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ORIGINAL RESEARCH

Descriptive theory of awareness for groupware development

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Abstract

People working in a cooperative manner need to be updated on events and informed about other users and their activities in their workspaces in order to collaborate effectively. It is necessary that group members feel they are part of the group, in particular when they are geographically dispersed. This kind of information is called awareness and it is an important research aspect in the computer supported cooperative work and computer supported collaborative learning areas. Supporting awareness has important, if subtle, benefits, such as increasing the effectiveness of collaborative work, fostering social relationships, and improving the general wellbeing of individuals. To create and define awareness mechanisms in collaborative environments supported by computers is a complex process that includes several steps that need to be considered, focused on understanding characteristics of interdependent group work with the objective of designing adequate computer-based technology to support cooperative work processes. However, in the literature it is so difficult to find out a structured method that allow designers to develop collaborative applications centered on awareness aspects. This paper proposes the definition of a framework that could assist groupware engineers to incorporate awareness mechanisms in their developments. This framework has a methodological proposal or set of phases to follow, as well as a taxonomy that includes the awareness information that should be incorporated to improve the collaborative experience. The paper presents a review of several awareness mechanisms, frameworks and uses proposed in the literature from a software engineering perspective, focusing on the aspects to be considered when designing and implementing awareness mechanisms in groupware tools. A descriptive theory of awareness for the purpose of supporting groupware development is thus generated. Finally, a case study is described using the framework proposed.

Keywords Awareness support · CSCW · Groupware · Taxonomy · CSCL

1 Introduction

Computer-supported cooperative work or CSCW is computer-assisted coordinated activity carried out by groups of collaborating individuals (Baecker et al. 1995). CSCW is the area of research in which the impact of technology on group interaction is studied in order to facilitate group work (Ellis et al. 1991). Groupware is distinguished from normal software by the basic assumption it makes: Groupware makes the user aware that he is part of a group, while most other software seeks to hide and protect users from each other (Lynch et al. 1990). Group members interact with each other either through the manipulation of artifacts or through direct communication channels (Tee et al. 2009). It is clear that group members need to remain updated on the state and changes of the virtual shared-space and the actions other group members are carrying out in order to interact

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smoothly. This kind of information is called "awareness information" (Dourish and Bellotti 1992).

Although not fully understood, awareness is a complex cognitive process that allows human beings to perceive and understand their environment or immediate context and adapt to it (Saner et al. 2010). Awareness in human beings allows them to *perceive, understand and adapt* to their environment or immediate context (Endsley 2000; Tenenberg et al. 2016). In groupware systems, awareness is a medium that provides contextual information about the past activities, present state, and future options of a virtual environment, triggering the cognitive process described above (Sohlenkamp 1999), so that group members can perceive the state and changes of their virtual shared space. The provided contextual information answers questions such as *who* does/did an action, *what* is/was done, *where* are/were the individuals/objects, *when* did an event occur and *why* did an event occur (Gutwin and Greenberg 2002; Abowd and Mynatt 2000). Thanks to contextual information users can perceive and understand what is going on in their shared environment and adapt their behavior accordingly (Dourish and Bellotti 1992). The inclusion of awareness mechanisms in a groupware application contributes to a reduction in the worker's meta-cognitive effort to understand what is going on in the virtual shared environment in order they can feel as a part of a group (Bostrom et al. 2009). By being aware, individuals can plan their own actions and acquire new information (Endsley 2000). As a consequence, the transition from individual to group work is eased (Teasley et al. 2000), making work a more natural and fluid process (Gutwin and Greenberg 2002), reducing the additional workload of coordination (Dourish and Bellotti 1992; Gutwin and Greenberg 2002; Nacenta et al. 2007), effort duplication and work integration. In addition, awareness enables an increase in opportunities for mutual communication and thus facilitates the tasks of coordination and cooperation (Gutwin et al. 2008). However, while awareness of others is something that we take for granted in the everyday world, maintaining this awareness has been demonstrated to be difficult in real-time distributed systems in which information resources are poor and people are geographically dispersed (Tran et al. 2006a; Greenberg and Gutwin 2016).

It is becoming increasingly apparent that being able to stay aware of others plays an important role in the fluidity and naturalness of collaboration, and supporting the awareness of others is considered to be one way of reducing the weakest characteristic of remote collaboration. Awareness is a concept that promises to significantly improve the usability of real-time distributed groupware (Dourish and Bellotti 1992; Gutwin et al. 1996b; Xiao 2013; Tang et al. 2014). Despite this attention, no clear overall picture of awareness has yet emerged from groupware researchers (Steinmacher et al. 2013; Lopez and Guerrero 2017). With a few exceptions, the awareness support presented to date involves localized solutions to specific domain problems, and isolated approaches and principles that are difficult to generalize for other situations. Most importantly, this aspect means that groupware designers have little principled information available regarding how to support awareness in other domains or new systems. Faced with a blank slate for each new application, designers must reinvent awareness from their own experience of what it is, how it works, and how it is used in the task at hand.

Current awareness systems have been influenced by the media spaces of the 80s, which supported sustained audio or video links among remote co-workers and emphasized the importance of awareness for maintaining social coherence (Bly et al. 1993). But the benefits of social awareness proved to be difficult to quantify (Gross et al. 2005). This aspect had a result, awareness systems were sometimes criticized as having marginal benefit and the problem with awareness in CSCW (Schmidt 2002), was largely ignored for a decade. But the advent of WWW and in some cases significantly cheaper consumer electronics have led to a resurgence of interest in awareness systems, both as research prototypes and in commercial systems. Awareness systems have moved from the office into domestic and healthcare environments and are starting to appear on mobile devices as well. Today, many of the functions that appeared in early research prototypes have reached the general public: instant messaging and mobile phones provide awareness cues about others who are currently on-line and internet-connected photo frames and robots permit users to display awareness information, either from broadcasts such as the weather, or from members of the participant's social network. As this technology becomes more affordable, with greater quality and diversity, awareness systems offer tremendous potential for innovation, with a wide range of forms and contexts for transforming the space around us (Markopoulos et al. 2007).

According to Schmidt (2002), the initial aim of awareness research in groupware was to produce the apparently seamless alignment of group members' actions when working in face-to-face settings. Thus, awareness was defined according to the different strategies used by researchers to achieve such an effect. The lack of a consensual definition of awareness (Tenenberg et al. 2016) hampers the definition of a systematic body of principles and guidelines for its design and evaluation; hence awareness mechanisms design is often addressed in an ad-hoc manner or entirely neglected in many groupware systems (Ackerman and Starr 1995; Schmidt 2002). Despite its importance, awareness support is not systematic and developers must build it from scratch for each new application. This situation led us to consider the objective of this work, and to pose a series of research questions to which we wanted to provide answers.

On the other hand, advances in networks, hardware and interfaces have made possible to develop collaborative systems that follow new paradigms such as the one of ambient intelligence (AmI) (Shadbolt 2003). The main aim of AmI is the intelligent adaptation of the behavior of a context-aware computational environment to our preferences and habits, so that our experiences and routines in daily life are improved (López de Ipiña et al. 2006). AmI starts from the idea of ubiquitous computing and adds a new layer of artificial intelligence in order to carry out the adaption aforementioned.

New styles of interaction appear in ambient systems. A difference is made between explicit and implicit interaction (Schmidt 2000). Where explicit interaction is the usual one, in which the user is aware of the fact that an interaction with a system is taking place, implicit interaction is that one in which the interaction happens and the user is not aware of it. User interfaces that are used in situations of implicit interaction may be quite different from the ones that have been usually present in situation of explicit interaction. Many of them deal with physiological information, such as information from the senses (Obrist et al. 2016) or the brain (Mealla et al. 2011).

In this kind of systems, where new kinds of interaction take place and new devices are used, the concept of awareness is even more important than in classic collaborative systems. As users are not always aware of the interactions when they happen, it is essential to provide them with a suitable way to get them aware and notified of all that is happening in the scope of the system and the collaboration. But it is worth noting that awareness support must be provided in a different way in this kind of systems, as they own some relevant specifities to be taken into account. There are several recent works that address the issue of awareness support in AmI systems (Kim and Yoon 2018; Alegre et al. 2018; Chung et al. 2018). Therefore, the validation of the work proposed in this paper has been made by applying it to an AmI scenario with implicit interaction.

Our main objective is, therefore, to propose a framework that assists groupware engineers to incorporate awareness mechanisms in their developments. This framework will include a *methodological proposal* or set of phases to follow, as well as a *taxonomy* that includes the awareness information (contextual information) that needs to be incorporated to improve the collaborative experience. Although a consensual definition of awareness may appear impossible to reach due to the limited understanding of the phenomena, many years of research has revealed some useful insights regarding its design (Gross 2013): awareness mechanisms require (a) the identification of the kind of information useful to provide, (b) the strategies for distributing such information, and the (c) method for representing such information (Lopez and Guerrero 2017; Antunes et al. 2014). The proposed process will incorporate as much phases as needed to support these three aspects.

The research conducted, and described in this article, aims to answer the following research question (RQ):

RQ. *Is it possible to provide groupware engineers with a method or set of phases to assist them in incorporating awareness into their developments?*

Since the research question under consideration may be a broad one, we propose a number of sub-questions that can help answer it:

RQ1. *What is the current state of research on methodologies or processes to guide groupware developers in incorporating awareness mechanisms into groupware development?*

RQ2. *What are the phases that a process of designing awareness mechanisms should incorporate?*

RQ3. *What aspects or design decisions should be taken at each stage?*

RQ4. *What types of awareness are usually supported?*

RQ5. *What awareness information (contextual information) should be collected or what aspects should be taken into account?*

The design of the methodological process and the proposed taxonomy is based on a detailed review of scientific literature on awareness for groupware systems from a Software Engineering perspective. This review also serves to better understand of what awareness is and how to design and implement awareness mechanisms. The paper also intends to give an insight into what kind of awareness representation might be useful according to the tool type and usage.

This paper is structured as follows. Section 2 is about the background of the work. Section 3 presents the research method followed in the development of the proposal. Section 4 describes the general components of awareness mechanisms, describing five phases for designing and developing awareness support: awareness information goals (Sect. 4.1), awareness information identification (Sect. 4.2), modeling (Sect. 4.3), information distribution (Sect. 4.4) and awareness user interfaces (Sect. 4.5). Section 5 presents a case study in a collaborative scenario: Ambient Intelligence (AmI), where it is depicted how the model proposed could be used. Section 6 discusses the challenges of incorporating awareness into groupware systems (privacy violation, information overload, interruptions and evaluation), the implications of using the proposed framework for researchers and practitioners, some guidelines and recommendations for its application, the limitations of the work done and finally some open issues and possible lines of continuation. Section 7 presents some conclusions and further work.

2 Background

The word awareness (noun) corresponds to the subject aware, which comes from the conjunction of two English words "ge" (associative prefix) and "war" (wary). Aware means "having or showing realization, perception or knowledge" and is associated with "vigilance in observing or alertness in drawing inferences from what one experiences", according to the Merriam Webster Dictionary. Although not fully understood, an interesting insight from neuroscience could explain the underlying process: awareness can be thought of as the ability to direct one's attention to specific aspects of the environment, selecting from among a range of perceived stimuli and storing the selected stimuli in working memory (Charlton 2000). Because this process has a longer duration than any other cognitive process (probably hundreds or thousands of milliseconds), the stimuli stored there remains active and has the chance to be integrated together (forming "cognitive representations") giving rise to complex thought. Therefore, that an effective collaborative interaction takes place depends not only on the technological aspect, but also on the human (cognitive) aspect, which is enhanced through a good support to awareness.

