness creation can happen in design-time or in run-time.
- There are methods that they address the security issues in awareness maintenance.
- Context Modeling has different types of methods: tuple and tree-like, mathematical and ontological.
- Context Distribution has different types of methods: Centralized and Distributed.
- Inference has two steps: First, context filtering, abstracting, reasoning and labeling. Second, Awareness Utilization that concerns with shaping the behaviors by rule-based or machine learning methods.

The last stage was to form the category-subcategory classifications. In this stage, by looking at the different methods, the following were proposed:

- The first step in awareness maintenance is Awareness Obtainment that involves Awareness Creation and Security Management.
- The second step in awareness maintenance is Context Representation that involves Context Modeling and Context Distribution.
- The third step in awareness maintenance is Context Analysis that involves Context Manipulation and Context Labeling. Context Manipulation includes Filtering, Abstracting and Reasoning. Labeling is related to artifacts, persons, time or location.
- The fourth step in awareness maintenance is Awareness Utilization.

Finally, taking the above points into consideration, a classification of methods in awareness maintenance, i.e. *Awareness Maintenance Framework* was derived.

3. Results

The results include (1) an Awareness Maintenance Framework and (2) a trend and a gap analysis based on demographic data collected from the final list of papers.

3.1. Awareness maintenance framework

Based on 131 papers, awareness maintenance is categorized into four categories; awareness obtainment, context representation, context analysis, and awareness utilization. Fig. 3 shows this classification framework. The following sections provide detailed explanations for each category.

3.1.1. Awareness obtainment

Awareness obtainment is a process in which an individual becomes aware of relevant information. The review shows that there are two types of work in this area; those that focus on creation of awareness and those that highlight the security issues in obtaining awareness.

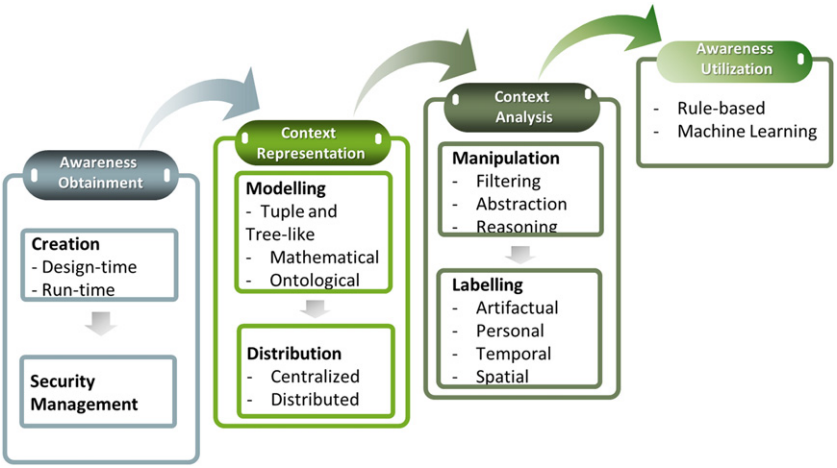

Fig. 3. Awareness maintenance framework.

Awareness creation is a process whereby one matches actual information with what one requires or desires to be aware of. The methodologies in this area usually define a dispatcher to match the required awareness with an information driver. The driver is attached to the information source to provide interfaces for dispatcher. Research in awareness creation can be classified further in regard to objectives. There are methodologies that look at how to create awareness in design-time and there are bodies of work that provide technologies for awareness creation in run-time. Table 3 summarizes these findings.

Awareness security involves traditional security concerns. Security in awareness obtainment cannot be isolated from awareness creation either in design-time or run-time. Where security support has appeared in awareness obtainment, it often covers the following topics: Confidentiality, Trust, and Identity. Confidentiality secures the relationship between individuals as they become jointly aware of information. Trust illustrates the degree of reliability of the created awareness and Identity gives access control and authorization to the created awareness. Table 4 summarizes these findings.

3.1.2. Context representation

Context representation involves techniques for modeling and distributing information that a system is aware of, where *modeling* refers to awareness research that gives context structures while addressing the following problems: distributed vs. centralized awareness, validation of awareness, quality of awareness, uncertainty in awareness, formal representation of awareness, and the implementation of awareness. The review shows that research in awareness supports three categories of context modeling techniques: (1) Tuple, tree-like modeling, (2) Mathematical modeling, and (3) Ontological Modeling. Table 5 summarizes these findings.

According to what we have explained above, awareness ideally is desired to support distributed computing. However, this lacks the central control, it arises opportunity to provide highly dynamic structures for context. *Distribution* refers to methods that represent context in centralized or distributed processing. Table 6 summarizes our finding in different techniques for distributing context.

3.1.3. Analysis

In computer supported cooperative work, an individual becomes aware of multiple types of context from variety of sources. The relevance of information to the individual can be meaningless, ambiguous, or imprecise. *Analysis* is the process in which one combines and scrutinizes the relevance of information

Table 3
Creation step of awareness obtainment.

Category	Methods
Design-time	• Daneshgar and Ray (2000a) proposes the process of cooperation enhancement based on awareness creation. They define awareness net (tree) where information in each node is attached to drivers. Once an individual is required to be aware of a piece of information, the associated node creates a dispatcher. They argue if there is dispatchers that can be connected to its appreciated driver, then this connection enhances the cooperation by creating awareness in the node dispatcher. • Ray et al. (2005b) extends the cooperation enhancement process by Daneshgar and Ray (2000a, 2000b) measuring the required awareness as a fuzzy attributes. • Riemer and Haines (2008) is a conceptual paper that proposes a theory for the dynamic creation of awareness in mediated settings using metaphor of pools fed by streams of communication. "Pools of awareness are held within users and gradually filled via signals from others. Users desire [require] different pools and direct the streams of interaction to feed those pools first." • Zacarias et al. (2010b) argues an importance of agent perspective to align individual and organizational views. This work proposes an ontological method to conceptualize awareness while designing an agent-based CSCW application for an organization. More: Frößler et al. (2007), Daneshgar et al. (2006), Ray and Chattopadhyay (2009), Kaiser et al. (2005), Lieberman and Selker (2010), and Ranganathan and Campbell (2003).
Run-time	• Context Tailor (Davis et al., 2003) provide a well-defined service called context service. The Context Service has well-defined dispatcher and driver. • SOCAM (Gu et al., 2005), Gaia (Román et al., 2002; Yiqiang et al., 2009; Salem and Rauterberg, 2004; de Freitas Bulcao Neto and da Graca Campos Pimentel, 2005; Oh and Woo, 2009; Borovoy et al., 2010) provide a service called context provider. This service interacts with the available contexts and creates awareness in the run-time. • Dey et al. (2001), Dey (2009), and Eddy and Pei (2010) in a similar way as SOCAM and Gaia provides widgets as driver and aggregators as dispatchers to create awareness in run-time. • Merino(Kummerfeld et al., 2003; (Chen et al., 2010; (Little, 2010; Gellersen et al., 2002) propose methods for creating awareness at the lowest level by interpreting historical references. More: Keiser and Kriengchaiyapruk (2008),Biegel and Cahill (2005), Lalbakhsh et al. (2009), Taconet et al. (2009), Müller et al. (2010), Wustmann et al. (2010), Baladrón et al. (2010) and Chtcherbina and Franz (2003).

Table 4
Security management step of awareness obtainment.

