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Reviewing the quality of awareness support in collaborative applications

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ABSTRACT

Awareness to users is a valuable feature of a collaborative system. Therefore, the designers of a system of this type may find it useful to receive hints on the awareness support provided by the system when it is under development or evolution. This paper proposes a tool for their use to obtain suggestions on the awareness features provided by the system and those not currently supported by it. The considered kinds of awareness were obtained from a review of a significant number of proposals from the literature. The tool is based on a checklist of design elements related to these awareness types to be applied by the application designer. The construction of this checklist was done as follows. The process started with an analysis of the types of awareness to be provided. This step ended with 54 selected design elements and six awareness types. Experts on the development of collaborative systems used their experience to provide correlations between the design elements and the types of awareness previously identified, thus encapsulating their expertise within the checklist. The proposal was applied to three existing collaborative systems and the results are presented. The obtained results suggest that the checklist is adequate to provide helpful hints that may be used to improve an application's awareness support.

1. Introduction

The words aware, cognizant, conscious, sensible, alive and awake mean having knowledge of something, according to the dictionary. *Aware* implies vigilance in observing or alertness in drawing inferences from what one experiences (Merriam-Webster, 2011). The term has been used at least since the 12th century. Much work has been done on consciousness/awareness in various areas, such as psychology and neuroscience. It even has philosophical implications, as pointed out by the Santiago theory of cognition (Maturana and Varela, 1980).

In the area of Computer Supported Collaborative Work (CSCW), Dourish and Bellotti (1992a,b) introduced the awareness term in their seminal paper. They defined it as "an understanding of the activities of others, which provides a context for your own activity." Various types of information can be included for this "understanding." Their classification is reviewed in Section 3.

Provision of awareness has proved to be a useful feature of collaborative systems (Gutwin and Greenberg, 1998, 1999, 2002; Salmon et al., 2007; Bardram and Hansen, 2010; Talaei-Khoei et al., 2011; Xiao, 2013). Awareness has been a focus of research in CSCW for over thirty years, and a thorough overview of its history was presented by Rittenbruch and McEwan (2009). Nevertheless, little research has been done to assess the quality of awareness support provided by a specific system. This assessment would be useful for concerned developers of a system encapsulating collaborative features or mobile work scenarios (Gavalas et al., 2011). Managers or users of this type of system may also be interested in knowing the extent of awareness support a system to be acquired provides.

A simple approach to do this assessment is by asking users about it. After all, users in a general sense are the final judges on the quality of a system. Questionnaires can be used for asking users after experiencing a system (MacMillan et al., 2004). Alternatively, user observation can be useful to understand how awareness is constructed. The analysis of logged interactions (Nacenta et al., 2007) and video recordings (Hornecker et al., 2008) may also provide some answers to the evaluation of awareness support. However, all these evaluation strategies require the actual participation of a group of users. Unfortunately, the participation of users is not always possible or available at the time of evaluation (Holzinger, 2005). In other scenarios, actual user participation may be expensive, if users must leave their current system aside and begin to use a candidate system just to evaluate it, including adequate training, real operation, data conversion, etc.

The approach reported in this paper does not require mandatory user participation, but requires counting on a prototype, or design,

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of the system to be evaluated. We propose an *awareness checklist* that may be useful to obtain hints on the awareness support of collaborative applications at various stages; for instance, during the development process or during the system evolution. The checklist may be particularly convenient to use when the development team members have some knowledge but are not experts in CSCW, because it will provide a large set of suggestions from which to choose the relevant ones. That is, the checklist acts as a reminder of the types of awareness elements that a development team should consider. It should be noted that this only partially responds to the need for assessing the quality of awareness support, since – although other stakeholders are encouraged to participate – it is oriented to one main type of stakeholder: a member of the development team who plays the role of *software designer*. Therefore, the checklist does not replace traditional usability evaluation, but may complement it.

Given this orientation, we analyze what awareness really means and the types of awareness it is possible to distinguish: we conclude that six types of awareness are important to consider. On the other hand, we try to identify the relevant software design elements: 54 of them are acknowledged. Both awareness types and design elements were obtained from a literature review. A key step is afterwards to define the correlations between the design elements and the awareness types; this step is done with the help of experienced CSCW system developers. The checklist is then built with these correlations. It is important to note that the goal is not encouraging developers to incorporate unnecessary features to an application, but rather to encourage reflection about which awareness elements would be valuable in a particular scenario. The checklist format does have some inherent limitations, e.g. it provides an overview of lacking features, but does not provide detailed feedback about usability or usefulness.

The paper continues with a review of related work (Section 2). Section 3 deals with the awareness types. Section 4 presents the proposed checklist. The use of this checklist in three cases is illustrated in Section 5. Finally, Section 6 discusses the proposed approach and Section 7 concludes the paper with a summary of the obtained results.

2. Related work

2.1. Evaluation of awareness support

Evaluation of the quality of awareness support can be traced back to Formal Technical Reviews (FTR) (Fagan, 1976). They have been widely adopted in software engineering (Aurum et al., 2002; Neill and Laplante, 2003). The reviews involve several people in a formal meeting during which a software artifact is presented, discussed and approved. FTR seek to identify defects and discrepancies in the software against plans, specifications, standards and best practices. They cover the whole software development lifecycle (Laitenberger and DeBaud, 2000). Yet it is interesting to note the FTR of early life-cycle artifacts is not commonly practiced in the software industry, apparently because they seem to lack maturity (Laitenberger and DeBaud, 2000).

Johnson (1998) analyzed the impact of software reviews on quality, showing that defects can be one or two orders of magnitude less costly to remove when found in initial development stages than after distribution to the customers. Moreover, software reviews were considered effective for discovering certain soft, but nevertheless costly, defects such as logically correct but poorly structured code.

CSCW brought together two main organizational assets: technology and humans. The development of CSCW systems has for long been considered a special branch of software development concerned with: design challenges associated with organizational goals; group characteristics and dynamics; communication, coordination and collaboration; conflict resolution and decision making; social context of work; and positive and negative effects of technology on tasks, groups and organizations.

Evaluation is essential to ensure the quality of collaborative systems developments. The problem now is that evaluation must assess a very wide range of factors related with multiple stakeholders (customers, managers, individual workers, formal and informal work groups), various domains of concern (business processes, goals, tasks, group well-being, culture, just to name a few) and multiple technology components (addressing various aspects of human-oriented activities such as communication, coordination, collaboration, and of course awareness). All in all, what distinguishes evaluation in the CSCW context is the need to assess the technology impact with an eclectic perspective.

Research shows that collaborative systems evaluation is difficult to accomplish. The first reason is the complexity, cost and time involved (Antunes et al., 2012). Second, the assessments tend to be informal (Pinelle and Gutwin, 2000). A prior study revealed that almost one third of systems are not assessed in a formal way (Pinelle and Gutwin, 2000). A more recent study (Antunes and Pino, 2010) found out that only 25% of the studies adopted a positivistic assessment (encompassing laboratory experiments, surveys, empirical methods, formative evaluation, simulation and analytic methods).

Third, CSCW involves conflicting views over technology and its impact in organizations, which may require diverse assessment methods. Herskovic et al. (2007) identified twelve methods and classified them according to various criteria such as development status, scope, time span of the assessment and who participates in the assessment. Of these twelve methods, six require the participation of end users in several ways, like focus groups and observations. However, significant participation of end users in systems evaluation turns the process costly and quite difficult to manage.

Of the remaining six methods, three require modeling and analyzing the system functionality at a very low level of detail. And finally the remaining methods adapt the FTR approach to the specific CSCW context. The methods are: Groupware Heuristic Evaluation (GHE) (Baker et al., 2002), Groupware Walkthrough (GW) (Pinelle and Gutwin, 2002) and Knowledge Management Approach (KMA) (Vizcaíno et al., 2005). GHE defines a procedure for inspecting how a collaborative system conforms with eight heuristics that codify best practices in collaborative systems development (2002). GW entails stepping through task sequences to conceptually explore task goals, actions necessary to perform tasks, knowledge needed to accomplish tasks, and possible performance failures (Gutwin and Greenberg, 2000; Pinelle and Gutwin, 2002). Finally, KMA involves using a checklist to assess how the system helps knowledge circulation (Vizcaíno et al., 2005).