In this paper we are interested in the technological support to awareness, but without ignoring the cognitive implications that including awareness mechanisms has (Tenenberg et al. 2016). At a technological level, it can be affirmed that the effective use of groupware systems relies on promoting three main characteristics (according to the 3C model): communication, coordination and cooperation/collaboration (Ellis et al. 1991; Teufel and Teufel 1995; Oemig and Gross 2017). Cooperation and collaboration are higher level processes that builds on the two previous ones (communication and coordination) (Gutwin et al. 2016). Thus, effective collaboration and cooperation depends on providing adequate support for these two aspects. It is necessary to point out that, although in this work we will not go deeper into the distinction between cooperation and collaboration, both concepts should not be used indistinguishably, since as pointed out by Dillenbourg et al. (1995) there are differences between them that should not be ignored and that affect the design and implementation of the groupware system (Molina et al. 2013)[1].

2.1 Awareness and support to communication

To perceive, to recognize and to understand other people's activities are basic requirements for interaction and human communication in general. The development of suitable human behavior requires awareness about people and work objects. People may use technology to communicate various types of information through many channels, both implicitly and explicitly. The initial groupware applications tended to be technical solutions that supported the explicit mechanisms of human cooperation: explicit communication with others, explicit coordination of activities, or implicit communication by means of allowing shared access to work objects (Dadlani et al. 2009).

In addition to coordinated behavior, communication allows group members to engage in informal interaction (Gutwin et al. 2008; Willaert et al. 2012). Whittaker and colleagues (1994) went even further by categorizing informal interaction as intended, when it is sought out by one party; opportunistic, when it is anticipated by one party but resulting from a chance encounter; and spontaneous, when it is unanticipated by either party. Critical to supporting the occurrence of such encounters is awareness of when and where the sought after person may be found.

Researchers and developers of technology to support distributed work teams have focused on creating lightweight awareness tools that would provide such accessibility information to non-collocated team members. A variety of tools have been implemented including those that provide background awareness, some that require active glancing, and others that provide real 3-D environments which simulate "running into" others, as one might do in a hallway or a cafeteria when people work in the same location.

2.2 Awareness and support to cooperation

Interest in awareness related topics results from the fact that awareness support is increasingly identified as a crucial part of successful cooperation (Talaei-Khoei et al. 2014a, b). It forms an essential and integral part of cooperative work. An example of the importance of awareness for collaborative work is provided by Gaver's model of shared work. This model identifies three levels of increasingly focused

[1] *Cooperation* entails the division of work to be performed, so that each person is responsible for his or her own portion of work. Members of the group pursue the same goals, but act independently in their own tasks, or perform the same task but in separate parts of the shared context. *Collaboration* entails the mutual commitment of the participants, as well as a coordinated effort to solve a problem. Collaboration is, therefore, a superior activity in which, in addition to cooperating, the members of the team have to work together on common tasks and towards a common outcome. The result obtained moves through different states to reach a state of final results obtained

Footnote 1 (continued)

by the group. In the final product, it is difficult to determine the contribution of each member of the group.

cooperation: serendipitous communication, division of labor, and focused collaboration (Gaver 1991). Awareness is necessary at all three levels of collaboration, but the degree to which it is required varies with the focus: increasingly focused collaboration requires additional awareness.

Nevertheless, it is usual that such approaches ignore the implicit aspects of human cooperation: the implicit communication based on nonverbal signals (Gabbott and Hogg 2000), the implicit coordination by means of the common control of a shared object (Reddy et al. 2001), and the implicit establishment of conventions for the use of groupware tools (Mark 2002). The difference between explicit and implicit communication is crucial: explicit communication consists of all the forms of structured communication, either via verbal channels (face-to-face mediated by technology), written documents, or passing messages. However, a significant amount of information is performed implicitly, mediated by a variety of channels such as gestures, suggestive fragments, etc. Implicit communication is often mediated indirectly by work tools. In this case, the state of the work objects provides the implicit means for communication between the group members. These tools provide the flexibility that is inherent and essential to most of the cooperation processes and information awareness provision thus becomes a fundamental element for addressing such implicit approaches.

Perhaps the main benefit of awareness support in CSCW software is the creation of the knowledge state that enables an effective interaction with the environment and aids the decision making process during task execution (Yuan et al. 2016; Tiwari 2016). These two features are needed in real life interactions and performance, so they are also needed in software-supported interaction and performance.

2.3 Conceptualization and support to awareness

The aforementioned concepts (communication and cooperation) are included in the 3C model. This model together with the Johansen's Time–Space Matrix (Johansen 1988) have been used several times in literature, more for classification purposes than as a conceptual or taxonomic model (Penichet et al. 2007a, b).

There are many different models and frameworks that have been used for conceptualizing the field of CSCW/CSCL, with the aim of making easier the process of developing collaborative systems. A detailed comparative analysis of conceptual frameworks in the CSCW area is described by Molina et al. (2013). Some of them are Group Task Analysis (GTA) (van Welie and van der Veer 2003), the team-enabled workflow reference model (van der Aalst and Kumar 2001), AMENITIES (Garrido et al. 2005), TOUCHE (Penichet et al. 2007a, b), CIAN (Molina et al. 2013), MoCA (Lee and Paine 2015) or CSRMF (Teruel et al. 2017).

Each model or framework owns some specific features, although there are some concepts and abstractions that appear in almost all of them. This way, most approaches try to formalize how an *actor* belonging to a *group* do a certain *work* (in the form of an *activity* or *task*) handling some *objects*. Also, tasks or activities usually can be split in work units of a lower level. It is important here the use of *task models* or similar abstractions, which is especially relevant in proposals such as CIAN. Some other concepts are present in just some of the proposals, such as *restrictions* that limit the work or *sessions* to organize who perform the work and when it is done. Therefore, a proposal that aims to help groupware developers must take all these concepts, or at least most of them, into account.

Some of these taxonomies or conceptual models have evolved to the proposal of graphical notations that allow specifying in a more abstract way the features that a groupware system should support (Penichet et al. 2007a, b; Molina et al. 2013). However, there are hardly any proposals that assist groupware engineers when designing awareness support, by means of taxonomies (Gallardo et al. 2011), formal methods and specification techniques (Penichet et al. 2009; Figueroa-Martinez et al. 2011), notations (Teruel et al. 2017) or proposing a series of phases that assist them in this task.

3 Research method

3.1 Systematic mapping study

In previous works, we have addressed several topics in the field of awareness. We have made contributions to the design and development of groupware applications and Computer-Supported Collaborative Learning (CSCL) systems (Collazos et al. 2003), even in AmI scenarios (Gallardo et al. 2018), the conceptualization of awareness (Gallardo et al. 2011), to the model-based development of these types of systems (Gallardo et al. 2012; Gallardo et al. 2013) and to the evaluation of awareness support in collaborative systems (Gallardo et al. 2011; Molina et al. 2015). Now, in order to update and complete the set of known references and contributions, we have faced the challenge of carrying out a systematic literature review and mapping study.

A systematic literature review provides an objective procedure for identifying the nature and extent of the research that is available to answer a particular research question (Kitchenham et al. 2011; Petersen et al. 2015). Our main research questions in this literature review was the sub-questions enumerated in the Introduction section. Answering these questions will allow us to know which methods, frameworks or design processes of awareness support have been proposed, to determine which awareness mechanisms and information should be collected, as well as the main

Table 1 Main search string used in the literature review

Concept	Alternative terms and synonyms	
Groupware	groupware OR CSCW OR CSCL OR "collaborative work" OR "collaborative learning" OR "collaborative applications" OR "collaborative systems" OR "collaborative software" OR "distributed applications" OR "distributed systems" OR "distributed software"	AND
Development/design/methodology	design* OR develop* OR checklist OR guide* OR method* OR process OR approach* OR framework OR taxonomy*	AND
Awareness	awareness	

The asterisk symbol * signifies any character whose purpose it is to include any word variation of each search term (e.g., the search term 'method*' includes the following words: method OR methodology OR methodological OR. . .)

design decisions that should be taken into account when incorporating awareness mechanisms into our developments.

Before carrying out the literature review, a search was made for other works that already described systematic literature reviews (SLR) on the concept of awareness and its support. We are aware of two SLR conducted in the field of awareness (Steinmacher et al. 2013; Lopez and Guerrero 2017) whose research methods belong to the evidence-based paradigm (i.e., SMS and SLR) (Kitchenham et al. 2004). The first one (Steinmacher et al. 2013) is centered in awareness support in a specific type of groupware systems: Distributed Software Development (DSD). DSD offers specific awareness requirements, therefore, some of the findings of this paper focus on this particular type of groupware, so they may not be generalizable to groupware systems in general. The second SLR (Lopez and Guerrero 2017) focused on the analysis of data gathering and notification mechanisms in CSCW systems, but the review was focused on awareness support on non-traditional (ubiquitous) interfaces.

Although several relevant studies and literature surveys concerning awareness have been reported (Schmidt 2002; Rittenbruch and McEwan 2009; Fitzpatrick and Ellingsen 2013; Antunes et al. 2014), we are not aware of any work of this kind about methodologies or processes to guide groupware designers to design awareness support. It demonstrates that there is a need for a more systematic identification of which methods or frameworks have been proposed for incorporating awareness support in groupware.

Following the guidelines proposed by Kitchenham (2004) and Petersen et al. (2015) a systematic literature review has been performed. We conducted and combined manual and automatic searches with the search string shown in Table 1 in several digital libraries: DBLP, Google Scholar, Science@Direct, ACM Digital Library, IEEEXplore, ISI Web of Science and Scopus. This last digital database was the main source for detecting primary studies. We also manually searched the conference proceedings and journals in which studies relevant in groupware and awareness had previously been published: International Conference on Collaboration and Technology (CRIWG), International Conference on Computer Supported Cooperative Work in Design (CSCWD), Computer Supported Collaborative Learning (CSCL), International Conference of the Learning Sciences (ICLS) and International Conference on Cooperative Design, Visualization and Engineering (CDVE) conferences, among others. Some of the main journals surveyed were: International Journal of Computer-Supported Collaborative Learning, International Journal of Human–Computer Studies, Interacting with Computing, Computers in Human Behavior, Information and Software Technologies, Journal of Systems and Software, among others.

The search covered studies published between 1992 and 2018. The literature review was focused on studies in English only. The search started in 1992, as this is the year in which the concept of awareness was introduced by Dourish and Belotti (1992). The initial search returned 169 candidate primary papers. Reviewing the results, it was found that some relevant works were missing, and that they were useful to define the taxonomy. In subsequent searches we further refined the search string by including terms such as: conceptual*, model*, specific*, metamodel, widget*, visualizat*. This new search returned 240 papers, but after the application of exclusion criteria, the removal of duplicates and the reading of the title and abstract, only 135 papers were really considered as relevant for answering the research sub-questions posed.

As exclusion criteria, we adopted the following:

- Papers that are not focused on awareness in groupware design and development.
- Introductory papers for special issues, books and workshops.
- Duplicate reports of the same study in different sources.
- Tutorials, slides and lectures.
- Papers in which the term awareness appears, but focuses more on the psychological or cognitive aspect of it and not on technological support.
- Papers not written in English.