Methods
• Sliman et al. (2009) proposes a framework that collects and generates policy-based security in cross-organizational scenarios. In addition to catering to specifications of security and business policies, the framework integrates contextual information to make the role-based framework flexible and express confidentiality requirements of users. • MeCoCo (George and Lekira, 2009; Khedr and Karmouch, 2005a; Gu et al., 2005) propose a fairly generic user's awareness framework for mediated communications. However, this work argues that the awareness cannot be totally generic, as it may harms the confidentiality requirements. As such, MeCoCo gives some classes based on the domain ontology which satisfy the confidentiality. • CASPER (Chow et al., 2009; Khungar and Riekki, 2005; Katsiri and Mycroft, 2006; Barbosa et al., 2008) propose a modeling-based method for awareness confidentiality. It models the world by nested containers. The hierarchy of containers provides abstraction in the model. • Cosmos (Kim et al., 2008a) provides an integrated awareness framework over the network sensors. The framework consists a security manager that provides Trust, Authorization, Authentication and Confidentiality services to the awareness engine. • Sheikh et al. (2008), Shabtai et al. (2010), and Griswold et al. (2003) provides labeling (explained in Section 3.1.3) to the awareness. This method uses generic quality attributes. Two of these attributes are Trust and Identity. • Solt et al. (2009) provides a method to classify awareness (in case of this paper, it is classification of diseases) using security policies covering Trust and Confidentiality. This paper lacks looking at Identity. • Shand et al. (2004), Biegel and Cahill (2005), Patrikakis et al. (2009), Butler (2001), Sharifi and Naghavian (2010) and Moura et al. (2009)use human notation of Trust for awareness in collaborative environments. • Nugent et al. (2008), Xirouhaki et al. (2002), Chang et al. (2008), Kühn et al. (2010), Baladrón et al. (2010) and Hong and Landay (2004) apply access control and authentication policies in its defined awareness obtainment process. • Gaia (Román et al., 2002), COCON (Wang et al., 2004), (Munnelly et al., 2007), and (Şensoy et al., 2009) provide access control for awareness. More: Robinson and Beigl (2004), Hoffmann (2005), Hoffmann and Stotz (2005), Bhatti et al. (2005) and Moore et al. (2010).

in order to interpret the awareness and manage uncertainty of acquired awareness. Analysis includes manipulating contexts to give them meaning while labeling them with meta-data.

Manipulation describes methods that involve processing a set of contexts to remove unnecessary context, add abstract context, and infer available context. This includes filtering, abstraction, and reasoning. Filtering are techniques dedicated to address the problem of validating the relevant information. These methods generally address the problem of awareness overload by identifying redundancy and contradictions in a set of contexts. While filtering removes some information from the set of relevant information, abstraction and reasoning can make the context increasingly meaningful, by raising the abstraction level of the context and relating it to the lower level abstraction. Reasoning involves the discovery of relations among data one is aware of. Table 7 shows the methods proposed in literature for these elements of analysis and manipulation.

Labeling refers to tagging relevant information to emphasize the quality of a context. Labeling refers to the additional information on the context used for utilization. There are several dimensions of labeling such as artifactual, personal, temporal, and spatial (what, who, when, and where). Table 8 shows the methods proposed in the literature for Context Labeling.

3.1.4. Utilization

When Riemer and Haines (2008) define awareness maintenance, they use the term "shape of behaviors". This means in their point of view, the last step for awareness maintenance is when an individual changes her/his behavior based on the obtained awareness to information that has been represented and analyzed in previous steps.

Utilization is the process of adapting the behavior of a system in response to changes of the context that the system is aware of, i.e. it shows the change of the system behaviors by the change of the relevant contexts in the environment. However, many awareness maintenance methods such as Dey et al. (2001), Schmidt et al. (2004), and Bardram (2005) do not support utilization; infrastructures that provide utilization usually are based on rule-based or machine learning techniques. Table 9 shows the different approaches in the literature for utilization.

3.2. Evaluation of methods

A four-step framework for awareness maintenance has been represented. However, how to evaluate the methods in respect to a particular application has not been addressed yet. The first step in any evaluation should be to clearly state the criteria.This section aims at providing a set of evaluation criteria for each of these steps, which allows us to evaluate existing methods for a particular purpose. It also provides a means by which the advantages and disadvantages of methods for a certain type of applications can be illustrated.

In order to extract such criteria, the cited studies in Table 3 to Table 9 were studied. In regards to the objectives and contributions of methods, the criteria proposed in Hong et al. (2009) are adapted and the relevance and applicability of certain criteria to each particular step is presented in this section (see Table 10).

Neale et al. (2004) state that contextual dependency involved in the methods of awareness applications makes the evaluation highly dependent on the nature of applications, which is difficult to address. This highlights two main effective factors in evaluation of awareness applications. First, it is important that what would be the criteria for a particular application becomes clear. Therefore, Table 10 gives the criteria that need to be considered while choosing methods in each step. Second, what is expected from each of the selected criteria should be also known. This requires paying a great attention to the application domain. These two factors should then be mapped to methods using a matrix to show awareness maintenance method is related to which criteria and their expectations. Mapping the awareness maintenance methods to the criteria and expectations alleviate issues associated with problem domain dependency of evaluation of methods.

3.3. Trend analysis

In this section, a demographic analysis of the 131 articles is presented. Fig. 4 shows the distribution of the papers over year of publication. It shows that there is an increase since 2000 of researchers' contributions to awareness maintenance. Further, the number of articles published between 2005 and 2010 has radically increased.

Fig. 5 demonstrates the distribution of the proposed methods in each phase of awareness maintenance framework on the year of publication. This figure illustrates that awareness obtainment has been the most cited phase of the framework since 2000. However, again, the number of the publications may not be an absolute indicator to the fact that awareness obtainment is more problematic; it can be taken as the current trend in the literature.

3.4. Gap analysis

The awareness maintenance framework can be used to identify limitations of existing approaches by using the evaluation table given in Section 3.2. One of the open questions in the framework that needs further research is how to identify awareness. Although the existing methods in the literature have addressed the problem of

Table 5
Methods for modeling context awareness.