2.2. Evaluation and awareness

We will now delve into the three FTR methods mentioned above to unravel how they address the quality of awareness support. As previously mentioned, GHE systematizes evaluation activities around a set of heuristics (Baker et al., 2002). These heuristics define a checklist with qualities that a collaborative system should have. Six of these heuristics point toward the importance of awareness, e.g. *Provide consequential communication of an individual's embodiment*, giving awareness of who is in the workspace and what they are doing, *Provide consequential communication of shared artifacts*, highlighting what artifacts are present in the workspace, as well as the manipulations done by the users on those artifacts, and *Facilitate finding collaborators and establishing contact*, giving indications about who belongs to the group and who is around.

GW involves stepping through task sequences to conceptually explore the actions users will perform. In order to formalize the analysis of the work context, Pinelle and Gutwin (2002) defined the Mechanics of Collaboration, a set of seven collaboration primitives that make up group dynamics (Gutwin and Greenberg, 2000). Within these primitives we find an explicit concern with awareness: *Monitoring*, or the ability to gather information about others in the workspace: who is there, where they are working and what they are doing.

KMA differs from the other techniques. Instead of focusing on the essential features of collaboration support, KMA seeks to evaluate how organizations are able to manage their knowledge while using collaborative systems (Vizcaíno et al., 2005). It focuses on analyzing situations where knowledge does not flow correctly. A checklist is provided with a set of questions that expose missing links, black holes and points of congestion in information flows. Unfortunately awareness is not explicitly considered in this approach. We may nevertheless find some indirect preoccupations with awareness in some of the questions of this checklist.

All in all, we observe that the concern with awareness is already present in some FTR methods, although in a mitigated way. Our research focuses on identifying and improving the awareness support.

2.3. Other methods to evaluate quality of awareness support

Convertino et al. (2004) developed a laboratory method to assess activity awareness in controlled settings. The method is based on collaboration scenarios drawn from field studies and assessed during laboratory experiments using questionnaires, interviews and observations. Unfortunately this approach requires significant time and effort to prepare and run the experiments. Furthermore, it requires a mature definition of the system functionality, which makes it difficult to apply at early design stages. Some other approaches to evaluating awareness are ad-hoc for specific application types, e.g. peripheral displays, or focused on measuring a specific aspect of awareness, such as affective benefits, and are discussed in a book devoted to the topic of awareness (Markopoulos et al., 2009).

Evaluation of awareness support has also been a major issue in a quite different research field: cognitive systems engineering. The main reference in this area is the work by Endsley et al. on situation awareness (Endsley, 1995; Endsley and Jones, 2001; Endsley et al., 2003). Endsley developed the Situational Awareness Global Assessment Technique (SAGAT) (Endsley et al., 1988) to measure situation awareness. SAGAT uses questionnaires to inquire users about perception, comprehension and projection in situations where working activities have been interrupted (Endsley and Garland, 2000). The main application areas of SAGAT deal with complex activities like piloting. Other techniques, like thinking aloud, filling mini situation reports and probing questions have also been used to measure situation awareness (Yanco and Drury, 2004). All these techniques involve end users in the assessment process.

Still regarding the cognitive perspective, Zhang and Hill (2000) developed a pattern-based approach to situation assessment. The approach uses spatial relationships in synthetic workspaces to represent the situation. Situation assessment is based on two major steps: data organization for perception (e.g. clustering) and matching against situation templates, which have to be predefined.

3. Awareness types for CSCW systems

We characterize awareness based on the fundamental distinctions concerning time, place and space. The seminal works of Johansen et al. (1991) and DeSanctis and Gallupe (1987) classified collaboration in the classic 4-square map defined by same/different and time/space dimensions, highly coupled with the physical properties of spaces and their impact on social and computationally-supported interaction. However, the extension of physical spaces toward the virtual ones has afforded new types of interaction and "places" more related with convenience than the constraints of the physical world (see e.g. (Tang et al., 2009) and (Yoo et al., 2008)). These affordances provide the starting point for developing our proposal of awareness types (Fig. 1).

3.1. Collaboration awareness

The fairly loose term "collaboration awareness" has been generally adopted to refer to the members' perception of group availability. Support for collaboration awareness has been considered an important design requirement for collaborative systems (Begole et al., 1999).

Group availability is concerned with whether people are in the same physical place or different places (Johansen et al., 1991), who is online/offline (Lauwers and Lantz, 1990; Schmidt, 2002), and their virtual availability, e.g. participants may be virtually colocated (physically distributed but accessible through high-quality audio/video links) or remote (physically distributed and with low-quality communication links) (Rodden and Blair, 1991).

Besides availability, the *communication mode* should also be considered; this mode may be synchronous, asynchronous or semi-synchronous. Synchronous communication gives a group the feeling of being almost at the same place (Rodden and Blair, 1991), as often seen in teleimmersive environments (MacEachren, 2005). Asynchronous communication implies reduced interaction, divergent work and potentially reduced collaboration awareness. Semi-synchronous systems typically exhibit the benefits and drawbacks of both modalities, while supporting multiple communication channels with various characteristics and flexible access to those channels.

Social theorists have studied the impact of communication channels on group collaboration. Studies of media synchronicity (Dennis et al., 2008) show that the fit between medium capabilities and the communication needs of the task influence group performance. As most tasks involve different needs, collaboration awareness becomes fundamental to adapt the media to the group and task, and conversely to adapt the group and task to the media (Kock, 2007). Thus we should expand our previous definition of collaboration awareness to account for these effects: collaboration awareness concerns the perception of temporal and spatial capabilities affecting a group of collaborating peers (Fisher and Dourish, 2004; Sacramento et al., 2004).

Still related with communication modes, we should also consider that network operations affect collaboration awareness. In particular, we note that perceiving network connectivity (connected/disconnected), message delivery (which affects the flows of communication and collaboration) and message delays have been considered important design features for collaboration support (Ferreira et al., 2011).

Several authors have made the distinction between the notions of place and space. Spaces provide structure to our three-dimensional world and in the specific CSCW context they serve to manage the needs for interaction (Harrison and Dourish, 1996). As people move around spaces, they become aware of the presence of other people and artifacts, which allows structuring the work activities. According to Harrison and Dourish (2006), the notion of place goes beyond space toward the consideration for the meaning and context for action. For instance, a meeting room is not only the physical or virtual space where the action occurs but also the collection of roles, conventions and rituals that set up a meeting place. As they put it, space is the opportunity; place is the understood reality.

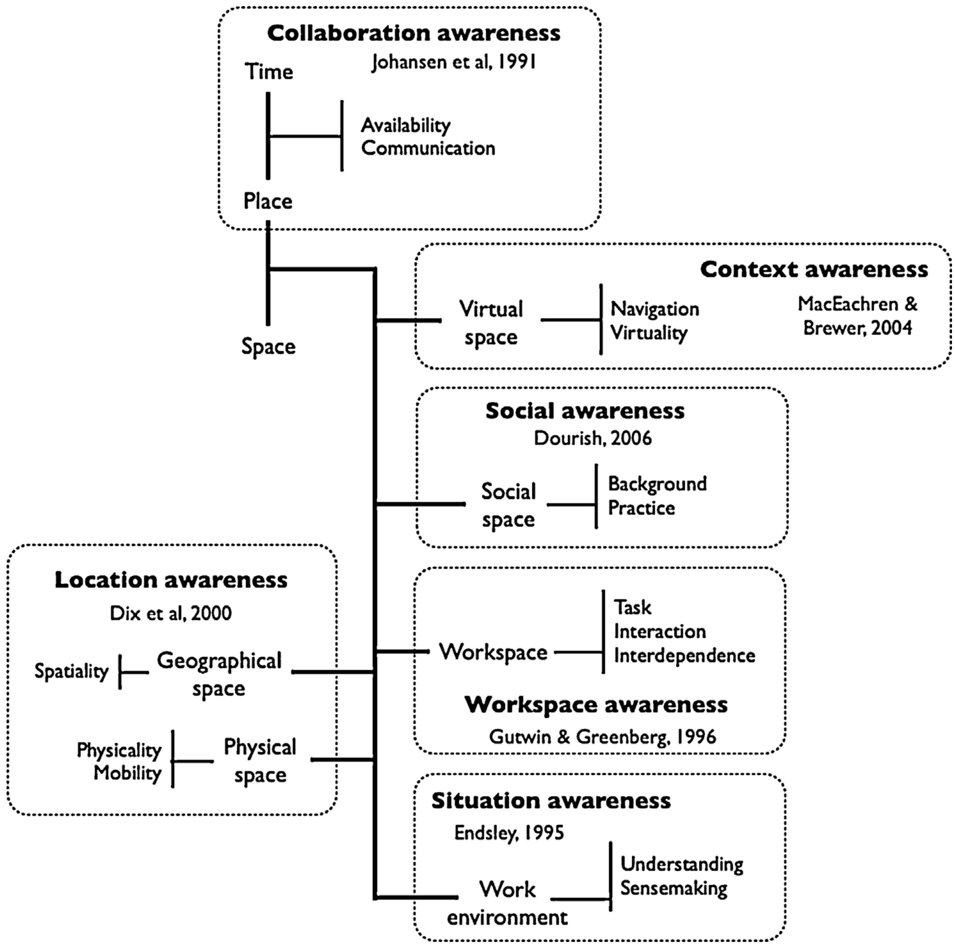


Fig. 1. Conceptual view of awareness support.