Most of the articles found were known to the authors of this paper, but the literature review made it possible to find new contributions and update the list of references. These new detected papers were read in full and considered in the process of creation of the method and taxonomy proposed in this work. The results of the analysis indicate that hardly any papers were found that proposed methods or processes to incorporate awareness support into collaborative systems (Talaei-Khoei et al. 2014a, b). Although there are relevant proposals on guidelines, checklists and techniques for specifying awareness mechanisms (Antunes et al. 2014; Teruel et al. 2017), they do not usually include a guide or set of steps to follow. Most of the works consulted are based on the framework proposed by Gutwin and Greenberg (2002). In addition, we detected the current interest in incorporating awareness support in games (Teruel et al. 2016; Wuertz et al. 2018). What allows the analysis of these proposals is to have a vision on the main types of awareness to support and the main awareness requirements to be supported (which makes it possible to respond to RQ4 and RQ5).

3.2 Taxonomy development process

As for the method used to create the *taxonomy* (described in Sect. 4.2), a *participatory design process* (Halskov and Hansen 2015) was followed in which the authors of this article (most of them experts with several years of experience in the development, design, modeling and evaluation of groupware systems and awareness support) and other colleagues (frequent users of this type of application) collaborated jointly. Expertise within the team included software development, gaming, pedagogical practice and interaction design.

The process of creating the taxonomy took several months in which articles that characterized and/or classified awareness mechanisms were jointly reviewed and a consensus was reached on their definition. Given the geographical distribution of the authors, collaborative repositories and e-mail were used to discuss the different phases of the process, the references found that might be useful, as well as the components of the taxonomy. Several face-to-face meetings were also held in the context of several conferences, workshops and short research stays that served to refine the proposal.

In the process of creating the taxonomy, the following phases were followed:

1. *Identification of basic categories and terms* (mainly types, subtypes and attributes of awareness). The basic terms of awareness domain were identified and definitions given for them and their properties were clarified and agreed upon. The main challenge in this stage was completeness. The different authors contributed with their perspective and previous experience when defining the final set of terms, definitions, categories, as well as the goals of the different types of awareness. The analysis of the related literature also allowed the initial listing to be refined. Two heuristics were applied in the creation of the draft: (a) *identification of most-frequent terms* and (b) *identification of synonyms or related terms*. In this process several concepts were added, others removed and others renamed.
2. *Creation of the classification of awareness support* (taxonomy structure) into main categories (*components*), subcategories (*attributes*) and supported awareness subtypes (*supports*). The main components of taxonomy are inspired by the Activity Theory (Engeström 2014; Engeström et al. 2016), which has been used on several occasions as a framework for specifying requirements in collaborative and workflow scenarios (Georg et al. 2015; Villegas et al. 2016), and the study of other conceptual frameworks on CSCW and CSCL in the literature (van Welie et al. 1998; van Welie and van der Veer 2003; van der Aalst and Kumar 2001; Garrido et al. 2005; Penichet et al. 2007a, b; Lee and Paine 2015; Teruel et al. 2017). The macro-categories (awareness components) were divided into a set of attributes. Static (*structure*) and dynamic (*state*) aspects were taken into account when determining attributes. Taking as inspiration the contributions of other authors, as well as the framework of Gutwin and Greenberg (2002), the list of attributes was completed and the relationship between the attributes and the subtype of awareness (*supports*) was determined.
3. Configuration of the *list of awareness mechanisms at a technological level* (*widgets*) and their relationship with the support of the different types and subtypes of awareness considered in the taxonomy.
4. *Detailed explanation* of all the terms included in the taxonomy, the main decisions or design alternatives related to them and inclusion of the main related bibliographical references.
5. *Discussion and refinement* of the proposal in *successive iterations*.

The following section describes the proposed framework, which includes the set of steps to be followed (*method*) to incorporate awareness mechanisms in collaborative systems, as well as the proposed *taxonomy* (Sect. 4.2).

4 A method for providing collaborative systems with awareness support

As pointed out in the introduction section, our goal is to provide a framework that helps software engineers in the process of designing and implementing awareness support in collaborative systems. Such framework should include

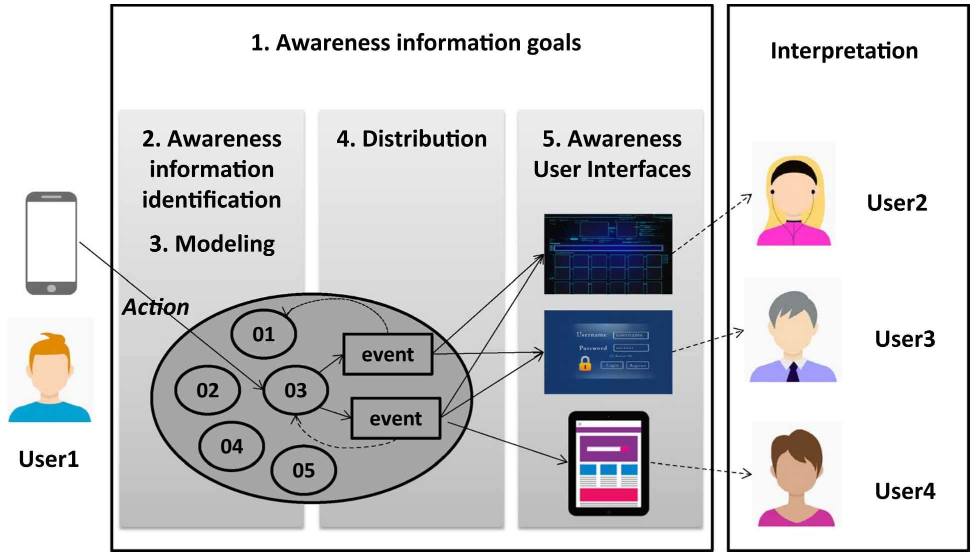

Fig. 1 The stages of Awareness support from the user's perspective. Adapted from (Sohlenkamp 1999)

a series of steps to guide the groupware developers in this work.

As pointed out by Sohlenkamp (1999), an awareness mechanism involves the support of at least three stages: recollection, distribution, and presentation of the awareness information. This framework has been used in the development of an application using awareness mechanisms in driving simulations environments (Alcazar et al. 2014). However there were some elements be updated, and in that way, we have defined a new model that is depicted in Fig. 1. The proposed model includes 5 stages: (1) Awareness Goals to support; (2) Awareness Information Identification; (3) Modeling, which is needed in order to integrate Awareness support in software systems developed through model-based methodologies (MDD); (4) Distribution; and (5) Awareness User Interfaces.

Figure 1 also serves as an outline for the rest of the paper, in which each of the proposed phases is described in detail. In the following sections the know-how acquired for implementing the challenges posed by the stages are presented.

As Schmidt (2011) reminds us, the purpose of providing awareness information to group members is to facilitate the seamless alignment of their actions. However, there is not yet a full understanding of the kind of information needed for creating such a seamless alignment or why it occurs. Section 4.1 (Phase 1) presents a summary of some strategies that have proven to be useful to groupware. If the design of the awareness mechanism focuses on the goal of providing such information throughout the four phases described, the evaluation of such a strategy may also be facilitated.

Regarding the identification stage, it requires the identification of the kind of awareness information to be perceived by group members and the context of where it occurs (Gross et al. 2005). The lack of contextual information when events are presented to users may lessen or distort their understanding (awareness) (Gross and Prinz 2004). Furthermore, it is important to determine the model of such information (e.g. events, actions, discourse items, etc.). This chosen model will impose a semantic interpretation on what can be perceived about the shared environment. The kinds of awareness information defined in the literature are varied and sometimes refer to similar concepts. In order to obtain an interesting classification, we have to focus on the context sources where information can be obtained. Section 4.2 presents such a classification (taxonomy).

Once the information has been identified and collected (Phase 2), it is temporarily or permanently stored in the system databases or repositories, where the previously modeled structure gives them meaning and their own place in the internal behavior (Phase 3). Then, it must be distributed to the users of the system. In order to do this, it is necessary to define a distribution strategy for propagation policies (e.g. broadcast, multicast, etc.), considering issues of privacy. Section 4.4 (Phase 4) describes some distribution strategies. In the fifth phase, the awareness and context-related information is rendered in the user's interface. At this point, representation metaphors must be carefully selected. Section 4.5 presents some interface strategies for representing information. Issues such as cognitive overload, interruption, preferences, etc. are also relevant at this stage.

4.1 Phase 1: Awareness information goals

The use of groupware systems depends on the needs and goals of users, groups and work teams to collaborate. The advance in information technologies and the WWW has led to rapid and profound advances in technologies, products and groupware functionalities and services: instant messaging,

Table 2 Types of awareness information that have been useful to CSCW

Awareness	Goal	Tool or research
Group	Inform about others' status, generally about group members	Almost every chat application (Gutwin et al. 2004)
Workspace	Inform about the shared workspace, including people, task and content information	Teamrooms (Digenti 2002), T-CUA (Pinelle and Gutwin 2008), (Rubart and Dawabi 2004)
Context	Provide a meaningful background for information	Magitti (Bellotti et al. 2008), Kimura (Voida et al. 2002)
Peripheral	Not an awareness type per se, but a technique to provide less cognitively demanding awareness	AROMA (Pedersen and Sokoler 1997), Sideshow (Cadiz et al. 2001)
Activity	Provide information about others' actions. This can include task and process information	TeamScope (Steinfield et al. 1999; Jang et al. 2002), T-CUA (Pinelle and Gutwin 2008)
Availability	Inform about group members availability	TeamScope (Jang et al. 2002)
Perspective	Inform about others' intentions and rationale. It is related to the Activity Awareness, but at the projection level	TeamScope (Jang et al. 2002), Magitti (Bellotti et al. 2008)
Community	Inform about shared interests and preferences	(Sumi and Mase 2000)
Presence	Inform about group members' presence	Talking in Circles (Rodenstein and Donath 2000), any chat application
Rhythm	Inform about others' future availability or presence. It is awareness at the projection level (Endsley 1995)	Awarenex (Begole and Tang 2007)

access to shared information repositories, shared authoring, social relationships, etc. In (Mittleman et al. 2008) a taxonomic model of collaboration technologies is proposed. The classification scheme proposed by these authors can be used to analyze, compare and contrast the capabilities offered by groupware products, since it includes indicators such as core functionality (conversation tools, shared editors, polling tools, video conferencing, etc.), the type of content supported (text, data-stream, etc.), or aspects such as access control or session persistence, among others.

However, in this paper we will not make a distinction at this level (of functionality or service offered), but will consider a distinction of a higher level of granularity. In this sense, two distinctions are traditionally made regarding the nature of group activities and the group goal. Work-related activities are studied in the area of CSCW while CSCL (Koschmann 1996; Stahl et al. 2006) studies learning situations. In both cases, successful group work is not simply the union of individual tasks but a set of coherent activities with good strategies of communication, cooperation and coordination among group members: communication is to share ideas, cooperation is to work together in some shared space, and coordination is to harmoniously combine the contributions from everybody (Ellis et al. 1991).

CSCW and CSCL pursue different goals. **CSCW** aims to support interaction in order to achieve a common goal reducing the effort required to do so; CSCL applications are intended to support a demanding interaction that allows learners to create knowledge while trying to achieve a common goal (Hinze-Hoare 2006). The CSCW literature has emphasized for some time that an effective and efficient cooperation requires that the individuals have at least information about other people's presence, availability, actions and shared artifacts (Schmidt and Bannon 2013). Table 2 summarizes some of the awareness information types that have been shown to be useful in CSCW applications.