Category	Methods
Tuple and Tree-like Modeling	• Multi-granularity model (Niu et al., 2010) uses tuples to exploit the relationships among different attributes of awareness, together with the corresponding multi-granularity management approach to strengthen the flexibility and context of dynamic service composition. • Schilit et al. (1994) models the context of application by pairs of tuples expressing the attributes[a] and their values. This approach emphasizes on dynamism of context by changing the value of attributes in the tuples. • Schnaitter et al. (2009) uses tuple-based modeling of context and proposes estimation for giving value to the attributes. • Dey (2009) provides a tree-like hierarchical context modeling technique for ambient systems • CASPER (Chow et al., 2009) builds containment trees to model context. The objective is to provide a model-based confidentiality method. The tree represents nested containers to model the abstraction of entities. • Markup languages typically are built upon a generic "profile" that represents context. The markup languages represent awareness using both tuple and tree-like approaches. The basic schema for these languages is Standard General Markup Language. Some of these approaches are as following: ○ A category of these languages is based on Composite Capabilities/Preferences Profile (CC/PP) such as DELI (Butler, 2001) and CSCP (Held et al., 2002) or User Agent Profile (UAProf) such as (Hinz et al., 2007). These approaches are based on RDF expressiveness structure and XML serialization. They normally extend the standard CC/PP or UAProf approach to address complexity and dynamism problems as popular challenges in this area. CC/PP Context Extension (Indulska et al., 2003) extends both CC/PP and UAProf by number of component-attribute trees related to some aspect of context awareness. ○ Pervasive Profile Description Language (PPDL) (Chtcherbina and Franz, 2003) that models the context with emphasis on their dependencies while the different contextual aspects and artefacts remain limited. Only few parts of this language are available to public. ○ Another category of markup languages is based on Usage Environment Description (UED) such as (Capra et al., 2001) and Digital Item Adaption (Vetro et al., 2006) or (Barbosa et al., 2008) . This XML-based language covers context about four categories of information: (1) the user characteristics and her/his preferences, (2) Hardware, (3) Network, and (4) Environment. • Awareness Net (Daneshgar and Ray, 2000b; Ray et al., 2005a) proposes to model context during cooperation with a tree structure. Information in each node is attached to drivers. Once an individual is required to be aware of a piece of information, the associated node creates a dispatcher. More: Bhatti et al. (2005), Citron (Yamabe et al., 2005), Confab (Hong and Landay, 2004), Context Shadow (Jonsson, 2001; Sharifi and Naghavian, 2010; Sharifi et al., 2009).
Mathematical Modeling	• McCarthy Model (McCarthy, 1993) avoids giving an explicit definition for context. Instead, the model presents context as an abstract mathematical entity with relevant properties to the situation. The significance of the model is to lifting the truth of a property from one context to another. McCarthy model supports in heritance. • Extended Situation Theory (Akman and Surav, 1997) uses first-class objects of situation theory to represent context related to a particular point of view. They model context by a parameter-free expressions supported by situation types which corresponds to the context. • And et al. (1998) uses formal first order predicate logic representation to facilitate the composition of context of individuals into more complex sensed context. • Gaia (Román et al., 2002) implements context using First Order Logic operations such as qualifications, implications, and conjunctions. • Ghidini and Giunchiglia (2001) although is more on reasoning about goal using context, it defines context as individuals' perspective subjective for the current situation. • Logic of General Awareness (Fagin and Halpern, 1988; Sillari, 2008b) models awareness as a set of relevant information to a situation and develops logic to change implicit knowledge to the explicit knowledge using awareness. • Zhang and Li (2007) describes awareness with dynamic fuzzy logic. In order to handle errors in the sensors, the system models robustness using awards. • Liu (2010) uses fuzzy logic to model context in image processing. The significance of the model is to improve the accuracy of texture classification. • Sakhanenko and Luger (2010) models context about change of context using a first-order logic-based probabilistic modeling language called Generalized Loopy Logic (GLL). More: Katsiri and Mycroft (2006) and Bannon and Hughes (1993).
Ontological Modeling	• Strang and Linnhoff-Popien (2003) proposes Aspect Scale Context (ASC) model to provide a uniform model for model core concepts as well as arbitrary amount of sub-concepts. This allows us to model context awareness. ASC implements monolithic Context Ontology Languages (CoOL). • CONON (Wang et al., 2004) provides upper context ontology for context. This approach models general concepts about basic context, and also provides ability to add hierarchical domain-specific ontology. • Kofod-Petersen and Mikalsen (2005) divides context in the following five categories integrated to form domain ontology: task, social, personal, spatio-temporal, and environmental. • SOCAM (Gu et al., 2005) provides two-level ontology to model context: domain independent and domain specific. • ACAI (Khedr and Karmouch, 2005b) provides ontology for context-aware applications. • KAD (Evangelou et al., 2005) provides context ontology by interweaving concepts from the Knowledge Management, Argumentation Theory, Decision Making, and Multicriteria Decision Aid disciplines. • PLIB (Pierra, 2008) provides conceptual ontology for awareness in industrial manufacturing. • Segev and Gal (2007) provides a formal mathematical framework that delineates the relationship between contexts and ontologies. The main purpose of this framework is to manage awareness uncertainty. • DEN-ng policy structure (Strassner et al., 2009) provides ontology to model context using policies. • Pereira et al. (2009) provides an ontological model of context to facilitate information retrieval. • (Stojanovic et al., 2010) discusses the use of ontologies as a high-level, expressive, conceptual modeling approach for describing awareness. • CAUCE (Tesoriero et al., 2010) is a model-driven development approach based on 3-layer ontology to implement context-aware application. More: Ejigu et al. (2008), De Leenheer et al. (2007), Castano et al. (2006), Soylu et al. (2009) and Hervás et al. (2010).

[a] These attributes some times are called variables. In some logic-based systems a propositional sentence can be presented by a set of tuples of variables and values.

Table 6
Methods for distributing context awareness.

Category	Methods
Centralized	• Ranganathan et al. (2004) uses spatial centralized database to persist context models. • SOCAM (Gu et al., 2005) includes a context database that stores ontological context models. • PACE (Moon et al., 2007) stores context, application, user data, domain knowledge and behavior in a centralized database. • LORE (Chen et al., 2010) addresses the aspects of building location-aware centralized services, including positioning, location-dependent query processing, tracking, and intelligent location-aware message notification. Three key components of the infrastructure are the location server, a moving object database, and a spatial publish/subscribe engine. More: Baladrón et al. (2010), OLLAF (Garcia and Granado, 2009).
Distributed	• Kaiser et al. (2005) provides a distributed event-based context representation. It considers the quality requirements. COSMIC also supports event channels with different timeliness and reliability classes. • Khungar and Riekki (2005) is a distributed physical storage that uses distributed servers to store context models. • Malik et al. (2009) estimates individual preferences by distribution of their context models. • Smart-Context (Moore et al., 2010) stores personalized context models. It uses OWL for communication between different nodes. More: WBLS (Moura et al., 2009; Liu, 2010).

Table 7
Methods for manipulating context.

Category	Methods
Filtering	• SOCAM (Gu et al., 2005) filters the context in order to remove conflicts and have higher degree of consistency. • Pinheiro et al. (2010) filters the context based on preferences. • Sentient (Biegel and Cahill, 2005) filters the context in order to ensure the certainty. It uses Bayesian networks. • I-Gaia (Xirouhaki et al., 2002) validates relevance of information to filter the context. This method can be used by fuzzy logic or First Order Logic. • Hong et al. (2009) and Şensoy et al. (2009) use ontology to filter redundant context. More: CARISMA (Capra et al., 2003), MoCoA (Senart et al., 2006; Chang et al., 2008; Kirsch-Pinheiro et al., 2005).
Abstracting	• Gaia (Román et al., 2002) provides logic-based abstraction. • Serral et al. (2010) provides a meta-model to abstract the context. • Kühn et al. (2010) presents a concept for the knowledge-driven opto-acoustic scene analysis based on an object-oriented modeling approach to recognize the required level of abstraction for the available context. • Shabtai et al. (2010) uses temporal concepts to abstract the context. • Hightower et al. (2002) uses a method based on probability to recognize the relations between contextual entities and create the higher level of abstraction. • EnviroTrack (Krishnamurthy et al., 2004) abstracts the context based on the network infrastructure. More: Chang et al. (2008), de Freitas Bulcao Neto and da Graca Campos Pimentel (2005), Griswold et al. (2003), Munnelly et al. (2007), van Kranenburg et al. (2006), CASPER (Chow et al., 2009).
Reasoning	• Demetriou and Kazi (2006) manipulates context by reasoning about tasks. • Logic of General Awareness (Fagin and Halpern, 1988; Sillari, 2008b) is a classical model First Order Logic that provides a method to manipulate the awareness by reasoning about awareness to others' knowledge or awareness. • Agostini et al. (2009) reasons about context using ontology techniques. • Cheng and Marsic (2001) reasons about context using Fuzzy Logic. • Zimmermann (2003) reasons about context using case-based reasoning techniques. • Julien et al. (2004) provide a state-based formal reasoning technique about location-aware mobility. • CARE (Agostini et al., 2009) using hybrid reasoning supports context awareness in web services. • Halpern and Rêgo (2009) provides awareness by reasoning about the knowledge of not-being-aware (i.e. unawareness). • Guesgen and Marsland (2010) provides awareness by reasoning in temporal and special aspect of context. • Ghidini and Giunchiglia (2001) uses awareness to reason about goals. Similar to partial theory of Worlds, it takes individuals' perspective subjective for the current situation to reason about the goal. More: And et al. (2001), Halpern and Pucella (2010), Sillari (2008a), Cummins et al. (1991), (Wustmann et al. (2010), Ma et al. (2009), and Kofod-Petersen and Mikalsen (2005).