This subtle but important distinction between place and space allows us to explore various meanings for space and the corresponding places. In our literature review we identified six kinds of space, which serve to characterize the five additional awareness types presented in Fig. 1. Next sections explain these awareness types.

3.2. Location awareness

Our first exploration of meaning for space is based on geographical relationships among collaborators such as location, distance, orientation and range of attention. These relationships define the *spatiality* of spaces (Harrison and Dourish, 1996; Dix et al., 2000). Dix et al. (2000) further characterized spatiality as either being Cartesian (based on the Cartesian geometry to define distance) or topological (using the more abstract notion of nearness).

Another meaning for space concerns physical spaces. They define the affordances of spaces, which are related with the *physicality* of our three-dimensional world (Harrison and Dourish, 1996). These properties, or constraints, include physical places, physical topology and physical attributes such as weather conditions and temperature (Pascoe et al., 1999). These attributes may require using sensing technology like GPS and RFID, or alternatively relying on indirect cues provided by devices present in the physical space, such as Wi-Fi routers.

An important attribute of physical spaces is *mobility*. Mobility concerns different location modalities, which have been categorized as wandering, visiting and traveling (Kristoffersen and Ljungberg, 1998). Dix et al. (2000) also point out that the elements present in a physical space may have several levels of mobility (fixed, movable and autonomous) and types of relationships with other elements (independent, embedded and pervasive).

Both the geographical and physical nature of spaces contribute to define location awareness. Location awareness concerns knowledge of the real world, such as perceiving where someone is physically located, oriented, moving toward, and looking at (Gutwin and Greenberg, 2002). In mobile work scenarios, location awareness can contribute to improve the usability and usefulness of mobile applications (Liu et al., 2011).

3.3. Context awareness

The third meaning for space concerns the notion of virtual space. Rodden (1996) conceptualizes virtual space as a collection of computer-supported interactive spaces. They are shared, populated, interactive and malleable. *Virtual* spaces support interaction with group and public objects. They have virtual attributes, virtual relationships and virtual constraints (Greenberg et al., 1999; Convertino et al., 2005).

Virtual spaces also have a virtual topology and allow *navigation*. Virtual spaces may accommodate several places such as meeting rooms, chat rooms and recreational places (Snowdon and Munro, 2000). An extensive body of research has developed navigational aids such as map views and viewports (Dourish and Bly, 1992; Greenberg, 1996; Gutwin and Greenberg, 1999). The navigation in virtual spaces is not necessarily spatial but may also be logical. For instance, the rooms-metaphor defines navigation in virtual spaces like discussion forums that are not spatially organized but rather organized according with a set of interests (Greenberg and Roseman, 2003). Virtual spaces may assume other complex structures, such as clusters, stacks, lists, tables and rooms (Grønbæk et al., 2002).

Virtual spaces typically disseminate interactional and navigational cues, thus supporting what has been defined as context awareness (Rodden, 1996). Context awareness is fundamental to allow a group of collaborators maintaining a sense of what is going on in the virtual space. In this research field, "context" refers simultaneously to the context of the group, the individual context of its members, and the context of the shared task (Brézillon et al., 2004).

3.4. Social awareness

The fourth meaning of space highlights the social context of collaboration. Carroll et al. (2003) point out the importance of understanding social *practice*, i.e. the others' roles and activities, or what and how the group members are contributing to a task.

Dourish (2006) and Brewer and Dourish (2008) also view social spaces as important to perceive broader issues related with the group *background*. This includes perceiving any particular privileges of the group members and also the group history. Dourish (2001) points out that social spaces emphasize the activities that take place instead of the work structure, which leads the designers to focus on practice (design for the interaction) rather than structure.

Thus social awareness is concerned with the social situation of group members (Tollmar et al., 1996) and linked with a sense of belonging and acting (Bødker and Christiansen, 2006).

3.5. Workspace awareness

The fifth meaning for space is associated with the notion of workspace. According to Snowdon and Munro (2000), a workspace is a container of places with ongoing activities. We may distinguish two different aspects of workspace, one that emphasizes place and another emphasizing space.

Workspaces that emphasize place serve to organize *tasks* according to logical sets. Tasks are characterized by who, what, when and how they are accomplished. A group editor is a good example of this type of workspace, as it serves to organize tasks like writing and revising, while maintaining a coherent view of the whole (Koch and Koch, 2000).

Another important issue to consider is *interaction*: how the group interacts with workspaces and what information is necessary to sustain it (Ferreira et al., 2009; Antunes and Ferreira, 2011). Feedback is required by humans to achieve their goals by approximation, comparing the obtained outputs with a reference (Meadows, 2009). Feedthrough is necessary to bring information about the other's actions, allowing the individual users making decisions based upon what the others are doing (Hill and Gutwin, 2003). Backchannel feedback is necessary to convey unintentional information indicating that the listeners are following the speaker (Rajan et al., 2001). More complex mechanisms may be used to complement this information with additional cues, for instance using tracking mechanisms to perceive what the others are looking at (eye-gaze cues) or speaking toward (voice cues) (Vertegaal et al., 2003).

Finally, the notion of workspace also brings forward the level of task *interdependence* perceived by the group. Various types of interdependence may be considered, supporting parallel activities, coordinated activities and mutually adjusted activities (van de Ven and Delbecq, 1976).

Gutwin and Greenberg (1999) defined workspace awareness as the capability to utilize all these cues to understand the activities being carried out in the workplace.

3.6. Situation awareness

The sixth and last meaning for space that we found in the literature corresponds to a generalization of the notion of workspace. According to Gutwin and Greenberg (2002), a work environment involves dynamic processes of perception and action. Endsley (1995) and Endsley et al. (2003) characterized these processes at three different cognitive levels. The first level concerns a global perception of the environment, which is constructed from events, actions, resources and other critical elements (e.g. physical stressors, salient cues, unexpected events, hazards).

The second level is focused on giving meaning to what is going on. The third level concerns the construction of future scenarios. Situation awareness is crucial in high-demanding work contexts such as emergency response (Bergstrand and Landgren, 2009).

Jensen (2009) combined situation awareness with *sensemaking*, a theory developed by Weick (1993, 2001) to understand how the environmental changes influence group decision-making through the articulation of several cognitive functions like perception, interpretation and anticipation of events (Weick, 1993). Cecez-Kecmanovic (2005) highlighted that sensemaking emerges from individual, coordinated and collaborative efforts.

3.7. Designing awareness support

The previous sections describe a conceptual view of awareness support (Fig. 1) articulating the fundamental notions of time, place and space. This conceptual view characterizes awareness support as the composition of six complementary awareness categories: collaboration, location, context, social, workspace and situation awareness. Each awareness category is related with one or more design categories that characterize the time/place and space/place relationships. For instance, social awareness is related with two design categories: background and practice. Each design category can be instantiated through design features. For example, in the case of background, it involves privileges and group history. Table 1 summarizes the design categories and design features for each awareness category. In that sense, Table 1 complements Fig. 1 by specifying the properties of each awareness category. Definitions for each of the design features can be found in Appendix A.

Table 1 constitutes our main roadmap for obtaining suggestions on the awareness support of a collaborative application. It relates a large set of design elements (54 in total), arranged in 14 design categories, with six different awareness categories. All these relationships were derived from the literature analysis and are thus purely theoretical. Typically just some of the design elements related to a design category are relevant to implement or evaluate the support for a certain awareness category. Determining which ones are relevant requires analyzing such elements with a particular collaborative application in mind. It should be noted that a particular application does not need to include all design elements to be considered to have "optimal" awareness support. On the contrary, if a system includes all design elements will probably be overloaded with unnecessary features. The value of the checklist is to provide designers a large number of design elements and their correlations to awareness types. The designers should choose only those design elements that are relevant for their application.