Awareness in **CSCL** is important for effective learning, playing a major role in the way that learning environments create natural and efficient collaboration opportunities (Ogata et al. 2001; Tang et al. 2014; Álvarez et al. 2016). Most research in CSCL identifies knowledge awareness (Guerrero et al. 2003; Ghadirian et al. 2016), concept awareness, task and social awareness (Goldman 1992; Ghadirian et al. 2016).

A strong focus in CSCW is placed on the coordination of group members' actions so they can achieve a common goal, whereas in CSCL, the emphasis is put on the social interaction occurring among learners (Kreijns et al. 2003). Learners (group members) need to engage in rich social interactions in order to build the knowledge required for a task. Such interaction cannot be taken for granted: it will not occur just because learners are working together. When appropriate interaction is developed, a sense of community may also be created; learners develop a sense of acceptance and a series of social conventions that may facilitate their interaction. Table 3 summarizes some of the awareness information types that have been useful to CSCL applications.

4.2 Phase 2: Awareness information identification

As explained in Sect. 4.1, it is necessary to define and model the information to be provided and its context once the awareness goals have been established. The Merriam-Webster dictionary defines context as "the interrelated conditions in which an event, action, etc. takes place". As it has been contrasted through the literature review, there is no

Table 3 Types of awareness information that have proven effective in CSCL

Awareness	Goal	Tool or research
Social	Provide information about social conventions developed by a group for achieving their goals	(Goldman 1992; Gross et al. 2005; Ghadirian et al. 2016)
Task	Information about learners' progression towards task accomplishment	(Goldman 1992)
Concept	Inform about concepts acquired by learners	(Goldman 1992; Collazos et al. 2003)
Workspace	Inform about learners' actions in the shared space	(Gutwin et al. 1996a)
Knowledge & Shared Knowledge	Provide feedback about learners' actions	KCA (Collazos et al. 2003; Ghadirian et al. 2016)
Expertise	Provide information about expertise. Facilitate unplanned interaction	Sharlock (Ogata et al. 2001), KnowledgeTree (Kwon et al. 2011)
Group	Inform about learners' presence and situation. Facilitate unplanned encounters	GAWS (Kreijns et al. 2003)
Creativity	Inform about good and novel ideas emerging from interaction	(Farooq et al. 2007)

consensual definition of context, but we may understand the concept from its fundamental properties. First, it comprehends whatever surrounds the awareness piece of information (thing) intended to be perceived by group members but it is not the thing itself. Second, the "whatever" components maintain a semantic relationship among them that provides meaning to the thing, and they are semantically close to the thing. Schilit et. al (2002) define context-aware communication as the "class of applications that apply knowledge of people's context to reduce communication barriers". They summarize the research on context-aware communication and characterize two dimensions in application design: the extent of autonomy in context-sensing and the extent of autonomy in communication actions.

There are various definitions of context given in previous work. Context has been defined as "knowledge about the users" and the state of Information Technology devices, including surroundings, situation, and to a lesser extent, location. Furthermore, we differentiate context with regard to: environmental context, social context, space–time context, resource context. Brézillon (Brézillon and Borges 2004) propose that context be described at different levels or grains of specificity: it could describe the project (i.e., awareness of documents, projects, and processes), the group (i.e., the location and status of the members) or the individual (i.e., availability). Regarding group contexts, Haake (2000) suggests that at a high level of abstraction a virtual shared space is composed by three main components: content, team, and process structure. Group members could align their future actions properly by being aware of these components.

Considering these approaches, we have reviewed and classified many research papers on awareness to define a *taxonomy* for context information sources, shown in Table 4. The taxonomy considers information and context related to three cornerstone elements of groupware: people, task and resources. For each of them we analyze properties such as their state, location, actions and activity as well as the interrelationships among them (structure).

We also make a distinction between *group and individual awareness*. Although it is recognized that requirements for individuals are different from group needs (e.g., navigation, artifact manipulation, and interfaces), people move back and forth between individual and group interaction modes (Dourish and Bellotti 1992). Their shared work imposes restrictions on them (e.g., deadlines) affecting their individual context (e.g., they have to update their personal agendas). Conversely, their contributions when working together are based on their knowledge, expertise and personal agenda. Individual context contributes to shaping the group context (Brézillon and Borges 2004).

Once group members decide to work together, they can do so in a loosely coupled fashion (e.g. asynchronously) or in a tightly coupled way (Schlichter et al. 1998). In every scenario the degree of relevance of group context depends on the coupling of their interaction: the more coupled the interaction, the more attention is directed to the task and the more relevant becomes the group context. We can see that individual and group work are edges of a spectrum instead of two opposite working modes.

Naturally, it would be incorrect to refer to "group awareness" because awareness is an individual's cognitive process; individuals are aware of their group context (i.e., project related information) or their individual context (i.e. the place where they are located). We understand the group context as the interconnected conditions related to group activities shared by the group members (Endsley 1995). Although both contexts interact and shape each other, we have focused our analysis on the group. The individual context is beyond the scope of this work.

Table 4 Taxonomy of context information sources

Component	Attribute	Supports	Awareness	Mechanisms
1. People	1. Structure	Social norms, conventions, roles	Organizational Awareness (Gutwin et al. 1996a), Social Awareness (Goldman 1992; Idrus et al. 2010; Lambropoulos et al. 2012), Social Networks (Wellman and Gulia 1999), Group Structural Awareness (Cockburn and Weir 1999), Conventions (Mark 2002), Access Roles (Botha and Eloff 2001)	Metaphors, avatars, notes, organization chart Telepointer, fingers, metaphors, avatars, earcons, notes, emoticons, list of categories
	2. State	Availability, activity, emotions	Informal Awareness (Dourish and Belloti, 1992; Willaert et al. 2012), Emotional Awareness (Garcia et al. 1999; Guzman and Bruegge, 2013; Reis et al. 2018), Presence (Dourish and Belloti, 1992), workspace awareness (Tuddenham and Robinson 2009; Teruel et al. 2014; Li et al. 2017)	
	3. Location	Presence, distance, visibility, space-place, metaphors	Workspace-location (Gutwin and Greenberg 2002), Casual Encounters (Greenberg 1996), Informal Awareness (Fish et al. 1993), Presence (Dourish and Belloti 1992), Co-presence (Ijsselsteijn and Riva 2003), Group time awareness (Romero et al. 2009)	Telepointer, fingers, radar views, multi-user scroll bars, metaphors, avatars, notes, CVE, VR
	4. Actions	Events, distortion (aggregation, animation, etc.)	Workspace-actions (Gutwin and Greenberg 2002), Active Knowledge Awareness (Ogata et al. 2001), Real-time Distributed Widgets (distortion) (Gutwin et al. 1996a), Action Awareness (Carroll et al. 2003), Knowledge Construction Awareness (Collazos et al. 2003)	Radar views, wysiwig windows, versions, notes, metaphors, asynchronous visits
	5. Activity	Activity, goals	Activity Awareness (Carroll et al. 2003), Situation Awareness (Belkadi et al. 2013; Endsley 2015; Endsley 2016), Contextual Awareness (Endsley 2000; Rittenbruch, 2002; Decouchant et al. 2009), Workspace-activity (Gutwin and Greenberg 2002)	Radar views, notes, participameter, contribution meter, metaphors, telepointer, Track Changes in Word, asynchronous visit
2. Task or project	1. Structure	Process planning	Workflow (Van der Aalst et al. 2003), Contextual Awareness (Fuchs et al. 1995), Process Awareness (Steinfield et al. 1999)	Versions, UML activity diagrams, Gantt charts
	2. State	State-based workflow	Workflow (Van der Aalst et al. 2003), Interaction-states (Jermann et al. 2001), Process Awareness (Steinfield et al. 1999)	Versions, notes, Gantt charts, Track Changes in Word
3. Resources	1. Structure	Spatial, semantic networks, TOCs	Workspace-objects (Gutwin and Greenberg 2002), Common Information Spaces (Bannon 2000; Ostwald 1996; Reddy et al. 2001; Suthers et al. 1995), knowledge awareness (Convertino et al. 2011)	Radar views, versions, conceptual maps, taxonomies (list of categories)

Table 4 (continued)

Component	Attribute	Supports	Awareness	Mechanisms
	2. State	Availability	MyTeam (Lai et al. 2003)	Radar views, versions, notes, workflow diagrams
	3. Location	Resource discovery, availability	Context-aware Computing (Dix et al. 2000), Resource Awareness (Espinosa et al. 2000), Knowledge Awareness (Ogata et al. 2001), Semantic Distance (Chen et al. 1999), Common Interests (Sumi and Mase 2000)	Radar views, versions, notes, concept maps, Web site maps

The following sub-sections describe the taxonomy components.

4.2.1 Component 1: People

4.2.1.1 People's Structure: Social norms, conventions, and roles People organize themselves in different organizational structures (e.g. hierarchical, subgroups, communities, etc.). These arrangements define roles, responsibilities, social norms and protocols. When users become aware of such a structure they regulate their interaction accordingly, facilitating coordination, cooperation and collaboration by means of developing explicit or implicit conventions or protocols (Carroll et al. 2003). Such structures may change with time (people are assigned new roles), they can be formal and very detailed as in a workflow (Botha and Eloff 2001), informal as in the case of community or social networks (Wellman and Gulia 1999), or created in an ad-hoc fashion as users interact (Rodenstein and Donath 2000). The provision of this information has been researched under the terms of social awareness (Ogata et al. 2001), organizational awareness (Gutwin et al. 1996a) or group structural awareness (Cockburn and Weir 1999).

4.2.1.2 People's state: availability, activity and emotions Generally, a state describes a condition held by an element (e.g., a user is busy) a stage (e.g., a document is under revision) or an emotion (e.g., the user is angry). When referring to people's state, most research focus on recognizing a user's availability and presence through direct observation (always-on audio and/or video connections) (Fish et al. 1993; Sohlenkamp 1999), or by users declaring their public status or availability through icons (Jang et al. 2002; Greenberg 1996).

Indirect strategies can also be used, e.g., exploiting historical data to determine presence, activity (Begole et al. 2002), or attendance (Horvitz et al. 2002); combining cross-device sensing and machine learning for forecasting user location and availability, or inferring a user's interruptibility based on sensing or reasoning rules (Alarcón and Fuller 2002). By being aware of their availability and presence, group members can engage in casual interaction or informal (not pre-arranged) interaction.

Regarding emotional states, emotions have been described as complex organized states consisting of cognitive appraisals, action impulses, and patterned somatic reactions (Lazarus et al. 1980). Others describe them as physiological states of the human body. The awareness of those states would allow humans to evaluate social information through analogies and become the basis of communication (Charlton 2000). This way, by being aware of others' emotional states, group members can adjust their interaction and develop social strategies, such as approaching a colleague, assessing and tuning his or her performance during exams (Garcia et al. 1999). Related research is also known as "emotional awareness" (Garcia et al. 1999; David and Katz 2016) and informal awareness (Dourish and Bellotti 1992).

4.2.1.3 People's location: presence, distance, visibility, space-place and metaphors A user or a resource can be located inside or outside the virtual shared space. In both cases, there are some concepts strongly related to "location": presence or the psychological sense of "being there"; co-presence or the psychological sense of "being together" (Ijsselsteijn and Riva 2003); distance among group members (e.g., physical, social, semantic); proximity, conceived of as a small distance among group members and visibility (Nova 2004). Other related concepts are space and place (Harrison and Dourish 1996; Dourish 2006). A place differs from a space because it is "invested with understandings of behavioral appropriateness, cultural expectations, and so forth". (Harrison and Dourish 1996); people's context differs, e.g., depending on whether they are in a theater or in a park.