awareness creation in the obtainment phase, they have not answered a fundamental question of what should be aware of. This open question has been pointed out by some researchers in CSCW (Ray et al., 2005b; Daneshgar et al., 2006) as well as in intelligent agents (Halpern and Pucella, 2010). Therefore, our framework lacks the methods for a step before awareness creation in the obtainment phase, which can be called awareness identification. *Awareness Identification* would be a process in which an individual identifies the relevance of information to its situation.

Policy-based Awareness Management Talaei-Khoei et al. (in press-a) – as an alternative for the problem of awareness identification – proposes the use of existing policies as a source to identify awareness and employs software agents to assist individuals for this purpose. Talaei-Khoei et al. (in press-b) also published a case study of the application of their proposed method in wireless communications at hospitals. However, Policy-based Awareness Management is one of the pioneer studies on awareness identification and has been proposed after the period of time that is being reviewed by the present paper.

4. Theoretical support

The concept of awareness has been borrowed from the field of CSCW. In this section, the implications of the awareness maintenance framework in the theory of situation awareness (Endsley 1995), and the theory of pools and streams (Riemer and Haines, 2008) are discussed.

Endsley (1995) introduces the theory of situation awareness, which concerns with the developing information technology solutions for information overload and uncertainty. The theory addresses how people process information to arrive at a behavior that removes a perceived uncertainty. The theory of situation awareness provides a conceptual model to the process of awareness maintenance. This theory states that once an individual captures the context (in our framework, it is called awareness obtainment), there are three levels of awareness; Level 1—perception (context representation). Level 2—comprehension (context analysis). Level 3—projection of future (awareness utilization). The theory emphasizes on the change of behaviors in respect to the above three levels of mental attitudes. However, as it is discussed in Section 3.4, the theory of situation awareness lacks the step for awareness identification. In the theory of situation awareness, once an individual wants to capture a context, there should be a way to identify which context is relevant to capture, otherwise the individual will suffer from the problem of information overload.

The hypothesis given by Riemer and Haines (2008) provides metaphors of pools and streams to explain the process of awareness maintenance. The metaphor "pools of awareness" refer to relevant contexts that are identifiable albeit to some extent uncertain.

Table 8
Methods for context labeling.

Category	Methods
Artifactual	• WS-Café (Little, 2010) provides standards for labeling contextual artifacts. • Aura (Ge et al., 2008) supports quality attributes for context. More: Bailey et al. (2002), COSMIC (Kaiser et al., 2005).
Personal	• Oh and Woo (2009) is specified for mobile applications and enables users to share their experiences in the format of labels and labels on the context. More: Sheikh et al. (2008).
Temporal	• Time-Frames method (Koen and Bender, 2000) provides labeling based on temporal attributes of context. • MUPE {Citation} labels context using temporal and certainty attributes. More: Cattuto et al. (2010) and Alduncin (2009).
Spatial	• LoSeCo (Yiqiang et al., 2009) proposes a method to tag location context in pervasive computing. More: Zhang and Li (2007), Borovoy et al. (2010), COSMIC (Kaiser et al., 2005).

Table 9
Methods for utilization.

Category	Methods
Rule-based	• Context Tailor (Davis et al., 2003) provides an API containing contextual, temporal, and statistical components for specifying rules. These APIs are called patterns. The pattern activator triggers an action if the context of the service matches with the context of the pattern. • CARISMA (Capra et al., 2003) defines intra i.e. external and inter i.e. internal policy rules. The awareness utilization happens once the inter and intra policy rules conflicts in a given set of awareness. • Korpipää et al. (2005) the awareness rules are defined in XML. The rule engine triggers a rule by matching the condition clauses in rule with the retrieved context. • DEN-ng (Strassner et al., 2009) policy structure used event-condition-action model to utilize awareness by different policy rules. • CASPER (Chow et al., 2009) provides a policy model. It uses ponder policy language for specifying its policy rules. The policy editor, policy specification interface, policy manager are components of the framework. CASPER utilizes a given set of awareness by a given set of policy rules when the retrieved aware context matches the rule. More: Ejigu et al. (2008), Sánchez et al. (2008), Kim et al. (2008b) and Eddy and Pei (2010).
Machine Learning	• Gaia (Román et al., 2002) supports Bayesian, neural network and clustering for machine learning for utilization. • Context (Kofod-Petersen and Mikalsen, 2005) uses case-based method for utilization. The significance is to retrieve a learnt case to decide what action to take in the current context. • Lieberman and Selker (2010) proposes a design methodology to use of machine-learning techniques for utilization. More: Ranganathan and Campbell (2003) and Korpipaa et al. (2003).

To remove this uncertainty, an individual directs streams to the pool, which results in increased contextual knowledge and removes some uncertainty. Therefore, when one becomes aware of a relevant context, one creates a pool. Consequently, when one adapts one's behavior to gain more knowledge about relevant context, one directs streams to the created pool. The theory of pools and streams also lacks to address the process in which the individual identify

Table 10
Evaluation of Methods.

	Concepts			Network Infrastructures					Middleware					
	Algorithm	Developing Guides	Schema	Context Data Mng.	Security Mng.	Protocol	Sensing	Network Requirements	Network Implementation	Autonomy	Reflectivity	Ontology	Adaptively	Goal-orientation
Awareness Obtainment	×	×		×			×	×	×	×	×	×	×	×
Creation	×	×	×	×	×	×		×	×	×	×	×	×	×
Security Mng.														
Context Representation		×		×	×			×				×	×	×
Modeling		×	×	×	×			×				×	×	×
Distribution	×	×		×	×	×		×	×	×	×	×	×	×
Context Analysis														
Manipulation	×	×		×						×	×	×	×	×
Labeling	×	×		×						×	×	×	×	×
Awareness	×	×	×		×			×	×	×	×	×	×	×
Utilization														

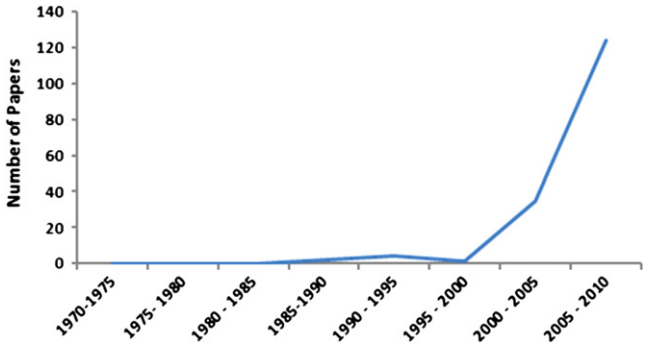

Fig. 4. The year distribution of articles.