The next section describes how Table 1 was used to create the awareness checklist, which we adopted to get hints on awareness support in FTR.

4. Awareness checklist

During this research, we observed that these relationships are more complex than what Table 1 implies. For instance, the

Table 1
Design elements contributing to awareness support.

Awareness category	Design category	Design elements
Collaboration awareness	Availability	*Availability* (e.g. same/different place, any place, virtually co-located, remote)
	Communication	*Communication mode* (i.e. synchronous/asynchronous), *network connectivity*, *message delivery*, *message delays*
Location awareness	Spatiality	*Cartesian locations*, *topological locations*, *distances*, *orientations*, *range of attention* (i.e. center of activity: focus/nimbus)
	Mobility	*Location modality* (wandering, visiting, traveling, fixed), *level of mobility* (autonomous, mobile, fixed), *relation with other devices* (independent from other devices, embedded in other devices, pervasive)
	Physicality	*Physical constraints*, *physical places*, *physical topology*, *physical attributes*
Context awareness	Navigation	*Virtual places*, *virtual topology* (places and links to other places), *map views* (radar views), *viewports* (over workspaces), *teleports* (to others' foci)
	Virtuality	*Group objects* (shared for members of a work session), *public objects*, *virtual attributes*, *virtual relationships*, *virtual constraints*
Social awareness	Practice	*Roles*, *activities*
	Background	*Privileges*, *group history*
Workspace awareness	Task	*Who*, *what*, *where*, *when*, *how*, *task history*
	Interaction	*Feedback* (individual inputs), *feedthrough* (group inputs), *backchannel feedback* (response tokens), *eye-gaze cues* (e.g. orientation), *voice cues* (voice directions, body orientation)
	Interdependence	*Parallel activities* (e.g. independent activities), *coordinated activities* (e.g. loosely coupled), *mutually adjusted activities* (e.g. tightly coupled), *access control* (based on users role)
Situation awareness	Understanding	*Events*, *actions*, *resources*, *critical elements*, *meanings*, *future scenarios*
	Sensemaking	*Individual sensemaking*, *distributed sensemaking*, *collaborative sensemaking*

communication mode design element mainly influences collaboration awareness. However, it also influences workspace awareness, especially because communication channels tend to be a limiting factor on the perception of what, when and where the group members are working. Therefore we may say that the communication mode design element has a direct influence on collaboration awareness and an indirect influence on workspace awareness. The same argument may be applied to many of the remaining 53 design elements.

However, finding out these relationships is no simple task. In order to do it, we had to request input from CSCW experts. These experts have been designing collaborative systems for at least fifteen years. The inquiry was accomplished in the following way.

We first had to select an adequate target population, composed of software engineers with experience developing or designing CSCW software, and who have therefore faced the practical questions and issues posed by awareness support. In order to screen the subjects, we defined a pretest.

Basically, the pretest inquired the subjects about the relationships between the design categories and the awareness categories, e.g. what is the perceived contribution of mobility to collaboration awareness, location awareness, etc. The obtained responses would give a measure of the perceived alignment between the generic design features and the awareness categories we defined. If the correlations provided by a subject were significantly misaligned with Table 1, then we would have to discard the subject as an expert in awareness support. These correlations were expressed in a two-point scale: 1 – there is a correlation; and 0 – no perceived correlation.

The pretest was applied to 12 software engineers selected by convenience. The results obtained from the pretest were analyzed using *Cohen's kappa* statistical measure of observer agreement. The selection criteria for being classified as expert was established as a moderate agreement, i.e. k between 0.41 and 0.60 (Landi and Kock, 1977). Two engineers were disregarded for obtaining k below 0.41. Of the remaining engineers, eight obtained k between 0.41 and 0.60, and two obtained a score above 0.60.

After the pretest, the subjects were requested to complete another table correlating the 54 design elements with the six awareness categories, by specifying a score reflecting the strength of the relationship between each design element and awareness category. This table presented a set of strong relationships, which could not be modified. The subjects were requested to specify supplementary strong, moderate and weak relationships (or to leave the cell blank in case there was no relationship). The strong relationships were derived from Table 1. The following four-point scale was adopted to express the relationships: 4 (strong); 2 (moderate); 1 (weak); and 0 (no relationship).

We summed-up the correlations obtained from the elected 10 experts. The scores that obtained a value below 10% of the maximum possible score were zeroed. This aimed to sort out the outliers.

The correlations table was then normalized in two ways: (1) we normalized the impact of each design category in the awareness scores, preventing that design categories with a higher number of design elements have more impact on the awareness scores; and (2) we normalized the awareness scale so the sum of all correlations for a given awareness category is 100%. The normalized correlations table is shown in Fig. 2.

We finally have all the necessary elements to construct the awareness checklist. First, we had to define adequate questions for each of the 54 design elements that should be evaluated. This was a critical task, since the questions should be concise, clear and avoid reliance on definitions that could be unknown to the evaluators. The list of questions should also avoid being too repetitive in order to diminish problems with wording and delivery mode (Presser et al., 2004). Several collections of questions were defined before the best ones were selected. The design elements are assessed in the following qualitative scale: +1 (adequate implementation); 0 (element is neutral/irrelevant); −1 (inadequate implementation)[1]. A fragment of the awareness checklist is displayed in Fig. 3. The complete checklist is included in Appendix B, which also includes a final open question intended to capture any other awareness element not included in the checklist.

We then developed the awareness report, which shows the results in a way similar to the House of Quality (HoQ), a generic quality assurance matrix used by many organizations to report on how an application composed by a set of software components (columns) accomplishes a quality measure expressed

[1] Our preliminary scale was derived from the HoQ literature and had five points (from −2 to +2). However, after analyzing and discussing the checklist usability with a group of five developers, they recommended using a three-point scale to represent the scores.

#	Design category	Design features	Awareness types					
			Collaboration	Location	Context	Social	Workspace	Situation
1	Availability	Availability	32.5	6.4		4.0	4.5	
2	Communication	Communication mode	8.1	1.8		1.3	1.0	
3		Network connectivity	8.1		0.8	0.8	0.7	
4		Message delivery	8.1		1.1	0.8	0.7	
5		Message delays	8.1					
6	Spatiality	Cartesian locations		5.7	0.6	0.7		
7		Topological locations		5.7	0.7			0.9
8		Distances		5.7	1.1	1.1		
9		Orientations		5.7	0.6	0.7		
10		Range of attention		5.7	1.1	1.2		0.9
11	Mobility	Location modality		9.2	1.1	2.2	1.1	2.0
12		Level of mobility	1.6	9.2	1.2			1.3
13		Relation with other devices	2.4	9.5	1.4			
14	Physicality	Physical constraints		7.1	1.7			2.3
15		Physical places		7.1	1.5			
16		Physical topology		7.1	1.6			
17		Physical attributes		7.1	1.6			0.9
18	Navigation	Virtual places			5.3	2.2	1.4	
19		Virtual topology		1.1	5.3	2.0	1.4	
20		Map views		1.6	5.3	1.3	2.6	1.7
21		Viewports		1.2	5.3	1.0	2.5	1.7
22	Virtuality	Group objects	0.8		4.2	1.5	3.1	
23		Public objects			4.2	1.2	2.9	
24		Virtual attributes			4.2		0.7	
25		Virtual relationships		1.1	4.2		0.9	
26		Virtual constraints			4.2		1.5	
27	Practice	Roles	3.2		4.2	13.4	1.7	2.6
28		Activities	2.8		3.4	13.4	2.2	3.4
29	Background	Privileges			4.2	13.4	1.7	2.6
30		Group history			2.4	13.4	1.4	1.9
31	Task	Who	1.1		1.2	1.2	3.7	0.9
32		What	0.8		1.5		3.7	1.4
33		Where	0.9	2.0	1.1		3.7	1.4
34		When	1.1		1.2		3.7	1.4
35		How			0.9		3.7	1.6
36		Task history	1.2		0.6	0.6	3.7	0.9
37	Interaction	Feedback	1.0		0.5	1.5	4.5	1.2
38		Feedthrough	1.0		0.5	1.6	4.5	1.5
39		Backchannel feedback			0.7		4.5	0.9
40		Eye-gaze cues			1.1	5.4		
41		Voice cues			1.1	5.4		
42	Interdependence	Paralell activities	1.2		0.9	0.8	5.6	2.1
43		Coordinated activities	2.2		1.2	1.2	5.6	2.3
44		Mutually adjusted activities	2.2		1.5	1.3	5.6	2.1
45		Access control	1.2		5.3		1.8	
46	Understanding	Events	0.8		0.8		1.3	5.0
47		Actions	0.8		0.6		1.3	5.0
48		Resources			0.5		1.7	5.0
49		Critical elements	0.8		0.7		0.8	5.0
50		Meanings	0.7		0.7	0.6	0.7	5.0
51		Future scenarios					0.7	5.0
52	Sensemaking	Individual	1.4		1.6		1.7	10.0
53		Distributed	2.7		1.6	1.6	3.0	10.0
54		Collaborative	3.0		1.2	3.3	2.6	10.0