People's location has been studied in CSCW with the aim of assisting teammates to develop a sense of community and understanding of their situation, so that users can adapt their actions accordingly. For instance, they can decide to approach a group member (casual interaction) (Isaacs et al. 2002), or ask him/her for help if the user is close. They can decide how to contact him/her (e.g., by phone to the office where he/she actually is), or postpone an interruption. Research in this area is known as "workspace location", "casual encounters" (Kraut et al. 1990), "social awareness", "presence awareness", "informal or presence awareness", related to providing information about a user's location in order to encourage informal encounters, "situation awareness" that provides unstructured information (e.g. video) so that remote colleagues can develop a sense of community and understand the user's situation (Greenberg 1996). Of course, issues related to privacy, security and social acceptance are particularly relevant to this approach (Palen and Dourish 2003).

4.2.1.4 People's actions: events and distortion (aggregation, animation, etc.) While these perspectives (structure, status and location) are referred to as "static" attributes, the dynamic aspects are understood by means of actions and activities. An action is seen as an act performed by a purposeful agent (person), while an activity includes a series of actions that can be meaningful.

Actions reflect the things done by a person, or the accomplishment of a thing usually over a period of time, in stages. Awareness of actions performed by other group members can allow a user to make informed decisions about his or her work, to provide timely help to their teammates, to avoid collisions or misunderstandings (Gutwin and Greenberg 1998) or to monitor the project's progress and the teammates' involvement in the global work. This last characteristic is particularly important for distributed groups because it helps group members to trust each other (Jarvenpaa and Leidner 1998). Research in this area is mainly referred to as awareness of workspace-actions (Gutwin and Greenberg 2002), and active knowledge awareness (Ogata et al. 2001).

4.2.1.5 People's activity: activity and goals Users perform various actions corresponding to specific tasks; however, actions do not convey enough information to be meaningful. Consequently, additional information must be provided in order to disambiguate actions and allow coordination. Hence, an activity can be seen as a set of purposeful actions performed by individuals or collectivities, they have a goal or object, they are mediated by tools, and they are situated within a broader context (e.g., work practices, culture, organizational structures, and interpersonal relations). Activities are considered to be the minimal piece of contextual information. Activity awareness includes higher-level information of the goals, plans and progress of a group of collaborators (Carroll et al. 2003). Activity awareness depends on knowledge of what one's collaborators are doing, rather than what a symbolic model says they should be doing. For instance, Begole (Begole et al. 2002) collected users' actions (keyboard/mouse, reading/sending e-mail) in a workplace, to obtain temporal, rhythmic patterns of users' activity and visually presented such patterns to work teams. A glance at such curves is enough to determine whether it is a good idea to interrupt a colleague or when could be a good day to make an appointment.

By being aware of others' activities, users can get and maintain an overview of ongoing interaction while working together (Carroll et al. 2003), facing eventual breakdowns and contingencies. Research in this area is known as situation awareness "knowing what is going on around you" (Endsley 2000), context awareness (Kofod-petersen 2006), awareness of others' activity (Greenberg et al. 1996), activity awareness (Convertino et al. 2004), and workspace-activity awareness (Guerrero et al. 2003).

4.2.2 Component 2: Task or project

4.2.2.1 Task structure: process planning Workflow is a very active area of research dealing with task structuring. The main workflow concern is the automation of procedures although it is also acknowledged that tasks are strongly related to the people who perform them. Documents, information or tasks are passed between participants in a workflow. This passing occurs according to a defined set of rules to achieve, or contribute to, an overall business goal. Group members can regulate their interaction by being aware of task structure. They can do so specifically by means of understanding how their contributions fit into the whole picture (Fussell et al. 1998), which actions could be done accordingly or who will be affected by performing them. However, exceptions, dynamic reconfiguration and unstructured processes become major difficulties because the workflow requires an anticipated, well-defined process. Awareness of this information is also known as process awareness (Steinfield et al. 1999).

4.2.2.2 Task or project state: state-based workflow Group interaction can also be described as a set of valid trajectories in a finite state space. This approach is mostly used in business process modeling, in which a transaction or activity is represented as a set of states allowing desired and undesired conditions to be handled [state-based patterns in workflow systems are presented by (Van Der Aalst et al. 2003)]. In CSCL, the desirable and undesirable interaction states that may occur in a learning scenario can be also modeled (Jermann et al. 2001). Group members can adjust their actions by being aware of tasks, activities or processes status. They can do this adjustment in order to achieve another state or they can understand better their situation in order to determine contingent actions.

4.2.3 Component 3: Resources

The nature of information is a complex phenomenon that requires some discussion before information sharing is discussed. There can exist information about the physical environment, information about the information environment (including meta-information) and information about the cognitive environment. Furthermore, that information can be organized in multiple ways. An important aspect in order to maintain awareness is to analyze shared resources people work in a collaborative activity. An important component is artifact awareness, defined as one person's knowledge of the artifacts, resources and tools that other people are working with (Tee et al. 2006). Shared resources may be concepts (Espinosa et al. 2000), information (i.e., documents), software artifacts (e.g., a web portal), work artifacts (e.g., report templates), and representations of physical objects (e.g., a shared printer URL or a user ID). The artifacts in the workspace generate awareness information (e.g. Dix et al. 1993; Gaver 1991). Artifacts provide several sorts of visual information: they are physical objects, they form spatial relationships with other objects, they contain visual symbols like words, pictures, and numbers, and their states are often shown in their physical representation. Artifacts also contribute to the acoustic environment, making characteristic sounds when they are created, destroyed, moved, stacked, divided, or manipulated in other ways (Gaver 1991). Tools in particular have signature sounds, such as the snip of scissors or the scratch of a pencil. By seeing or hearing the ways that an artifact changes, it is often possible to determine what is being done to it.

4.2.3.1 Resource structure: spatial and semantic networks Resources can be organized, e.g., in spatial structures or dependence structures. Structures in all cases describe a semantic relationship understood by group members who create a "web of significance": a means for interpreting the relationships among resources. Group members regulate their interaction by being aware of such a structure, specifically, by means of creating a community of practice. For instance, (Reddy et al. 2001), use a *patient record* allowing physicians, nurses and pharmacists to coordinate their actions through a collaborative dialog. Ostwald (1996) assigned annotations to sketches and interface mockups during prototype design, making restrictions and design choices persistent. In Belvedere (Suthers et al. 1995), students engaged in a discussion to create a conceptual map with a meaning that they agreed upon. This strategy is also known as common information spaces (Bannon 2000), and knowledge awareness (Ogata et al. 2001).

4.2.3.2 Resources state: availability Again, as workflow systems modeling includes the resources needed for an activity or process, some interesting resources' statuses are also modeled (e.g., whether a machine is available or not). The status of products created by the group is also reported. For example, comments in a discussion are marked as "new", "answered", etc. or documents posted in a software engineering Web portal can be marked as "draft" or "final" version.

Group members can make informed choices and plan contingent actions by being aware of resource status. Izquierdo and Damian (2005) developed a mechanism to support changes to requirements in software engineering using the idea of artifacts availability, identifying who performed changes in the requirements, and their availability for further classification.

4.2.3.3 Resources location: availability and resource discovery Resources may be located in the shared environment, which may be seen as a common spatial frame inhabited by objects, representing people, information, artifacts, etc. For instance, Virtual Rooms (Henderson and Card 1986), allows users access to a set of predefined tools and information contained in a room. The shared environment can be represented as two-dimensional or three-dimensional (VRML system) interfaces. Space can also be a geometric representation of the real world, modeled with location sensors. Such shared space may include virtual representations of physical objects and their availability. For instance, CampusSpace (Ferscha et al. 2001) collects and interprets the position information of mobiles (devices, equipment or people) within a campus, from the signal to noise ratio of IEEE 802.11 radios, and cartographically mapped RFID (radio frequency identification) tags. Information collected is presented in a Web based three-dimensional campus. This approach is widely studied in context-aware computing, whereby users can find available nearby resources such as printers, restaurants, etc. (Dix et al. 2000). Other researchers model space as graphs of interconnected objects, containing semantic relationships among them, enabling definitions such as semantic distance (Chen et al. 1999). Finally, some researchers consider users' knowledge or expertise as a resource, and their main interest is to locate who the person with the desired knowledge is (Ogata et al. 2001).

4.3 Phase 3: Modeling

Software modeling is a fundamental process in any software development methodology, and the design of collaborative systems is not the exception. As we have already mentioned, awareness is an important aspect in the design of collaborative systems, as it is the base of natural interaction. Thus, an important issue in the development process of these kind of systems is how to model awareness support.

In traditional groupware development, awareness is modeled and supported without much care taken about awareness meaning, correct representation and relation with the rest of the system. During model based development expressive awareness models are required in order to hold the information required for the development (Molina et al. 2013). Having this type of models can allow to apply processes aligned with the Model Driven Software Development (MDSD) (Brambilla et al. 2017) in the development of groupware applications. This is an emerging and promising line of research in Software Engineering. It proposes basing the development process on the conceptual modeling of the collaborative application (Gallardo et al. 2012, 2013). This approach minimizes both the cost and time of software development thanks to the automation processes it supports. The focus of this new paradigm is a shift from programming to modeling. MDSD has the potential to greatly improve current practices in software development such as increasing the productivity of the developer and the maintainability of the developments, capturing domain knowledge, improving communication among stakeholders, considering models as long-term assets or making the delay of technological decisions possible, among other benefits.

In the field of MDSD, awareness support is poor due to the gap between conceptual and characterization models. Characterization models allow the definition of system useful entities that can be used by the system directly (Gallardo et al. 2012, 2013). The conceptual models allow recognizing awareness components as a part to integrate in the system (Gallardo et al. 2011). Although there are several collaborative systems modeling methods (Molina et al. 2009a, b; Teruel et al. 2017), few of them address the specification of awareness mechanisms. Gutwin and Greenberg (2002) proposed a mechanism for awareness modeling in collaborative systems focused on the domain of awareness design in interactive systems, but do not take into account any specific technological implementation. On the other hand, specialized frameworks can be used during awareness support implementation (Antunes et al. 2014). Their purpose is to integrate awareness support to the general structure of the system, facilitating the development and maintenance of the resulting awareness mechanisms. Thus, for example, (Kirsch-Pinheiro et al. 2005) propose a web-oriented framework for Context-Awareness support, with the purpose of reducing the cognitive information load of mobile system users by filtering the relevant information depending on the current context.

Among the few proposals that address the conceptual specification or modeling of awareness, we will now comment on some of the most noteworthy ones. In (Figueroa-Martinez et al. 2011) it is proposed the UsiXML (Limbourg et al. 2005) extension, in which awareness is integrated into the first phases of a methodology, so that awareness can be represented as an information requirement linked to tasks. The UsiXML model based approach enables the manipulation of awareness models and the generation of mapping (Montero et al. 2006) between models, creating in this way a traceable structure between awareness requirements and user interfaces. The inclusion of awareness as an information required is also proposed by (Penichet et al. 2009) in the requirements template for groupware development. (Teruel et al. 2017) propose the CSRMF framework, consisting of three components: a requirements engineering modeling language able to represent collaboration among users as well as awareness needs, a set of design guidelines that drive CSCW system specification by means of five different types of diagrams, and a supporting computer-aided software engineering tool to specify and validate CSCW system requirements. CSRMF provides Requirements Engineers with a complete solution to the specification of awareness-demanding collaborative systems, as they can now take advantage of a language and a set of guidelines supported by a tool to guide them in specifying system requirements. In (Bibbo et al. 2017) a language called CSSL v2.0 is proposed. This language allows to define in a precise, concise and friendly manner the abstract concepts of collaborative systems. Specially, the language makes available the concepts of awareness and collaborative processes. The language is independent of both the framework and the development tools and allows the application of the MDSD approach to the development of such systems. The CSSL v2.0 language was designed as a UML extension using the metamodeling mechanism and was implemented with open source tools on the Eclipse platform.