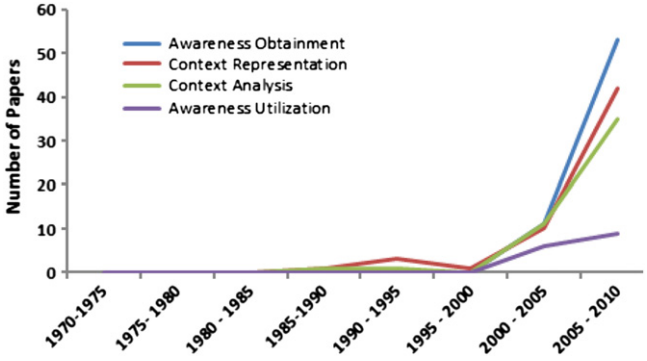

Fig. 5. The year distribution of the papers related to each phase of the awareness maintenance framework.

awareness. As we discussed in this paper, an individual who wants to removes some uncertainty may be overloaded by the irrelevant or loosely relevant information, if she/he is not able to identify awareness of relevant information. This refers to the lack of the awareness maintenance framework for awareness identification.

5. Summary and outlook

Researchers in CSCW and intelligent agents have been long interested in awareness. Although there have been several comprehensive literature reviews in awareness and context-sensitive systems (Sarma, 2005; Storey et al., 2005; Bricon-Souf and Newman, 2007; Omoronyia et al., 2010), the integration of proposed methods as a classification framework for awareness maintenance is new with this work. The review provides a four-phase framework for awareness maintenance and provides a clearer understanding of different phases in awareness maintenance.

An additional contribution of the paper is to corroborate the theory of situation awareness and the hypothesis of Pools and Streams regarding the proposed methods of awareness maintenance in the literature. However, these two theoretical perspectives are conceptual models; the study presented in this paper uncovers four clear phases for employing intelligent agents to assist in awareness maintenance.

The awareness maintenance framework can be used to identify limitations of existing approaches. The evaluation criteria given in Section 3.2 illustrate the expected requirements expected for a particular type of applications. Table 10 customizes the proposal of Hong et al. (2009) for the steps given in the awareness maintenance framework. Therefore, this table provides a means by which the expectations of awareness applications for introduced criteria can be mapped in a particular domain. This, therefore, demonstrates the limitation of methods. One of these limitations concerns with awareness identification that is pointed out in the literature of CSCW (Ray et al., 2005b; Daneshgar et al., 2006) as well as in intelligent agents (Halpern and Pucella, 2010). Recently, Talaei-Khoei et al. (in press, 2011b) have proposed a policy-based awareness management that makes use of existing policies for awareness identification.

References

Acquisti A, Gross R. Imagined communities: awareness, information sharing, and privacy on the Facebook; 2006. p. 36–58.
Agostini A, Bettini C, Riboni D. Hybrid reasoning in the CARE middleware for context awareness. International Journal of Web Engineering and Technology 2009;5:3–23.
Akman V, Surav M. The use of situation theory in context modeling. Computational Intelligence 1997;13:427–38.
Alduncin G. Analysis of augmented three-field macro-hybrid mixed finite element schemes. Analysis in Theory and Applications 2009;25:254–82.
And PG, Gray PD, Salber D. Modelling and using sensed context information in the design of interactive applications. In: Proceedings of the eighth IFIP international conference on engineering for human computer interaction; 2001. p. 317–36.
And PZ, Öztürk P, Aamodt A. A context model for knowledge-intensive case-based reasoning. Special issue on using context in applications. International Journal on Human-Computer Studies 1998;48:331–55.
Bailey C, El-Beltagy S, Hall W. Link augmentation: a context-based approach to support adaptive hypermedia. Hypermedia: Openness, Structural Awareness, and Adaptivity 2002:211–4.
Baladrón C, Cadenas A, Aguiar J, Carro B, Sánchez-Esguevillas A. Multi-level context management and inference framework for smart telecommunication services. Journal of Universal Computer Science 2010;16:1973–91.
Bannon LJ, Hughes JA. The context of CSCW. Developing CSCW Systems: Design Concepts 1993:9–36.
Barbosa V, Carreras A, Arachchi HK, Dogan S, Andrade MT, Delgado J, et al. A scalable platform for context-aware and DRM-enabled adaptation of multimedia content. In: Proceedings of the ICT mobile and wireless communications summit; 2008.
Bardram JE. The Java Context Awareness Framework (JCAF)—a service infrastructure and programming framework for context-aware applications. Pervasive Computing 2005:98–115.
Bhatti R, Bertino E, Ghafoor A. A trust-based context-aware access control model for web-services. Distributed and Parallel Databases 2005;18:83–105.
Biegel G, Cahill V. A framework for developing mobile, context-aware applications; 2005. p. 361–5.
Borovoy R, McDonald M, Martin F, Resnick M. Things that blink: computationally augmented name tags. IBM Systems Journal 2010;35:488–95.
Bricon-Souf N, Newman CR. Context awareness in health care: a review. International Journal of Medical Informatics 2007;76:2–12.
Butler MH. DELI: a Delivery Context Library for CC/PP and UAProf. Hp Laboratories Technical Report Hpl; 2001.
Capra L, Emmerich W, Mascolo C. CARISMA: context-aware reflective middleware system for mobile applications. IEEE Transactions on Software Engineering 2003;29:929–45.
Capra L, Emmerich W, Mascolo C. Reflective middleware solutions for context-aware applications, vol. 2192; 2001. p. 126–33.
Castano S, Ferrara A, Montanelli S. Matching ontologies in open networked systems: techniques and applications. Journal on Data Semantics 2006:V 25–63.
Cattuto C, Benz D, Hotho A, Stumme G. Semantic grounding of tag relatedness in social bookmarking systems. The Semantic Web-ISWC 2008; 2010. p. 615–31.
Chang J, Na S, Yoon M. Intelligent Context-Aware System Architecture in Pervasive Computing Environment.Los Alamitos, CA, USA: IEEE Computer Society; 2008 pp. 745–750.
Chen Y, Chen XY, Rao FY, Yu XL, Li Y, Liu D. LORE: an infrastructure to support location-aware services. IBM Journal of Research and Development 2010;48: 601–15.
Cheng L, Marsic I. Fuzzy reasoning for wireless awareness. International Journal of Wireless Information Networks 2001;8:15–26.
Chow CY, Mokbel MF, Aref WG. Casper*: query processing for location services without compromising privacy. ACM Transactions on Database Systems (TODS) 2009;34:1–48.
Chtcherbina E, Franz M. Peer-to-peer coordination framework (p2pc): enabler of mobile ad-hoc networking for medicine, business, and entertainment; 2003.
Cummins DD, Lubart T, Alksnis O, Rist R. Conditional reasoning and causation. Memory and Cognition 1991;19:274–82.
Daneshgar F, Ray P. Awareness modelling and its application in cooperative network management. In: Proceedings of the seventh international conference on parallel and distributed systems'2000; 2000a. p. 357–63.
Daneshgar F, Bunker D, Lee KM. Identifying opportunities for enhancing collaboration in the Australian health insurance sector. International Journal of Business Process Integration and Management 2006;1:210–8.
Daneshgar F, Ray P. Awareness Modeling and Its Application in Cooperative Network Management.IEEE Computer Society; 2000. p. 357.
Davis J, Sow D, Blount M, Ebling M. Context tailor: towards a programming model for context-aware computing. In: Proceedings of the first international ACM workshop on middleware for pervasive and ad-hoc computing; 2003.