Fig. 2. Normalized correlations table.

by a set of quality items (rows) (Hauser and Clausing, 1988). In our case, the matrix was constructed in the following way. The rows present the set of 54 design elements. The columns reflect the awareness categories. However, since we are gathering two different types of scores – positive and negative – and we do not have a consistent way to relate them, we had to duplicate the columns in order to display both types of scores. Figs. 6, 9 and 11 show the structure of the awareness report, where the groups with positive and negative scores are visible.

Please assess if/how the following design features have been implemented in your application Use the 3-point scale shown on the right	O Adequate implementation - Neutral / not relevant X Inadequate implementation

#	Design category	Design features	Questions	Evaluator
1	Availability	Availability	The system informs who are the users available to collaborate?	
2	Communication	Communication mode	The system informs whether other users are working online, offline or both?	
3		Network connectivity	The system informs when the network connectivity is lost or recovered?	
4		Message delivery	The system informs the user when her/his messages are received by the target users?	
5		Message delays	The system informs the users about the time spent in message delivery?	
6	Spatiality	Cartesian locations	The system indicates the physical location of potential collaborators?	
7		Topological locations	The system inform whether other users are nearby?	
8		Distances	The system indicates the physical distances to other users?	
9		Orientations	The system indicates the orientation of other users (e.g. where they are moving towards)?	
10		Range of attention	The system gives cues about the user's centre of activity (e.g. what they are looking at)?	
11	Mobility	Location modality	The system indicates the type of users' mobility (e.g. whether they are wandering, visiting or traveling)?	
12		Level of mobility	The system recognizes the type of device mobility (e.g. whether the device is stationary or moving by a user or autonomously)?	
13		Relation with other devices	The system recognizes whether the device is independent of other devices, embedded into another device (e.g. a car), or spread throughout the environment?	
14	Physicality	Physical constraints	The system deals with the constraints imposed by the physical environment where it is used?	
15		Physical places	The system has a metaphor for "physical places" (e.g. meeting rooms and cafeteria)?	
16		Physical topology	The system gives cues about the complexity of the physical environment where it is used?	
17		Physical attributes	The system gives cues about the environmental conditions of the place where it is used (e.g. weather conditions)?	
18	Navigation	Virtual places	The system supports the concept of "virtual places" (different places for collaboration)?	
19		Virtual topology	The system represents the topology of the virtual environment (i.e. moving between virtual places)?	
20		Map views	The system gives an overview of the virtual environment?	
21		Viewports	The system allows users to peek the others' activities?	
22	Virtuality	Group objects	The system allows users to share objects/resources?	
23		Public objects	The system identifies the public objects/resources?	
24		Virtual attributes	The system displays the attributes of objects/resources in the workspace?	
25		Virtual relationships	The system displays the relationships between objects/resources in the workspace?	
26		Virtual constraints	The system gives cues about object/resource constraints (like location or ownership)?	
27	Practice	Roles	The system displays the users' roles?	
28		Activities	The system gives cues on the users' current activities?	
29	Background	Privileges	The system informs the user about the others' privilegies in the system?	
30		Group history	The system highlights the conventions/protocols agreed by the users to collaborate (e.g. who leads the discussion)?	
31	Task	Who	The system indicates who is doing a particular task?	
32		What	The system shows the activity being performed by a particular user?	
33		Where	The system indicates the place where a user is currently working on?	
34		When	The system informs when a task is being (or was) carried out?	
35		How	The system gives indications on how a task is being (or was) carried out?	
36		Task history	The system shows the sequence of tasks performed over time?	
37	Interaction	Feedback	The system provides feedback about the user's current actions?	
38		Feedthrough	The system notifies the user about the other's current actions?	
39		Backchannel feedback	The system notifies the user whether the others are following what her/he is doing?	
40		Eye-gaze cues	The system gives cues about where the users are looking at?	
41		Voice cues	The system provides feedback about who is talking to whom?	
42	Interdependence	Paralell activities	The system indicates if the users are doing parallel activities?	
43		Coordinated activities	The system indicates if users are doing coordinated activities (e.g. through a workflow)?	
44		Mutually adjusted activities	The system informs if users are doing mutually adjusted activities (i.e. modifying their own work according to others' activities)?	
45		Access control	The system notifies about who is in control of a shared object/resource?	
46	Understanding	Events	The system shows the past events that occured in the collaborative environment as a way to help users understand what is going on?	
47		Actions	The system shows the users' actions over time?	
48		Resources	The system displays the objects' changes over time?	
49		Critical elements	The system highlights the presence of critical issues in the working environment (e.g. events or situations)?	
50		Meanings	The system gives a strategic view about what is going on in the working environment?	
51		Future scenarios	The system gives cues about future situations that may occur in the working environment?	
52	Sensemaking	Individual	The system provides information that helps users reflecting over their course of action?	
53		Distributed	The system gives cues about environmental changes that may be relevant for the course of action?	
54		Collaborative	The system provides information that helps users keeping a shared sense of their goals and achievements?	

Fig. 3. Awareness checklist (fragment).

The intersection between all these rows and columns gives an indication of how an application implements each design element and addresses each type of awareness. Besides this detailed view, we also provide aggregate results for the awareness categories (see e.g. Fig. 6). The aggregated results are displayed using two inversely related numeric scales:

- Positive scale – It ranges from 0 to 100, where 0 means the application does not provide any positive contribution in the designated awareness category; 100 indicates the application fully supports the designated awareness category;
- Negative scale – It ranges from 0 to 100, where 0 means the application does not provide any negative contribution in

the designated awareness category; 100 indicates the application is fully detrimental to the designated awareness category.

Using these scales, we observe that an application that has all 54 design elements assessed as positive (+1) will obtain 100 positive and 0 negative results in all six awareness categories. On the opposite side, an application that has all 54 design elements assessed as negative (−1) will obtain 0 positive and 100 negative results in all six awareness categories.

Consider, for example, a case where a hypothetical reviewer realizes that "the system informs who are the users available to collaborate", i.e. she responds +1 to question #1 in the checklist. According to the normalized correlations table, which establishes the relationships between the availability design feature and awareness types, the awareness report will give the following results:

- collaboration awareness: 32 points,
- location awareness: 6.4 points,
- context awareness: 0 points,
- social awareness: 4.5 points,
- workspace awareness: 4.1 points,
- situation awareness: 0 point.

Since this hypothetical reviewer knows that each awareness category is measured in a 0–100 scale, these results indicate that the availability design feature is very important to collaboration awareness but does not have any impact on context and situation awareness. Suppose now that the reviewer considers "the system informs whether other users are working online, offline, or both" as inadequate, i.e. answering question #2 with −1. The correlations calculated in this case are:

- collaboration awareness: −8 points,
- location awareness: −1.8 points,
- context awareness: 0 points,
- social awareness: −1.5 points,
- workspace awareness: −0.9 points,
- situation awareness: 0 point.

These results indicate that the communication mode design feature erodes the awareness support, although the overall results are still positive. The analysis of the overall results in conjunction with a more detailed analysis of positive and negative scores provides a comprehensive view of the existing design tradeoffs.

The details of the process followed to calculate the aggregated results shown in the awareness report are presented below.