Having obtained in this phase the awareness requirements and well defined information that is modeled according to the development methodology, the next phase is the distribution of the previously captured and, maybe, generated awareness information.

4.4 Phase 4: Distribution

A member of a design group makes knowledge explicit when traducing it into some representation supported by the environment. However, it is not enough to make knowledge explicit; it is also necessary to provide group members with mechanisms that inform them the knowledge is there. Only when a group member perceives the new knowledge the socialization process may occur (Nonaka and Takeushi 1995). In that way, it is necessary people determine the way information awareness be delivered in order to feel they are part of the group.

Supporting the notification of changes that occur in the group and in the shared context means implementing mechanisms at both technological and social levels (Shen and Sun 2002; López and Guerrero 2014; Tam and Greenberg 2006). At the level of technology support, it involves implementing distribution strategies and propagation policies (e.g. broadcast, multicast, etc.). However, we will focus on the support that awareness offers to notification and not to its implementation at a low level.

Various strategies have been proposed for delivering awareness information (Poulovassilis and Xhafa 2013; Cai and Yu 2014; McGrenere et al. 2010). Important considerations when providing the awareness information are the real needs of the receivers and the care to avoid receivers' information overload. Delivering strategies follow two main approaches, as presented below. The provision of awareness should be supported in several modes so as to enable highly configurable awareness mechanisms. Awareness delivery could be "*passive*" or "*active*". In a passive mode, the awareness information is delivered to group members without requiring any specific actions on their part. Passive delivery is most suitable for time-sensitive awareness information as it can be configured to generate timely awareness information, including context (e.g. member availability, location or show up in a workspace) (Xhafa and Poulovassilis 2010).

4.4.1 Notification mechanisms

This approach is also known as passive awareness as users do not play an active role. In this case the information is delivered to group members without requiring any specific actions on their part. The main drawback of the approach is that the mechanism informs users about events' occurrence by interrupting them in other activities they may be doing (Carroll et al. 2003; Niu et al. 2017). However, some studies (Iqbal and Horvitz 2010) show that users value the awareness provided by notifications and are willing to incur some disruption in order to maintain that awareness. Passive delivery has nonetheless some limitations. First, group members receive the awareness information according to an a priori configuration. Second, group members may be overwhelmed by too much information, which could in some situations be intrusive to group work. Thus, the passive mode should be complemented with the active mode, which requires group members to take specific actions to request awareness information.

4.4.2 User-driven discovery

Under this approach, users navigate through the shared environment in order to discover the changes that have occurred since their last visit. This is often regarded as active awareness (Rittenbruch 2011), and it requires group members to undertake specific actions to request awareness information.

4.5 Phase 5: Awareness user interfaces

Findings in the discipline of Human–Computer Interaction provide insights into the appropriate design of awareness information interfaces. Many techniques have been applied in several systems to support awareness. The more commonly used mechanisms of capturing and presenting awareness information are the called *2D on-screen awareness mechanisms*. This group includes the WYSIWIS (*What You See Is What I See*) technique, and the incorporation of telepointers, radar views, multi-user scrollbars, or fisheye views (Stefik et al. 1987; Gutwin et al. 1996b) in graphical user interfaces of groupware systems. All these mechanisms are based on capturing and tracking keyboard events, mouse events or viewports to obtain information about collaborators' activities in a shared workspace. Also, awaress information is relevant in systems where tangible interaction is used. Cherek et al. (2018) have proved that in a large multitouch system with many users, there is a higher awareness of others' tangible actions. Other systems incorporate audio and video-mediated awareness mechanisms. The use of audio and video channels is very useful in supporting communication between members of a group (Paul and Beyer 2002). In recent years a new category of awareness mechanisms has gained attention by researchers: *sensor-mediated awareness* mechanisms (Lopez and Guerrero 2017). This approach proposes the use of specialized sensors, visual signals and devices to support group awareness. Examples of such tools include eye tracking, electronic badges and sensors or even wearable appliances (Gallardo et al. 2018).

We rely on support not only for awareness of people and information, but also for selection, interpretation and action. Thus, it is necessary to make a decision, in representing people and artifacts, as to what to include and what to exclude, what to represent in detail and what is abstract, what we actively interpret and what we leave for human interpretation.

Awareness user interfaces (AWUI) must deal with the constant updating of values, generally with little space and lots of content. In order to create effective AWUI the designers must use all the available representation resources, such as graphical user interfaces, voice or synthesized speeches, sensorial interfaces, mechanical components (Braille), etc. The most widely used user interfaces are graphical, but that depends on the final users.

Graphical user interfaces can use lots of representation mechanisms such as 2D and 3D canvases, varying sizes, layering, color, narratives, movement, etc. (Tufte 1990) Auditory user interfaces can use volume and pitch variation, rhythm, melody, voices, music, etc. Sensorial user interfaces are less common and include other sensorial methods such as smell, touch, hot or cold feeling, humidity, pressure, etc. (Nijholt et al. 2006).

In the area of graphical user interfaces, some specific groupware widgets encapsulating mechanisms for providing specific awareness information have been developed (Kreijns and Kirschner 2002; Hill and Gutwin 2004; Saparova et al. 2011). Telepointers, office snapshots, video glances, document/project tracking, and background noise are just a few examples of such representations. Some studies (Gutwin and Greenberg 2002; Dourish and Belloti 1992) provide some insights about their effectiveness within shared workspaces.

There are widgets which can be very useful when the provision of information for certain kinds of awareness is needed (Table 3). Some traditional and non-traditional awareness mechanisms are presented below. As for the widgets to be used in classic groupware environments we find the following:

- *People's Structure*: it is possible to use an organizational chart or some structural or hierarchical representation alongside people's avatars.
- *People's State*: it is possible to use emoticons, auditory icons, and avatars. The coding of states by colors is also common in groupware systems. Everything that could represent the current state is valid and the limit is the imagination of the designers.
- *People's Location*: The inclusion of people's identity and maybe state along with the representation of the locating region, such as a map. In the case of Workspace-Location the use of radar views is a good alternative. Radar view renders the entire shared workspace within a miniature overview window on which each user's location of activity is superimposed (Tran et al. 2003, 2006b). The radar view also shows viewports to indicate users' viewing locations, and telepointers to indicate the positions of users' mouse cursors.
- *People's Actions*: Icons (graphics) or phrases (text) may be used, e.g., date, time and user name of a contribution sent to a discussion forum. Actions can have their own avatars according to the technical resources. For example, a specific sound can represent an action, or a tactile rhythm.
- *People's Activity*: The same mechanisms as those of the previous category can be used. The action's location inside the activity flow can also be represented.
- *Task Structure*: It is possible to use activity diagrams (such as those used in UML). Gantt charts could also be used.
- *Task or Project State*: It is possible to use Gantt charts, or a mechanism based on Gantt charts, which would dynamically show the advance state of each activity. The information given depends on the user requirements.
- *Resources Structure*: Conceptual maps are typically used for this purpose. Some authors propose the use of more formal representations such as UML diagrams, or extensions of such notation (Rubart and Dawabi 2004).
- *Resources State*: Tables, diagrams and icons may be used. The word "State" opens the door to innumerable representations depending on the purpose of the information during the required task.
- *Resources Location*: The same as people's location.

When developing non-classical collaborative applications (social networks, collaborative AmI applications or CSCL systems), it is also necessary to consider non-traditional awareness mechanics. Some examples are:

- *Physical context*: Typically used in context-aware applications (Baldauf et al. 2007) including location, weather, time and date, objectives. Maps, icons, metaphors, meters and avatars can be used (Alcazar et al. 2014).
- *Community context*: Refers to group values linked to the community. Useful in social networks (Gilchrist 2009). Meters for community values, icons, number and text representations can be used.
- *Conceptual or semantic context*: Used in CSCL to categorize knowledge and working behavior (Collazos et al. 2003). Structure representations such as diagrams and conceptual maps combined with state and category representations such as icons can be used.
- *Technological context*: This is important in certain groupware applications, in which users work with different technological resources which should be known by the

Table 5 Utility of the different types of awareness in the amusement park scenario

Awareness	Importance	Explanation
Group	Very high	Users perform the visit in groups, so they should have all the information about their partners
Workspace	Low	The work to be carried out is the visit of the park, so the *workspace* concept is not so important
Context	Very high	Context is very important in AmI, especially when implicit interactions take place
Peripherial	Low	Not very important in this case
Activity	High	Group members should know about what attractions, shows or restaurants are their partners attending
Availability	Low	This information is not as useful as the other types in this case
Perspective	High	Future actions of the remaining group members are relevant for the users
Community	Low	Information about future actions throughout the park (*perspective* type) will include relevant items in this sense
Presence	High	It is quite relevant to know where the members go throughout the park
Rhythm	High	It will be important to know about the future presence of the group members

co-workers or co-learners (Yang 2006). Icons and text can be used for this purpose.

Different users can perceive the same Awareness User Interface and the same awareness data in a different way. For one user, the AWUI (Awareness User Interface) may be smaller but bigger for another, or might be distracting to one user but insufficient for others (Endsley 1995). Adaptation and personalization (also known as user customization) allow system and users to find the most effective AWUI for each user. Adaptation mechanisms are managed by the system, while personalization is managed by the users.

Adaptation can be achieved by the filtering of awareness information (Yao et al. 2010), reorganization, inclusion or exclusion of AWUI, etc. Personalization can be obtained by giving the users some configuration options that, in the end, change the normal behavior of the Awareness mechanisms.

The purpose of these adaptation techniques is to deal with the information overloading problem, and in the case of personalization, to deal with some aspects of privacy.

Next section will describe how the model proposed could be implemented in a scenario of Ambient Intelligence.

5 Case study: a scenario of an ambient intelligence collaborative system

Awareness is a very important issue in collaborative systems. However, collaborative systems can be found now in very different ways. As has been mentioned previously, in a previous work (Alcazar et al. 2014), and following Sohlenkamp framework, an application using these awareness mechanisms in driving simulations environments. A new version of the framework has been proposed on this paper, and in order to validate the framework proposed a short survey with CSCW/CSCL experts (from some Iberoamerican countries) was performed, where some questions were asked (The framework is understable, easy to execute, complete). The results were good (average 4.8, in a 1 to 5 likert scale).

In order to have an example of using the method in a real scenario in the scope of Ambient Intelligence, next we are going to apply it to a real world case. This case study is one of the scenarios shown in (Gallardo et al. 2018). In that paper, the *awareness cards* technique was used in order to help developers to define awareness support in some scenarios of collaborative work. This scenario consists of an amusement park in which a group of visitors enjoy the different services provided. Such services include attractions, shows and restaurants. Users usually visit the park following a roadmap previously set up or discussed on the fly. Therefore, the members of the group should have knowledge about aspects such as where the remaining team members are or whether a show they are willing to attend is about to begin. An Ambient Intelligence system integrated in the park may provide users with that information. Thus, whereas in that paper we described a specific technique (*awareness cards*) for the support of a specific kind of awareness, here we are proposing a full framework that may be applied in any situation in which awareness support is needed.