Demetriou A, Kazi S. Self-awareness in g (with processing efficiency and reasoning). Intelligence 2006;34:297–317.
Dey AK, Abowd GD, Salber D. A conceptual framework and a toolkit for supporting the rapid prototyping of context-aware applications. Human–Computer Interaction 2001;16:97–166.
Dey AK. Modeling and intelligibility in ambient environments. Journal of Ambient Intelligence and Smart Environments 2009;1:57–62.
Dieste O, Grimán A, Juristo N. Developing search strategies for detecting relevant experiments. Empirical Software Engineering 2008;14:513–39.
De Leenheer P, De Moor A, Meersman R. Context dependency management in ontology engineering: a formal approach. Journal on Data Semantics VIII 2007:26–56.
de Freitas Bulcao Neto R, da Graca Campos Pimentel M Toward a domain-independent semantic model for context-aware computing. Presented at the Web Congress, 2005. LA-WEB 2005. Third Latin American; 2005. p. 10.
Eddy WF, Pei GP. Structures of rule-based belief functions. IBM Journal of Research and Development 2010;30:93–101.
Ejigu D, Scuturici M, Brunie L. Hybrid approach to collaborative context-aware service platform for pervasive computing. JCP 2008:3.
Endsley M. Toward a theory of situation awareness in dynamic systems: situation awareness. Human Factors 1995;37:32–64.
Evangelou C, Karacapilidis N, Khaled OA. Interweaving knowledge management, argumentation and decision making in a collaborative setting: the KAD ontology model. International Journal of Knowledge and Learning 2005;1:130–45.
Fagin R, Halpern J. Belief, awareness, and limited reasoning. Artificial Intelligence 1988;34(76):39.
Frößler F, Klein S, Riemer K. In: Proceedings of the 28th international conference on information systems (ICIS), Montreal; 2007.
Garcia S, Granado B. OLLAF: a fine grained dynamically reconfigurable architecture for OS support. EURASIP Journal on Embedded Systems 2009. 10:2–10:2.
Ge FB, Yang L, Wang JX, Wang ZZ. AURA model based on attribute and security context constraints. Computer Engineering 2008:34.
Gellersen HW, Schmidt A, Beigl michael. Multi-sensor context-awareness in mobile devices and smart artifacts. Mobile Networks and Applications 2002;7:341–51.
George S, Lekira A. MeCoCo: a context-aware system for mediated communications. International Journal of Interactive Mobile Technologies (iJIM) 2009;3:26–33.
Ghapanchi AH, Aurum A. Antecedents to IT personnel's intentions to leave: a systematic literature review. Journal of Systems and Software 2011;84:238–49.
Ghidini C, Giunchiglia F. Local models semantics, or contextual reasoning= locality+compatibility. Artificial Intelligence 2001;127:221–59.
Griswold WG, Boyer R, Brown SW, Truong T.M. A component architecture for an extensible, highly integrated context-aware computing infrastructure. In: Proceedings of the 25th international conference on software engineering; 2003. p. 363–72.
Gross T, Stary C, Totter A. User-centered awareness in computer-supported cooperative work-systems: structured embedding of findings from social sciences. International Journal of Human-Computer Interaction 2005;18:323.
Gu T, Pung HK, Zhang DQ. A service-oriented middleware for building context-aware services. Journal of Network and Computer Applications 2005;28:1–18.
Guesgen HW, Marsland S. Spatio-temporal reasoning and context awareness. Handbook of Ambient Intelligence and Smart Environments 2010:609–34.
Gutwin, C., Stark, G., Greenberg, S. Support for workspace awareness in educational groupware; 1995. pp. 147–56.
Gutwin C, Greenberg S. Support for Group Awareness in Real-Time Desktop Conferences. University of Waikato; 2007.
Halpern JY, Pucella R. Dealing with logical omniscience: expressiveness and pragmatics. Artificial Intelligence 2010.
Halpern JY, Rêgo LC. Reasoning about knowledge of unawareness. Games and Economic Behavior 2009;67:503–25.
Held A, Buchholz S, Schill A. Modeling of context information for pervasive computing applications; 2002.
Hervás R, Bravo J, Fontecha J. A context model based on ontological languages: A proposal for information visualization. Journal of Universal Computer Science 2010;16:1539–55.
Hightower J, Brumitt B, Borriello G. In: Proceedings fourth IEEE workshop on the mobile computing systems and applications; 2002. p. 22–28.
Hinz M, Pietschmann S, Fiala Z. A framework for context modeling in adaptive web applications. IADIS International Journal of WWW/Internet 2007:5.
Hoffmann M. User-centric identity management in open mobile environments. Privacy, Security and Trust within the Context of Pervasive Computing 2005: 99–104.
Hoffmann M, Stotz JP. Trustworthy user-centric identity management based on personalised java cards. Wireless Personal Multimedia Communications (WPMC), Aalborg, Denmark; 2005.
Hong JI, Landay JA. An architecture for privacy-sensitive ubiquitous computing. Presented at the second international conference, Boston, MA, USA; 2004. p. 177.
Hong J, Suh E-H, Kim J, Kim S. Context-aware system for proactive personalized service based on context history. Expert Systems with Applications 2009;36: 7448–57.
Hong J-yi, Suh E-ho, Kim S-J. Context-aware systems: a literature review and classification. Expert Systems with Applications 2009;36:8509–22.
Indulska J, Robinson R, Rakotonirainy A, Henricksen K. Experiences in using CC/PP in context-aware systems. In: Proceedings of the international conference on mobile data management (MDM), vol. 2574; 2003. p. 247–61.
Jonsson M. Context shadow: a person-centric infrastructure for context aware computing. In: Proceedings of the artificial intelligence in mobile systems workshop in conjuction with European conference on artificial intelligence (ECAI); 2001.
Julien C, Payton J, Roman G-C. Reasoning about context-awareness in the presence of mobility. Electronic Notes in Theoretical Computer Science 2004;97: 259–76.
Kaiser J, Brudna C, Mitidieri C. COSMIC: s real-time event-based middleware for the CAN-bus. Journal of Systems and Software 2005;77:27–36.
Katsiri E, Mycroft A. A first-order logic model for context-awareness in distributed sensor-driven systems. In: Proceedings of the first international workshop on requirements and solutions for pervasive software infrastructures; 2006.
Keiser J, Kriengchaiyapruk T.. 2008 IEEE Congress on Services 2008-Part I. 2008. p. 105–6.
Khedr M, Karmouch A. ACAI: agent-based context-aware infrastructure for spontaneous applications. Journal of Network and Computer Applications 2005;28:19–44.
Khedr M, Karmouch A. ACAI: agent-based context-aware infrastructure for spontaneous applications. Journal of Network and Computer Applications 2005;28:19–44.
Khungar S, Riekki J. A context based storage system for mobile computing applications. ACM Journal of Mobile Computing and Communications Review 2005;9:64–8.
Kim M, Lee JW, Lee YJ, Ryou JC. Cosmos: a middleware for integrated data processing over heterogeneous sensor networks. ETRI Journal 2008a;30: 696–706.
Kim M, Lee JW, Lee YJ, Ryou JC. Cosmos: a middleware for integrated data processing over heterogeneous sensor networks. ETRI journal 2008b;30:696–706.
Kirsch-Pinheiro M, Villanova-Oliver M, Gensel J, Martin H. Context-aware filtering for collaborative web systems. Presented at the the 2005 ACM symposium, Santa Fe, New Mexico; 2005. p. 1668.
Kitchenham B. Procedures for performing systematic reviews, 2004.
Kitchenham B, Pearl Brereton O, Budgen D, Turner M, Bailey J, Linkman S. Systematic literature reviews in software engineering—a systematic literature review. Information and Software Technology 2009;51:7–15.
Koen DB, Bender W. Time Frames: temporal augmentation of the news. IBM Systems Journal 2000.
Kofod-Petersen A, Mikalsen M. Context: representation and reasoning—representing and reasoning about context in a mobile environment. Revue D'intelligence Artificielle 2005;19:479–98.
Korpipää P, Malm EJ, Salminen I, Rantakokko T, Kyll\önen VK\äns\äl\ä I. Context management for end user development of context-aware applications. In: Proceedings of the sixth international conference on Mobile data management; 2005. p. 304–8.
Korpipaa P, Mantyjarvi J, Kela J, Keranen H, Malm EJ. Managing context information in mobile devices. Pervasive Computing, IEEE 2003;2:42–51.
Krishnamurthy S, Luo L, Son S, Stankovic J, Stoleru R, Wood A, et al. In: Proceedings of the 24th International Conference on distributed computing systems; 2004. p. 582–9.
Kühn B, Belkin A, Swerdlow A, Machmer T, Beyerer J, Kroschel K. Knowledge-driven opto-acoustic scene analysis based on an object-oriented world modeling approach for humanoid robots. In: Proceedings-ISR/ROBOTIK 2010, 2010.
Kummerfeld, B., Quigley A, Johnson C, Hexel R. Merino: Towards an intelligent environment architecture for multi-granularity context description; 2003.
Lalbakhsh P, Sohrabi N, Fesharaki MN. The role of service oriented architecture in battlefield situational awareness; 2009.
Leinonen P, Järvelä S, Häkkinen P. Conceptualizing the awareness of collaboration: a qualitative study of a global virtual team. comput. supported coop. work 14; 2005. p. 301–22.
Lieberman H, Selker T. Out of context: Computer systems that adapt to, and learn from, context. IBM Systems Journal 2010;39:617–32.
Little M. Ws-caf: contexts, coordination and transactions for web services. On the move to meaningful internet systems 2007: CoopIS, DOA, ODBASE, GADA, and IS; 2010. p. 439–53.
Liu H. Context-aware agents in cooperative design environment. International Journal of Computer Applications in Technology 2010;39:187–98.
Ma SM, Wang RC, Ye N. An uncertainty reasoning approach based on set pair analysis for context awareness. Nanjing Youdian Daxue Xuebao (Ziran Kexue Ban) 2009;29:64–7.
Magalhães R. Organizational knowledge and technology: an action-oriented perspective on organization and information systems. Edward Elgar Publishing; 2004.
Malik NA, Javed MY, Mahmud U. Estimating user preferences by managing contextual history in context aware systems. JSW 4, 2009.
McCarthy J. Notes on formalizing context. Presented at the Proceedings of the 13th international joint conference on Artificial intelligence, USA; 1993.
Moon A, Kim H, Kim H, Lee S. Context-aware active services in ubiquitous computing environments. ETRI Journal 2007;29:169–78.
Moore P, Hu B, Wan J. Smart-context: a context ontology for pervasive mobile computing. The Computer Journal 2010;53:191–207.
Moura AI, Ribeiro CHC, Costa AHR. WBLS: a signal presence-based Wi-Fi localisation system for mobile devices in smart environments. International Journal of Knowledge-based and Intelligent Engineering Systems 2009;13:5–18.
Müller C, Martín-Díaz O, Ruiz-Cortés A, Resinas M, Fernández P. Improving temporal-awareness of WS-agreement. Service-Oriented Computing—ICSOC 2007; 2010. p. 193–206.