1. When we have several evaluators filling up individual checklists, we average their scores in the awareness report;
2. For each awareness category, every design element in the checklist that receives a positive score is multiplied by the corresponding correlation expressed in the normalized correlations table for that awareness category;
3. The same operation is executed for the elements that receive negative scores;
4. For each awareness category, the aggregated positive results are obtained by adding the adjusted results from step 2. The results are normalized to a [0–100] scale;
5. For each awareness category, the aggregated negative results are obtained by adding the adjusted results from step 3, which are again normalized to a [0–100] scale.

Considering a particular computer-supported collaborative application, the awareness checklist is used during FTR in the following way. The reviewers respond individually to the 54 questions. Each answer considers two aspects of a design element: (1) *relevance of a particular design element to the application under evaluation* (the lack of relevance is expressed by a 0 score), and (2) *how suitable is the implementation of a design element by the application* (+1 and −1 indicate if the implementation is acceptable or unacceptable). The positive and negative scores are thereby always related with design elements considered relevant to the application. However, the neutral scores are either related with design elements not relevant to the application (e.g. aspects of mobility are irrelevant to desktop applications) or design elements the evaluators do not have a strong opinion about. Table 2 summarizes the meaning of these scores.

For usability reasons it is recommended to fill the awareness checklist in two phases: (1) identify irrelevant design elements, and (2) qualify the relevant ones. The first step determines which elements do not need further consideration since they are irrelevant to the assessment. It reduces the complexity to fill the checklist and allows reviewers to focus on relevant elements. During the second step the evaluators only indicate (through a score) the acceptability of the implementation, since relevance was already established.

Once the evaluators have filled the individual checklists, there are two options to consolidate the results: (1) average the individual scores; and (2) perform a meeting to discuss the differences and try to reach a consensus. The second option is more time demanding but it also seems more accurate than the first one.

Once the individual scores are consolidated, the calculated positive and negative results are shown according to the 14 design categories and the six awareness categories. This gives at the same time a global view of the awareness support and a more detailed view based on the various design categories. Clearly, the negative scores indicate the areas where the awareness support must be improved.

We note again that the most positive outcome that may be achieved in one awareness category is having a result of 100-positive and 0-negative, while the most negative outcome is having 0-positive and 100-negative. Again, a specific application does not need to support any fixed number of awareness categories in order to be a high quality application.

Typically, different awareness mechanisms have different levels of relevance depending on the application being considered (Garcia et al., 2008). Although this evaluation method does not classify the relevance of the awareness categories using a formal scale, that relevance can be easily identified analyzing the total score (considering the positive and negative ones) assigned by the reviewers to each awareness category.

5. Examples of use

This section briefly discusses the inspection of three collaborative applications: MobileMap, Dropbox and COIN. MobileMap supports firefighters attending regular emergencies in urban areas (Monares et al., 2011). Dropbox is a widely used application that almost seamlessly shares files between user groups. COIN

Table 2
Rating the design elements in a collaborative system.

Relevance	Implementation	Score
Relevant	Acceptable ("good")	+1
Relevant	Unacceptable ("bad")	−1
Relevant	Neutral ("do not know")	0
Irrelevant	("do not care")	0

(Construction Inspector) supports a team of construction inspectors when they review physical infrastructures in construction sites (Ochoa et al., 2011; Rodríguez-Covili and Ochoa, 2013). In this last case, two different versions of the system were analyzed using the proposed checklist. The feedback obtained from the study of the first version of the system, was then used to develop the new COIN, which has shown to be more useful for the end-users.

In the selection of the applications to be analyzed we considered mainly the availability of some of their developers to play the role of evaluator. This is because each evaluation team should consist of two evaluators: a developer who had participated in the system design and a user (with the exception of Dropbox, which was studied by two users with experience in other systems' design). Evaluators were asked to participate in just one evaluation to avoid the learning effect. One of the authors acted as observer of all evaluations. It is important to note that the evaluators may be part of the development team of the application they analyze (which is useful to obtain feedback to evolve a product), but they may also be users with some experience in the application and some preliminary knowledge about CSCW.

Two teams inspected each application. The analysis process for an application consisted of three steps: (1) each team inspects the application and completes the awareness checklist, (2) both teams perform a joint consensus meeting to discuss the discrepancies and obtain consolidated rates for the checklist design elements, and (3) the evaluators examine the awareness report in a meeting, whose goal is to identify the main issues – if any – that could help improve the application. The analysis process was completed within just one day, because then the evaluators had the analysis knowledge in mind, which made the process more effective and less time demanding. We strongly recommend doing the same in practice.

After completing the reviewing processes of each application, one of the two teams was interviewed as a way to obtain the evaluators' feelings about the usability and usefulness of the proposed technique. The following questions were used to guide these interviews:

1. *Did the technique help you understand the strengths and weaknesses of the application in terms of awareness support?* If the answer is yes,
2. *What exactly did you learn about this application design after applying the technique?*
3. Considering the obtained result, *do you think it is worth the evaluation effort?*

The next sections briefly introduce the analyzed collaborative applications, describe how to use the technique to study them, and discuss the obtained results. These sections also include a summary of the interviews done to the reviewing teams.

5.1.1. Analysis of MobileMap

Fire truck drivers use MobileMap to guide themselves to their destination, and firefighter commanders use it to share information about an emergency (e.g. type of incident, location and complexity), to know the assigned resources (e.g. type and location of vehicles), and review the affected area (e.g. location of the closest fire hydrants, or surrounding buildings that eventually need to be evacuated). The application also manages several emergencies in separate work sessions, and the shared resources and events related to an emergency are visible only to the members of that session. Using MobileMap, the incident commander (i.e. the person in charge of the emergency response) visualizes almost in real-time the location of the resources available to deal with the emergency. This view is also shared with other commanders and the team

Fig. 4. MobileMap user interface.

leaders participating in the emergency response, which may contribute to better situation awareness.

Fig. 4 shows MobileMap's main user-interface, which presents two arrows pointing from the fire truck's current location: the white arrow indicates the direction in which the fire truck is moving; and the black arrow shows the direction in which the truck should move to get to the emergency place. Each fire truck reports its location periodically to an alarm center, which serves as shared repository and coordinator among vehicles attending to an emergency.

5.1.2. The analysis process

Two teams studied MobileMap and completed the checklist shown in Fig. 3 (i.e. the first step of the analysis process). That process took 89 min for the first team, and 123 min for the second one.

Then, both teams participated in the consensus meeting to discuss the discrepancies and get a final score for the checklist items (i.e. the second step of the analysis process). In that meeting, which lasted 35 min, the final score shown in Fig. 5 was obtained. These results identify the awareness categories where the positive scores (i.e. the dark line) were greater than the negative ones (i.e. the clear line); in this case, they were collaboration and location awareness. In the case of the collaboration category the unsatisfied need for awareness support is close to zero, which means there are few (or no) pending awareness requirements in that category. In the case of location awareness, the application already provides a good support (e.g. to visualize resources in real-time); however it still

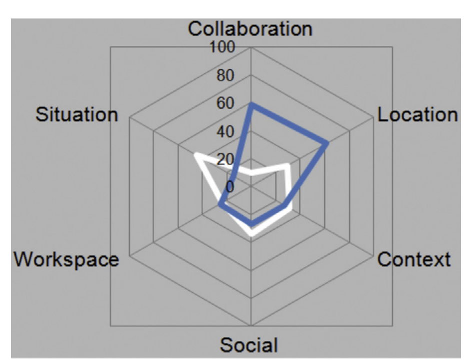


Fig. 5. MobileMap review (dark line: positive scores; clear line: negative scores).

may require to include other location services like identifying cross-organization resources and positioning response teams in the field.

Concerning the context, social and workspace awareness, the implemented and non-implemented mechanisms are on par. Considering situation awareness, the evaluators clearly expressed an imbalance toward missing features. Situation awareness requires that the system constantly gives information about the emergency and the teams' response, but the application just provides information about the location of some resources, which was considered insufficient to help the decision makers in the field. Clearly, awareness support for these last four categories must be improved.

5.1.3. Analysis of the scores

The analysis of the scores is the third step of the evaluation process, and its main goal is to try to identify key awareness design elements that must be improved, according to the users' and designers' opinions. Fig. 6 presents a portion of the awareness report in which we can identify the opportunities for improvement. The value in each cell indicates the extent the corresponding design element positively or negatively affects the support for a particular awareness category.