Next, we are going to review the phases for designing and developing awareness support that we have detailed previously and we are going to give some details about how they may be faced when the system that is being modeled is the one giving support to this specific scenario. This way, we will have a complementary point of view for this scenario regarding awareness support. This will be a different way to face awareness support for the scenario.

5.1 Phase 1: Awareness goals

At this phase, it is relevant to make clear which are the kind of awareness that are more important to consider in the amusement park scenario. In this sense, the most

Table 6 Taxonomy of context information sources applied to the amusement park scenario

Component	Attribute	Relevance	Explanation
1. People	1. Structure	Low	There is no hierarchical structure in the group
	2. State	Low	Availability and emotions are not the most important features to consider
	3. Location	Very high	It is essential for the group members to have information about where the remaining members are
	4. Actions	High	Information about events that happen is relevant in order to follow the plan
	5. Activity	High	Users may want to know which goals their partners have in their visit to the park
2. Task or project	1. Structure	Very high	Group members perform the visit following a plan
	2. State	Low	There will rarely be the need for a state-based workflow in this scenario
3. Resources	1. Structure	Low	The structure of the knowledge being handled is not so complex for this feature being needed
	2. State	Low	This will not be one of the most relevant features
	3. Location	High	New places to attend may be discovered during the users' activity

relevant awareness types will be *context* awareness, as it is crucial to model the context in ambient systems, and *group* awareness, as it will be essential for the group members to be aware of information of other members of the group located throughout the park. Other kinds of awareness that may be relevant for ambient systems will be the ones of *activity, perspective, presence* or *rhythm*. However, other types such as *workspace, availability* or *community* may be less useful. In Table 5 we summarize this information.

5.2 Phase 2: Awareness information identification

Again, the idea here is to identify which information from the depicted in Table 4 is the more relevant to collect in the system that support the amusement park scenario. Regarding the *People* component, information about *location, actions* and *activity* may be the most important ones. Users of such a system mainly will want to know where the other users are throughout the park and what they are doing or going to do: which shows will they attend, etc. However, *structure* and *state* attributes will be less important. Regarding the component about *task or project*, the *structure* attribute is quite important, as the interaction in this scenario is based on a prefixed plan. The *state* attribute will not be so relevant, though. Lastly, with regards to *resources*, their attributes will not be among the most important ones in this scenario. All this analysis is depicted in Table 6.

5.3 Phase 3: Modeling

If possible, a specific framework that takes into account the particularities of ambient intelligence systems should be used. An interesting option is the use of the framework mentioned in (Gallardo et al. 2018). This framework takes into account the classical framework by Gutwin and Greenberg (2002) and other related works in order to consider both explicit and implicit interaction. In fact, this scenario was modeled using the *awareness cards* technique described in (Gallardo et al. 2018). The awareness card for this scenario can be seen in Fig. 2.

5.4 Phase 4: Distribution

Distribution of awareness information in the amusement park scenario may be a combination of both notification mechanisms and user-driven discovery. Notification mechanisms will be of help as users may be provided with information in a moment in which they are involved in an activity. For example, a notification may be delivered when some users leave an attraction and the remaining users want to be aware of it. But also user-driven discovery is relevant, as some information will be discovered by users in an active way. For example, a user may want to know if some partners of his/her group are attending a show when being next to where it is taking place.

Awareness areas and dimensions	Context and environment awareness / When
Information elements	Event history
Interaction	⟳
Input	⇥ Arrival to a location(x,y); user(u); appointment in the meeting agenda(a) ⏰ present time { ⦿ Geolocation sensor ○ GPS }
Output	↦ Update and display: location(x,y,u), meeting agenda(a,u), state(u); play an audio cue { ⦿ Audio cue ○ Speaker } { ⦿ List of participants; Group state; Meeting agenda ○ Screen }

Fig. 2 Awareness card for the amusement park scenario. Adopted from (Gallardo et al. 2018)

5.5 Phase 5: Awareness user interfaces

The specific widgets, controllers and tools for this scenario will include some examples of widgets that can also be used in *classic* groupware together with some other ones that are specific of implicit interaction systems. Taking into account which are the components and attributes relevant to this case (phase 2) and the modeling done by means of the *awareness cards* technique (phase 3), some of the widgets, controllers and tools that may be integrated in the user interfaces of this system will be the following ones:

- *List of participants*. This list will include and identify the group members.
- *Group state*. It will be an indicator of how the group performs its activity.
- *Meeting agenda*. It will be used to organize the plan and inform users about it.
- *Radar views*. They will be used to locate relevant places in the park and where the group members are in an easy way.
- *Avatars*. Users will be identified with avatars.
- *Participameter*. This widget will inform about the level of participation of each group member.
- *Contribution meter*. This is a similar concept to the previous one, and will also be used to have a measure of how each group member is performing the visit.
- *Gantt charts*. This chart, or a similar one, may be used for organizing the plan of visit.

6 Discussion

Groupware applications are hard to build and their difficulties go beyond technical restrictions. On the other hand, an increase in awareness information of the activities of others is not always beneficial (Greenberg and Gutwin 2016). Therefore, in this section we begin by commenting on some of the challenges posed by incorporating awareness mechanisms into groupware systems. Below are some recommendations or guidelines that emerge from the work done. Finally, this discussion section concludes by listing some of the limitations of the work described, as well as possible lines of continuation that could help to mitigate them.

6.1 Challenges for providing awareness

We have presented the beneficial effects of awareness within the collaborative work and its implementation requirements. These benefits, however, carry some challenges to be dealt with. Some of these challenges, analyzed by (Endsley 1995, 2015), belong to the following areas:

- *Human factors*: Pre-attentive processing, attention, perception, working memory, long-term memory, goals, preconceptions, abilities and training.
- *Task and system factors*: System design, Interface design, stress, complexity, workload, automation (experience replacing Situation Awareness).

These factors are taken into account during system development, user interfaces design and some are used to design adaptation and personalization mechanisms to refine the user experience.

6.1.1 Privacy

Privacy is very important in an environment designed to present the actions of a person to the rest of the group (Greenberg and Gutwin 2016). Obviously, people do not wish for all of their information to be shown or revealed. The difficulty is to find a balance between the user's privacy, and the need to offer information that is required for developing collaboration mechanisms (Sohlenkamp 1999; Erickson and Kellogg 2000).

Detailed information regarding people's activities helps to obtain an increase in the collaborative activities within a group, but it can also be used in an unintended way by other people. For this reason, it is important to establish *social protocols* and conventions similar to those used in real world collaboration (Mark 2002).

Privacy policies may be applied according to time. For instance, Alarcón (Alarcón et al. 2005), take into account the passing time by means of a progressive forgetting or authorship blurring function. An interesting approach to privacy concerning awareness information is given by (Drury and Williams 2002), which proposes the distribution of awareness information only to the users that require it. This approach is also used by (Martinez et al. 2010) in their proposed models for representing awareness requirements information.

6.1.2 Information overload

Information overload (Schultz and Vandenbosch 1998) is a general problem in computational environments mainly due to managing great volumes of information. The addition of awareness information in such an environment can therefore dramatically increase the amount of information available. Furthermore, the presentation of such information becomes an additional problem: there is not only a lot of information, it also appears in an unexpected form and moment, forcing the users to switch their mental context in order to understand the information arriving (Carroll et al. 2003; McFarlane 1999).

It is therefore desirable that the information is shown only when it is needed. Awareness mechanisms are intended to provide information according to user needs, but such needs and roles change over time. Some authors propose the use of awareness filters (David and Borges 2001), while others attempt to estimate the relevance of the information and deliver it through diverse channels depending on its relevance (Alarcón and Fuller 2002). The usage of other communication channels or techniques such as peripheral user interfaces (Cadiz et al. 2001) is also useful.

6.1.3 Interruptions

Users can be interrupted or disturbed from their work by receiving constant awareness information about others' actions that may be uninteresting and unexpected. Finally, users may be overloaded with awareness information when everything that happens to the other participants is displayed. Providing awareness of relevant information or events with a minimal strain on cognitive resources promises to be increasingly valuable to users. On the other hand, capturing users' attention with the upcoming alert may be a desired effect, if for example a user needs to be alerted to a fact or individual. Nevertheless, the main goal of groupware awareness is to enable fluid cooperation, and any interruption has the opposite effect: the cooperation is suspended.

To achieve high information awareness with low intrusion, developers can choose to support *Peripheral Awareness mechanisms* in order to improve collaboration without interrupting the workflow, or to include *adaptation and customization mechanisms* to let users tailor their awareness mechanisms (Blichmann and Meißner 2017).

6.1.4 Social and dynamic issues

As mentioned above, awareness allows us to simulate, in a distributed way, what a face-to-face meeting or communication should be. However, there are aspects that are not yet adequately addressed through the current awareness mechanisms. Some of these aspects are: the transmission of non-verbal or emotional information (although there are proposals along these lines), the pragmatics of the messages and communications that are produced (extra-linguistic and intentional factors) or the interrelationship between physical spaces and social interaction. This last aspect is considered by the so-called *social translucence approach* proposed by Erickson and Kellogg (2000), which consider the characteristics of visibility, awareness, and accountability as building blocks of social interaction. As these authors claim, supporting the dimensions of social translucence in the digital domain enables participants to be aware of what is happening, the understanding of the physics that underlie the visibility of their social interactions and to be held accountable for their actions as a consequence of public knowledge of that awareness. Although the concept of *accountability* (Erickson and Kellogg 2000) is not addressed in the current taxonomy proposal, it is worth exploring in future work the difference between the assignment of a task and the responsibility for its performance. The performance of the work and the responsibility for it are differentiable aspects.

On the other hand, it is also worth considering the difference between *actors* and *roles*. A role is defined as the set of tasks or responsibilities to be played by one or more actors. An actor is a subject, human or not, that interacts with the system and can play a role at any given time. With regard to the actors, we can be mainly interested in knowing their characteristics (for example, their skills in using computers, their specific skills in a particular area, their language, etc.). The actors do not necessarily need to be specific individuals; they may represent classes of individuals who share certain characteristics. The actors perform tasks but always in the form of a specific role.

Another aspect that must be taken into account is the inherent *dynamism* in the functioning of organizations and work teams that can affect the assignment of responsibilities, the inheritance of responsibilities, changes in the hierarchy of the organization, changes in the assignment of roles to different actors, etc. In addition, such changes may be permanent or temporary. On the other hand, the workflow may vary over time, including the emergence and the disappearance of people, tasks and resources in the organization. Few works address the dynamism in groupware systems (Garrido et al. 2005; Molina et al. 2009a), and little research has been done on how awareness mechanisms should notify or make users aware of these changes.

If group work is to be supported as faithfully as possible, all these aspects should be analyzed and addressed, proposing appropriate awareness mechanisms.

6.1.5 Evaluation and validation

Awareness is closely related to groupware systems and their development. Validation mechanisms and evaluation techniques are needed to ensure software quality and correct behavior during system runtime (Lopez and Guerrero 2017). However collaborative validation and evaluation is difficult to accomplish (Antunes et al. 2012, 2014); due to reasons such as the amount of perspective and aspects that must be considered: organizational goals, coordination, shared context, control access, social context of the work, group characteristics and dynamics, and so on. In the case of CSCL systems, in addition to taking into account the aforementioned aspects, it is necessary to consider other aspects such as: the formation and configuration of student groups, the alignment of the tasks to be carried out with the learning objectives, the quality and the cognitive load imposed by the didactic materials to be used, the consideration of the student's previous knowledge, their learning style or motivation, the adequate support for solving problems, as well as discussion, argumentation and decision-making, etc. (Häkkinen et al. 2004).