Munnelly J, Fritsch S Clarke S. An aspect-oriented approach to the modularisation of context. In: Proceedings of the fifth annual IEEE international conference on the pervasive computing and communications'2007, PerCom '07; 2007. p. 114–24.

Neale DC, Carroll JM, Rosson MB. Evaluating computer-supported cooperative work: models and frameworks. In: Proceedings of the 2004 ACM conference on computer supported cooperative work, CSCW '04. ACM, New York, NY, USA; 2004. p. 112–21.

Niu W, Li G, Zhao Z, Tang H, Shi Z. Multi-granularity context model for dynamic Web service composition. Journal of Network and Computer Applications 2010;34:312–26.

Nugent C, Dersingh A, Liscano R, Jost A, Ahmad MS, Saxena V, et al. Context-aware access control using semantic policies. Ubiquitous Computing And Communication Journal (UBICC) Special Issue on Autonomic Computing Systems and Applications 2008;3:19–32.

Oh S, Woo W. CAMAR: Context-aware mobile augmented reality in smart space; 2009. p. 48–51.

Omoronyia I, Ferguson J, Roper M, Wood M. A review of awareness in distributed collaborative software engineering, vol. 40; 2010.

Patrikakis CZ, Kyriazanos DM, Voulodimos AS, Nikolakopoulos IG. Trust and security in personal network environments. International Journal of Electronic Security and Digital Forensics 2009;2:365–76.

Pereira R, Ricarte I, Gomide F. Information retrieval with FROM: the fuzzy relational ontological model. International Journal of Intelligent Systems 2009;24(3):340–56.

Pierra G. Context representation in domain ontologies and its use for semantic integration of data. Journal on Data Semantics X 2008:174–211.

Pinheiro MK, Carrillo-Ramos A, Villanova-Oliver M, Gensel J, Berbers Y. Context-aware adaptation in web-based groupware systems. Advanced Information and Knowledge Processing 2010:1.

Ranganathan A, Campbell RH. An infrastructure for context-awareness based on first order logic. Personal and Ubiquitous Computing 2003;7:353–64.

Ranganathan A, Muhtadi J, Chetan S, Campbell R, Mickunas D. MiddleWhere: a middleware for location awareness in ubiquitous computing applications. In: Proceedings of the fifth ACM/IFIP/USENIX international conference on Middleware. Springer-Verlag New York, Inc., Toronto, Canada; 2004. p. 397–416.

Ray P, Shahrestani S, Daneshgar F. The role of awareness modelling in cooperative management. Journal of Information Systems Frontiers 2005a;7:299–316.

Ray P, Chattopadhyay S. Fuzzy awareness model for disaster situations. International Journal for Intelligent Decision Technologies 2009.

Ray P, Shahrestani SA, Daneshgar F. The role of fuzzy awareness modelling in cooperative management. Information Systems Frontiers 2005b;7:299–316.

Rennecker J. Promoting awareness in distributed mobile organizations: a cultural and technological challenge. In: Proceedings of the 2005 international ACM SIGGROUP conference on supporting group work; 2005. p. 442–3.

Riemer, K., Haines, R., 2008. Pools and streams: a theory of dynamic, Practice-Based Awareness Creation in Mediated-Communication.

Robinson P, Beigl M. Trust context spaces: an infrastructure for pervasive security in context-aware environments. Security in Pervasive Computing 2004:119–29.

Román M, Hess C, Cerqueira R, Campbell RH, Nahrstedt K. Gaia: a middleware infrastructure to enable active spaces. IEEE Pervasive Computing 2002;1:74–83.

Sakhanenko NA, Luger GF. Model failure and context switching using logic-based stochastic models. Journal of Computer Science and Technology 2010;25:665–80.

Salem B, Rauterberg M. Multiple user profile merging (MUPE): key challenges for environment awareness. Ambient Intelligence 2004:196–206.