Analyzing the table that totalizes these scores (see tag "A" in Fig. 6) we can quickly identify the main strengths and weaknesses of the application, in terms of awareness support. In the case of MobileMap, the *collaboration* and *location awareness* seem to be quite well implemented since the positive scores are considerably higher than the negative scores for these categories. Contrarily, the mechanism implemented to provide *situation awareness* is clearly deficient because its negative score is higher than the positive one. The rest of the awareness categories are quite balanced. This means that the current mechanisms implemented to provide supporting information about those categories are useful, but there might be also an important space to improve them.

Once the main improvement areas of the application have been identified (e.g. the support for *situation* awareness), we can analyze more in detail the matrix to determine how to do this improvement. The scores in the *situation* awareness column show that the *understanding* and *sensemaking* design categories are not well considered in the application, since they have the highest negative scores for an awareness category (Fig. 6, tag "B"). Following the same reasoning, we can see that the *roles* (belonging to the *practice* design category) and *privileges* (belonging to *background*) are not well considered in the application, negatively affecting the *social* (tag "C") and *context* awareness (tag "D").

We can also identify the improvement areas by analyzing the rows of the matrix. For instance, the implementation of services to support user *roles* and *privileges* will help the application to improve its *collaboration*, *context*, *social*, *workspace* and *situation* awareness (tag "E"). The same occurs if we implement services to monitor the response process (i.e. *understanding* and *sensemaking* design elements) that will allow the application to improve the *collaboration*, *context*, *workspace* and *situation* awareness (tag "F").

Although MobileMap offers an adequate support for *location* awareness (see tag "A" – the total positive score), the results show unsupported awareness needs related to the identification of the *physical environment* and *distances* (tag "G"). These weaknesses represent opportunities for improving the application. The same occurs with any other highly positive implementation of an awareness mechanism including some weaknesses.

In the third step of the evaluation process, the evaluators identified several opportunities to improve the system: (1) giving feedback about the location and activities performed by teams in the emergency area; and (2) highlighting the user roles and privileges, which would make the users more aware of the roles teams play during emergencies. Concerning the fourth step, the evaluators provided positive feedback on the use of the checklist.

The time spent in the matrix analysis and the identification of key design elements to be improved was 75 min.

5.1.4. Evaluators feelings

One of the teams was interviewed to get its members' feelings about the usability and usefulness of this technique. To the first question (*did the technique help you to understand the strengths and weaknesses of the application in terms of awareness support?*), the evaluators answered 'yes' and expressed their surprise about the level of detail given by the matrix when discussing possible improvements to the application. To the second question (*what exactly did you learn about this application design after applying the technique?*), the evaluators answered that "*before this evaluation I never was conscious about the relevance of implementing roles and privileges in the system*". One evaluator mentioned that "*I didn't know a technique that allows me at the same time to identify the system weaknesses and also to analyze the impact of the possible improvements*". This evaluator also mentioned "*by analyzing the matrix I can identify deficiencies that are not so visible when we complete the checklist or discuss our discrepancies*". Finally, the last question considered the effort involved in the proposed technique (*do you think the result is worth the evaluation effort?*). The evaluators agreed that before the analysis they believed the process would be shorter. After the analysis, they thought "*the process is longer than our expectations, but it is short if we consider what we can get as evaluation results. It's definitely worth it*".

5.2. Analysis of COIN

A construction inspection is an activity in which a team of inspectors reviews and diagnoses the physical facilities of an infrastructure (i.e. a building or a bridge) in a coordinated way. Fig. 7 shows the user interface of the first version of COIN (Construction Inspector), a mobile application that is used by inspectors on a tablet PC to annotate digital blueprints related with construction projects (Ochoa et al., 2011). These annotations are done in the field and used in the construction company headquarters to schedule maintenance tasks to sub-contractors. The application is able to perform several on-demand interaction activities, such as synchronizing the inspectors' digital annotations and perceiving the availability of people when required to discuss contradictory annotations, which are typical activities in the inspection process.

The application also manages several construction projects as particular workrooms, through which the inspectors can share digital resources (e.g. annotations and blueprints). COIN uses a mobile ad-hoc network to support users' interactions in the construction site and also to implement a buddy list that indicates which inspectors are in the surrounding area and whether they are available to collaborate. The tool also implements synchronous messaging; for example a chat and the delivery of predefined notifications (e.g. "I finished my job") to members of an inspection team. The first version of the system was studied using the proposed checklist, and two teams composed of a designer and a regular user of this application. Next section describes that analysis process and the obtained results. Using such a feedback, a new version of COIN was developed and evaluated also using the proposed checklist. The new version of the system and its analysis results are presented in Section 5.2.2.

5.2.1. Analysis of COIN 1.0

The reviewing process (i.e. completing the checklist) lasted 93 min for the first team and 106 min for the second one. Then, they performed the scores consolidation, which took 47 min. Fig. 8 shows the obtained results after the consensus meeting. The worst

#	Design category	Design element	Positive: Collaboration	Positive: Location	Positive: Context	Positive: Social	Positive: Workspace	Positive: Situation	Negative: Collaboration	Negative: Location	Negative: Context	Negative: Social	Negative: Workspace	Negative: Situation
1	Availability	Availability	32	6.4		4.0	4.5							
2	Communication	Communication mode	8.1	1.9		1.3	1.0							
3		Network connectivity	8.1		0.8	0.8	0.7							
4		Message delivery												
5		Message delays												
6	Spatiality	Cartesian locations		5.7	0.6	0.7								
7		Topological locations		5.7	0.7			0.9						
8		Distances								5.7	1.1	1.1		
9		Orientations		5.7	0.6	0.7								
10		Range of attention												
11	Mobility	Location modality		9.2	1.1	2.2	1.2	2.0						
12		Level of mobility	1.6	9.2	1.2			1.3						
13		Relation with other devices	2.4	9.5	1.4									
14	Physicality	Physical constraints								7.1	1.7			2.3
15		Physical places		7.1	1.5									
16		Physical topology								7.1	1.6			
17		Physical attributes								7.1	1.6			0.9
18	Navigation	Virtual places												
19		Virtual topology												
20		Map views								1.6	5.3	1.3	2.6	1.7
21		Viewports								1.2	5.3	1.0	2.5	1.7
22	Virtuality	Group objects	0.8		4.2	1.5	3.1							
23		Public objects			4.2	1.2	2.9							
24		Virtual attributes												
25		Virtual relationships		1.1	4.2		0.9							
26		Virtual constraints												
27	Practice	Roles							3.2		4.2	13	1.7	2.6
28		Activities	2.8		3.4	13	2.2	3.4						
29	Background	Privileges									4.2	13	1.7	2.6
30		Group history												
36	Task	Task history												
46	Understanding	Events							0.8		0.8		1.3	5.0
47		Actions							0.8		0.6		1.3	5.0
48		Resources			0.5		1.7	5.0						
49		Critical elements							0.8		0.7		0.8	5.0
50		Meanings							0.7		0.7	0.6	0.7	5.0
51		Future scenarios												
52	Sensemaking	Individual												
53		Distributed							2.7		1.6	1.6	3.0	10
54		Collaborative												
		Total positive / Total negative	59	61	27	27	26	15	10	30	31	34	24	45

Fig. 6. Partial view of MobileMap awareness report.

scores were for the location, context and the social awareness, although workspace and situation awareness are also deficiently supported according to the users. In case of location awareness the unsatisfied users' demands come from two already known COIN deficiencies: (1) the lack of support for knowing the current position/activity of other team members during an inspection process (i.e. *spatiality* and *mobility* design categories), particularly when they are working indoors, and (2) the lack of capability to deal with the physical environment (i.e. *physicality* design category). This second aspect is a consequence of using mobile ad