Validation is mostly related to software requirements and implementation. Validation of awareness mechanisms requires awareness to be represented as some type of requirement, either through model or specification. Penichet et al. (2009) propose a set of templates for gathering requirements for groupware applications. These templates include a part for the "Awareness Issues", which are an informal representation of awareness information requirements. Martinez et al. (2010) propose the inclusion of awareness in the requirement specifications phase in UsiXML methodology through a set of conceptual models that could be used to generate and validate the awareness mechanisms and awareness user interfaces. Teruel et al. (2017) propose the CSRMF framework. CSRMF provides requirements engineers with a complete solution to the specification of awareness-demanding collaborative systems, providing a language and a set of guidelines supported by a tool to guide them in specifying system requirements. All these approaches show the general trend of including awareness as an information requirement during groupware development.

Evaluation is mostly related to human behavior, such as interaction flow and user interfaces, but also with interruption and information overload. The design and evaluation of user interfaces is a world per se. Different methods have been proposed to evaluate groupware systems and, in particular, their usability and awareness support. The work carried out by Pinelle and Gutwin (Pinelle and Gutwin 2002) proposes the concept *groupware usability*, that can be defined as the "extent to which a groupware system allows teamwork to occur—effectively, efficiently and satisfactorily—for a particular group and a particular group activity". Some of the new techniques for groupware usability evaluation are basic inspection methods, cognitive walkthroughs adapted to collaborative systems (Pinelle and Gutwin 2002) and an adaptation of the Nielsen heuristics for application to groupware systems (Baker et al. 2001).

Other works address the evaluation of awareness support of collaborative systems. Works like the one by Matthews et al. (2007) propose a set of general evaluation criteria for user interfaces (mainly peripheral displays) including *awareness* as one of them. In Convertino et al. (Convertino et al. 2004), the authors carried out some evaluation studies about *activity awareness*, proposing a laboratory method to assess this aspect in controlled settings. Several authors have proposed frameworks, taxonomies and *checklist* and have tried to help developers and evaluators when considering awareness in the development and evaluation of collaborative systems. One of the most outstanding contributions in this field is the *Theory of Awareness* by Gutwin and Greenberg (2002), which includes a framework that defines different awareness elements and makes the validation of awareness support possible by means of a set of relevant questions. The main contribution of this work was to identify the elements of knowledge that make up the core of *workspace awareness*, each one related to the question answered to provide that element of knowledge. Lastly, we want to mention the evaluation tool proposed by Antunes et al. (2014), who designed a checklist for evaluating awareness support in collaborative applications. They started by identifying six awareness types: (i) collaboration awareness, which refers to the members' perception of the group availability; (ii) location awareness, which includes perceiving where someone is physically located, oriented, moving toward and looking at (Gutwin and Greenberg 2002); (iii) context awareness, which will allow collaborators to maintain a sense of what is going on in a virtual space; (iv) social awareness, which refers to the social situation of group members (Tollmar et al. 1996) and the concepts of belonging and acting (Bødker and Christiansen 2006); (v) workspace awareness, which is the *classic* concept of awareness defined by Gutwin and Greenberg (2002) as the one that helps to understand the activities being carried out in the workplace; and (vi) situation awareness, which comes from a generalization of the concept of workspace.

Starting from those six awareness types, Antunes et al. identified 54 design elements, which were grouped in 14 design categories. Afterwards, authors specified a question for each design element, giving birth to an *awareness checklist* to be used to evaluate awareness support in collaborative applications. The answers to the questions in the checklist have an effect on the overall evaluation of each one in the six awareness types depending on a correlation that was obtained by the authors in a study with experts. Such a tool is a very interesting approach for the evaluation of awareness support, for which reason we have taken it into account in our work.

Most of these awareness evaluation techniques are based on heuristic frameworks and the use of questionnaires and checklists completed by experts (in the case of heuristic evaluation) or by system users. Therefore, most of these techniques are subjective and the results obtained in their application can be subject to biases. In order to solve this problem, some authors have proposed the application of more objective evaluation methods (Molina et al. 2015).

6.2 Implications for research and practice

The method (set of phases) proposed may guide software engineers to provide awareness support in applications that are under development or evolution. For each of the stages, it has been specified what design decisions must be made and what alternatives exist.

The taxonomy proposed (Table 4) codifies and classifies a large amount of CSCW expertise about awareness mechanics and widgets, thus helping software designers reflect on the awareness support their application should provide. The awareness types identified and the design elements come from an extensive review of the CSCW and CSCL literature.

At the theoretical level, the proposed taxonomy can be considered as a conceptual framework that aims to organize and classify the large number of terms, aspects, definitions and meanings, sometimes not consensual, that characterize this field of study.

The findings of the framework proposed have implications for both researchers who are working in the area of groupware and for practitioners who are working in Software Development companies and are creating collaborative applications.

6.3 General guidelines and recommendations

When applying the proposed framework, the following recommendations can be taken into account:

- First of all, it is necessary to determine the *type of groupware* application to be developed (traditional vs. non-traditional, CSCW vs. CSCL, AmI, social network, etc.), which will have implications both for the goals and awareness information to be collected and supported (phase 1) as for the widgets to be incorporated into the visualization or user interface (phase 5).
- Although the *taxonomy* proposed would make it possible to specify, in tabular format (as shown in the case study), the different types of awareness to be supported and the context information sources (phases 1 and 2), as well as their usefulness and relevance, it would be desirable to have a *notation* (phase 3) that would allow the application's awareness requirements to be specified more systematically and formally. In the case study described, a specific notation is used to model awareness support in AmI scenarios (Gallardo et al. 2018). Another technique for modeling awareness requirements, which we consider appropriate for this purpose, is the one proposed by (Teruel et al. 2017).
- In phase 5 (related to visualization) we propose to use the *awareness checklist* proposed by Antunes et al. (2014) as a guide. This work can be considered as one of the most complete and current work that identifies and compiles a large number of awareness widgets (54 design elements in total). The checklist proposed by these authors constitutes a very useful roadmap for obtaining suggestions on the awareness support of a collaborative application. In addition, and as pointed out in the description of that phase, in order to create effective AWUI the designers must use all the available representation resources, such as graphical user interfaces, voice or synthesized speeches, sensorial interfaces, mechanical components (Braille), etc.
- As for aspects related to privacy issues, information overload or possible interruptions that awareness support may entail, *commitment and balance decisions* must be made. Some of these problems can be solved by allowing awareness mechanisms to be adapted to the needs and preferences of users. Therefore, developers of such systems must implement such *customization* capabilities.
- One of the aspects that continue to be a challenge is the *evaluation* of awareness mechanisms and their effectiveness in improving the collaborative experience. We propose to apply evaluation techniques that combine users' subjective perception of the usefulness and ease of use of the different awareness mechanisms supported, with more objective evaluation techniques, as described in (Molina et al. 2015) .

6.4 Limitations and open issues

This subsection discusses some of the limitations of the work performed.

One of the main problems of awareness area of study is the lack of unified terminology and the large number of concepts and aspects to be dealt with, for which there is often no consensus or standard solutions. Conceptual frameworks or taxonomies are needed to harmonize perspectives and create a common ground for researchers and practitioners. Although the contribution made can be improved, the proposal made is intended to respond to this need or, at least, to provide a basis for generating debate on this issue.

In order to have a broad vision of the main existing contributions in terms of design processes or methodologies to support awareness and their characterization, a literature review has been carried out. The results summarized in tables or graphs have not been presented in this article, as is usual when describing SLR and mapping studies. Presenting the results of such a review is not the main objective of this paper and exceeds its limits. Our objective in doing this was to update and complete the knowledge that the authors of this article (awareness experts) already know. Systematic searches of various sources and databases have made it possible to improve the taxonomical proposal and provide a better foundation, with more up-to-date references. The review of the literature carried out presents the limitations inherent to this type of work, such as that the results were limited by the search terms used and the sources (digital databases) selected. On the other hand, the digital libraries, the conference proceedings and journals considered in the manual search were selected based on past experiences of the authors of this paper, and some sources may have been overlooked.

The filtering and selection of relevant papers depends on subjective decisions and the background and expertise of the authors. These two latter aspects have also influenced the creation of the method described and the taxonomy on which it is based. The findings of the literature review performed and the proposal of the taxonomy may have been affected as classification is a human process and it is based on some subjective criteria. Moreover, the participation of several researchers in the process added subjectivity to the design process. Cross revision between researchers was conducted to reduce this bias. However, the need to evaluate with a set of experts both the taxonomy of contextual information and the suitability of the proposed phases is detected. We have to request feedback (opinions and suggestions) from CSCW and CSCL experts. But this work has been raised as a possible future work.

The review of the literature has also made it possible to identify gaps in current research and detect areas for further research. Thus, for example, in the area of graphical user interfaces, some specific groupware widgets encapsulating mechanisms for providing specific awareness information have been developed and proposed, however not many studies provide some insights about their effectiveness within shared workspaces. In this sense, it is necessary to have methods to evaluate the usability, usefulness and effectiveness of these visualization techniques. As future work, we consider a review of the literature on methods for evaluating awareness mechanisms, as well as the main techniques (objective and subjective) that other authors have proposed on this subject. In fact, one of the possible improvements to the proposed method is to incorporate evaluation phases throughout the process, which have not been included in the current version.

Another of the aspects in which several of the authors of this article have been working and we want to deepen in the future is the modeling phase of the awareness mechanisms. The review of related work has revealed that there are very few contributions in this area. Although there are notable collaborative systems modeling methods, few of them address the specification of awareness mechanisms. Appropriate modeling techniques for this purpose would provide even more comprehensive support for model-based development methods existing in the literature.

7 Conclusions and further work

Current information systems make extensive use of networking, and a growing number of activities are becoming collaborative and distributed geographically. It therefore becomes increasingly important to consider more advanced computational support for these group processes. The design of systems for supporting collaboration requires considerable effort by software designers and developers.

Within this area, the increasing interest in topics related to awareness has made it an important element, and it has been identified as a crucial aspect of the success of collaborative schemes. Awareness is a fundamental element in enabling a given user to perceive the sensation of working in a group.

It is commonly accepted that there are great advantages to incorporating awareness to different types of systems, in which benefits and improvements are obtained at the level of usability. Awareness is required in order to support all forms of cooperation: it is needed to coordinate and fine-tune cooperative work, allowing informal communication, and to establish conventions in the usage of shared understanding material.

Providing awareness information is a complex problem involving technical, organizational, social and legal questions. Furthermore, to perceive the shared environment requires some cognitive processes from the users that have to be supported by the systems. The process of supporting awareness involves several steps, and to become aware of others' activities, it is necessary to collect information about: who, when, why, where and what questions regarding state changes (awareness contextual information). In addition, different methods of collaboration require different types of awareness. For all these reasons, awareness mechanisms should be conveniently identified and characterized.

In this article we have proposed a framework consisting of a descriptive theory of awareness (a taxonomy) and a set of phases (a method with five stages: awareness information goals, awareness information identification, modeling, information distribution and awareness user interfaces) that guides software engineers in the process of designing and implementing awareness support in collaborative systems. As a case study we have showed how these stages could be adapted in a scenario like collaborative systems in Ambient Intelligence. We consider these proposals as a very useful contribution in the field of design and development of CSCW and CSCL systems.

As future work, we propose to validate the proposed framework in a greater number of collaboration scenarios, as well as to gather the opinion of experts in the design of CSCW and CSCL systems with respect to the proposed taxonomy and method.

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