Sánchez L, Rosario Suárez M, Villar JR, Couso I. Mutual information-based feature selection and partition design in fuzzy rule-based classifiers from vague data. International Journal of Approximate Reasoning 2008;49:607–22.

Sarma A. A survey of collaborative tools in software development. UCI, ISR Technical Report, UCI-ISR-05-3, 2005.

Schilit B, Adams N, Want R. Context-aware computing applications. In: Proceedings of the workshop on mobile computing systems and applications; 1994. p. 85–90.

Schmidt A, Gross T, Billinghurst M. Introduction to special issue on context-aware computing in CSCW. Computer Supported Cooperative Work (CSCW) 2004;13: 221–2.

Schnaitter K, Spiegel J, Polyzotis N. Depth estimation for ranking query optimization. The VLDB Journal 2009;18:521–42.

Segev A, Gal A. Putting things in context: a topological approach to mapping contexts to ontologies. Journal on data semantics 2007;4:113–40.

Senart A, Cunningham R, Bouroche M, Reynolds V, Cahill V. MoCoA: customisable middleware for context-aware mobile applications. Journal of Cooperative Information Systems 2006:1722–38.

Serral E, Valderas P, Pelechano V. A model driven development method for developing context-aware pervasive systems. Ubiquitous Intelligence and Computing 2010:662–76.

Şensoy M, Zhang J, Yolum P, Cohen R. Poyraz: context-aware service selection under deception. Computational Intelligence 2009;25:335–66.

Shabtai A, Kanonov U, Elovici Y. Intrusion detection for mobile devices using the knowledge-based, temporal abstraction method. Journal of Systems and Software 2010;83:1524–37.

Shand B, Dimmock N, Bacon J. Trust for ubiquitous, transparent collaboration. Wireless Networks 2004;10:711–21.

Sharifi M, Naghavian L. Providing location privacy in pervasive computing through a hybrid mechanism. International Journal of Internet Technology and Secured Transactions 2010;2:160–73.

Sharifi M, Rahmani S, Kolahdooz S. A routing-aware middleware-level mechanism for tuple-based pervasive systems; 2009. p. 242–46.

Sheikh K, Wegdam M, Van Sinderen M. Quality-of-context and its use for protecting privacy in context aware systems. Journal of Software 2008;3:83.

Sillari G. Models of awareness. Logic and the Foundations oF game and decision theory (LoFt 7) 3, 209; 2008a.

Sillari G. Quantified logic of awareness and impossible possible worlds. The Review of Symbolic Logic 2008b;1:514–29.

Sliman L, Biennier F, Badr Y. A security policy framework for context-aware and user preferences in e-services. Journal of Systems Architecture 2009;55:275–88.

Solt I, Tikk D, Gál V, Kardkovács ZT. Semantic classification of diseases in discharge summaries using a context-aware rule-based classifier. Journal of the American Medical Informatics Association 2009;16:580.

Soylu A, Causmaecker PD, Desmet P. Context and adaptivity in pervasive computing environments: links with software engineering and ontological engineering. JSW 2009:4.

Stojanovic L, Schneider J, Maedche A, Libischer S, Studer R, Lumpp T, et al. The role of ontologies in autonomic computing systems. IBM Systems Journal 2010;43:598–616.

Storey M-AD, Čubranić D, German DM. On the use of visualization to support awareness of human activities in software development. Presented at the the 2005 ACM symposium, St. Louis, Missouri; 2005. p. 193.

Strang T, Linnhoff-Popien C. Service interoperability on context level in ubiquitous computing environments. In: Proceedings of the international conference on advances in infrastructure for electronic business, education, science, medicine, and mobile technologies on the internet (SSGRR2003w); 2003.

Strassner J, de Souza JN, van der Meer S, Davy S, Barrett K, Raymer D, et al. The design of a new policy model to support ontology-driven reasoning for autonomic networking. Journal of Network and Systems Management 2009;17:5–32.

van Kranenburg H, Bargh MS, Iacob S, Peddemors A. A context management framework for supporting context-aware distributed applications. Communications Magazine, IEEE 2006;44:67–74.

Taconet C, Kazi-Aoul Z, Zaier M, Conan D. CA3M: a runtime model and a middleware for dynamic context management. On the move to meaningful internet systems: OTM 2009; 2009. p. 513–30.

Talaei-Khoei A, Solvoll T, Ray P, Parameshwaran N. Maintaining awareness using policies; enabling agents to identify relevance of information. Journal of Computer and System Sciences, in press-a. doi:10.1016/j.jcss.2011.05.013.

Talaei-Khoei A, Solvoll T, Ray P, Parameshwaran N. Policy-based awareness management (PAM): case study of a wireless communication system at a hospital. Journal of Systems and Software, in press-b. doi:10.1016/j.jss.2011.05.024.

Tesoriero R, Gallud JA, Lozano MD, Penichet VMR. CAUCE: model-driven development of context-aware applications for ubiquitous computing environments. Journal of Universal Computer Science 2010;16:2111–38.

Ulieru M, Worthington P. Adaptive risk management system (ARMS) for critical infrastructure protection. Journal of Integrated Computer-Aided Engineering, Special Issue on Autonomic Computing in Engineering in Integrated Computer-Aided Engineering 2006;12(2):63–80.

Vetro A, Timmerer C, Devillers S. Digital item adaptation-tools for universal multimedia access. The MPEG-21 Book 2006:282–331.

Wang XH, Zhang DQ, Gu T, Pung HK. Ontology based context modeling and reasoning using OWL. In: Proceedings of the IEEE international conference on pervasive computing and communications workshops, IEEE Computer Society, Los Alamitos, CA, USA; 2004. p. 18.

Woolridge M, Wooldridge MJ. Introduction to Multiagent Systems. John Wiley & Sons, Inc; 2001.

Wustmann P, Braun I, Dargie W, Berger M. A comprehensive approach for situation-awareness based on sensing and reasoning about context. Ubiquitous Intelligence and Computing 2010:143–57.

Xirouhaki C, Gallardo-Antolín A, Koubarakis M, Navia-Vázquez A, Molina-Bulla HY, Rodrí?guez-González AB, et al. I-Gaia. Presented at the the first international joint conference, Bologna, Italy; 2002. p. 1272.

Yamabe T, Takagi A, Nakajima T. Citron: A Context Information Acquisition Framework for Personal Devices.Los Alamitos, CA, USA: IEEE Computer Society; 2005 pp. 489–495.

Yiqiang Chen, Zhuo Sun, Juan Qi, Hao Hu, D, Qiang Yang. LoSeCo: Location-based search computing for pervasive device augmentation. In: IEEE International Conference on Pervasive Computing and Communications, PerCom 2009; 2009. pp. 1–6.

Zacarias M, Pinto HS, Magalhães R, Tribolet J. A context-aware and agent-centric perspective for the alignment between individuals and organizations. Information Systems 2010a;35:441–66.

Zacarias M, Pinto HS, Magalhães R, Tribolet J. A context-aware and agent-centric perspective for the alignment between individuals and organizations. Information Systems 2010b;35:441–66.

Zhang Y, Li F. A model of context awareness agent system based on dynamic fuzzy logic. In: Proceedings of the fourth international conference on fuzzy systems and knowledge discovery—volume 01, FSKD '07. IEEE Computer Society, Washington, DC, USA; 2007. p. 555–61.

Zimmermann A. Context-awareness in user modelling: requirements analysis for a case-based reasoning application. Case-Based Reasoning Research and Development 2003:1064.

Zotero Co., 2010. Zotero [WWW Document]. URL 〈http://www.zotero.org/〉.