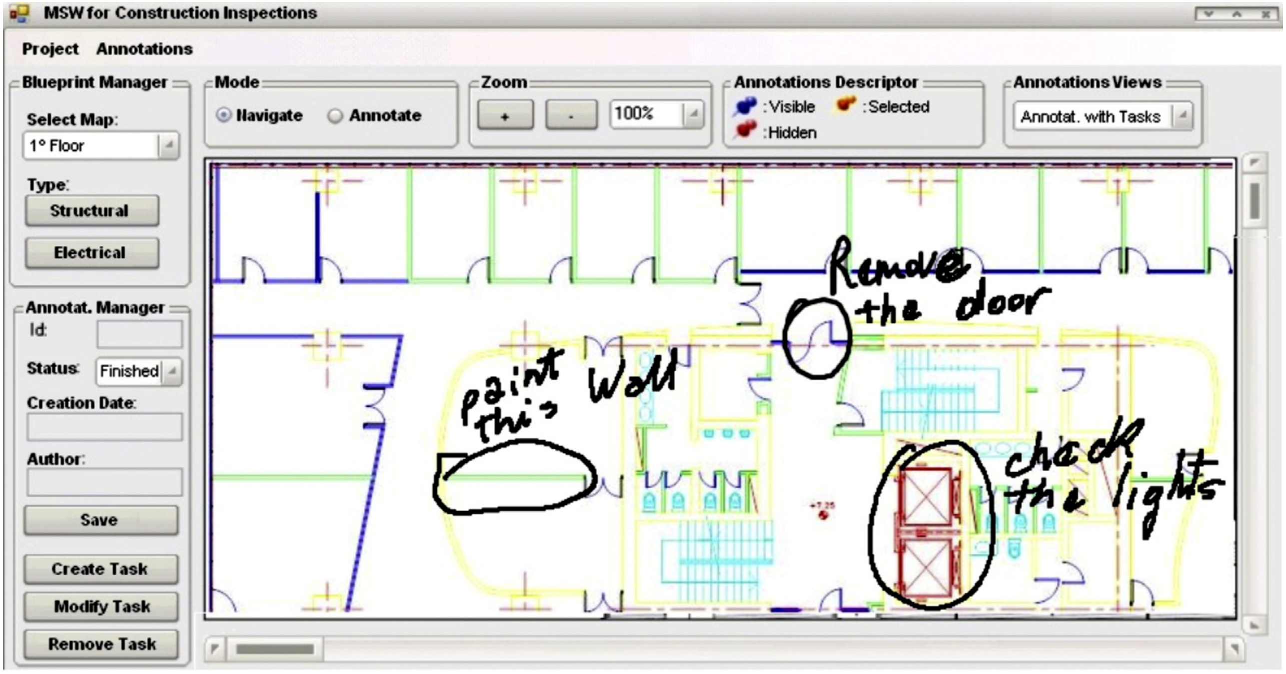


Fig. 7. COIN user interface.

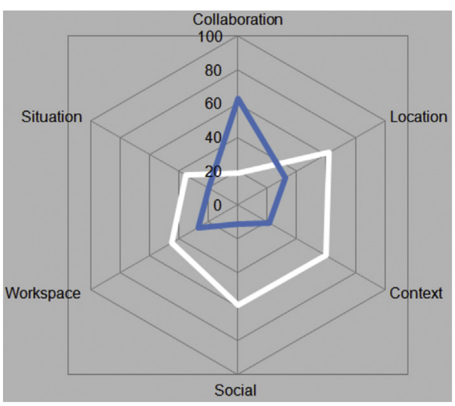


Fig. 8. COIN 1.0 review (dark line: positive scores; clear line: negative scores).

hoc networks that are affected by the physical scenarios built with concrete and bricks and also by the environmental conditions.

Fig. 9 presents the COIN awareness report where we can see detailed information about each evaluation aspect. The worst scores were for the *location*, *context* and *social awareness* (see total negative scores – tag "A"), although *workspace* and *situation* awareness are also insufficiently supported according to the evaluators.

The users are also unsatisfied because of the services provided by COIN for project *navigation*, user *roles* (and *privileges*) support, and also information provision about users' current activities (i.e. the *task* design category). This becomes clear in tags "C", "D" and "E". Observing Fig. 9 we can see that some of these design issues form a cluster (tag "F") that affects negatively the support for all awareness categories, particularly the *context*, *social* and *workspace* awareness. Therefore if we implement services addressing these needs, then the system awareness support will improve in the six areas.

Since COIN manages multiple projects and several digital blueprints (i.e. views) for each project, it becomes mandatory to provide mechanisms that allow an inspector to find potential collaborators to synchronize and eventually check the annotations. This COIN version does not provide a simple mechanism to change the view in which a user is working on, or the possibility to manage more than one active view. Moreover, the application allows identifying potential collaborators if they are just working on the same digital blueprint, which is clearly insufficient to find other collaborators and know what they are doing. These are the reasons why the context awareness mechanisms ratings in COIN are low.

The analysis of the obtained results also shows that the application needs to improve the supporting information about users' roles, activities and privileges, as well as the group history; i.e. the social aspects of teamwork. The reviewers mentioned that COIN should be used as an integral tool, which is used by inspectors, the foreman, the project leaders and also the subcontractors to perform their work. All of them access the project information according to their role and the privileges given to them. Thus, it would be possible to improve the coordination among the current actors and avoid the delivery of printed information. Implementing services to support the *practice* and *background* design categories will improve the social and context awareness.

The workspace awareness can be improved by implementing services that provide information about the current task activities (i.e. the *task* design category), e.g. informing who, what and when a task is being performed. These services would also contribute to increase the situation awareness.

After analyzing the matrix the evaluators identified the main issues to be improved in the tool. These issues were the following: (1) to provide users' location/activity awareness independently of the construction site physical scenario, and (2) to assign users roles (and privileges) to allow all actors in a construction project to get access according to the shared resources. This activity took 64 min.

5.2.2. Analysis of COIN 2.0

Using these evaluation results, a new version of COIN was developed. The main features that were included in the new version of COIN were related to the users' location and movement, and also the activities performed by them. Fig. 10 shows the new user interface of this tool.

The analysis was similar to the one described in the previous section. Two teams, different to the previous ones, participated in the process. The first review took 96 min, the second one lasted 82 min and the duration of the scores consolidation was 43 min.

#	Design category	Design features	Positive: Collaboration	Positive: Location	Positive: Context	Positive: Social	Positive: Workspace	Positive: Situation	Negative: Collaboration	Negative: Location	Negative: Context	Negative: Social	Negative: Workspace	Negative: Situation
6	Spatiality	Cartesian locations								5.7	0.6	0.7		
7		Topological locations		5.7	0.7			0.9						
8		Distances								5.7	1.1	1.1		
9		Orientations								5.7	0.6	0.7		
10		Range of attention												
11	Mobility	Location modality								9.2	1.1	2.2	1.1	2
12		Level of mobility	1.6	9.2	1.2			1.3						
13		Relation with other devices							2.4	9.5	1.4			
14	Physicality	Physical constraints								7.1	1.7			2.3
15		Physical places		7.1	1.5									
16		Physical topology								7.1	1.6			
17		Physical attributes								7.1				0.9
18	Navigation	Virtual places									5.3	2.2	1.4	
19		Virtual topology								1.1	5.3	2	1.4	
20		Map views								1.6	5.3	1.3	2.6	1.7
21		Viewports								1.2	5.3	1	2.5	1.7
27	Practice	Roles							3.2		4.2	13	1.7	2.6
28		Activities							2.8		3.4	13	2.2	3.4
29	Background	Privileges									4.2	13	1.7	2.6
30		Group history												
31	Task	Who							1.1		1.2	1.2	3.7	0.9
32		What							0.8		1.5		3.7	1.4
33		Where	0.9	2	1.1		3.7	1.4						
34		When							1.1		1.2		3.7	1.4
35		How												
36		Task history							1.2		0.6	0.6	3.7	0.9
		Total positive / Total negative	63	32	22	11	27	20	19	62	60	59	45	35

Fig. 9. Partial view of COIN awareness report.

Fig. 11 shows the radar graph with the obtained results, both positive (Fig. 11a) and negative (Fig. 11b). The dotted line represents COIN 2.0 results, while the solid line represents COIN 1.0 scores.

These results show that the negative scores have reduced their relevance in most awareness categories. Moreover, the positive scores have increased in every category. This means that the new awareness mechanism embedded in the new version of COIN have had a transversal positive impact in the usefulness of the system. Although the tool still has several aspects to be improved, they can be identified using the feedback provided by the proposed checklist. Next section presents the users' feelings about both, the use of the instrument and the process to identify candidate awareness elements to be included in the system.

5.2.3. Evaluators feelings

In both analyses, a reviewing team was chosen at random for the interview. Concerning the first question (*did the technique help you to understand the strengths and weaknesses of the application in terms of awareness support?*), both participants answered 'yes'. One evaluator mentioned that "*before this evaluation I believed that COIN was a good application to support the inspection process. Now I realized that it is clearly limited*". Concerning the second question (*what exactly did you learn about this application design after applying the*

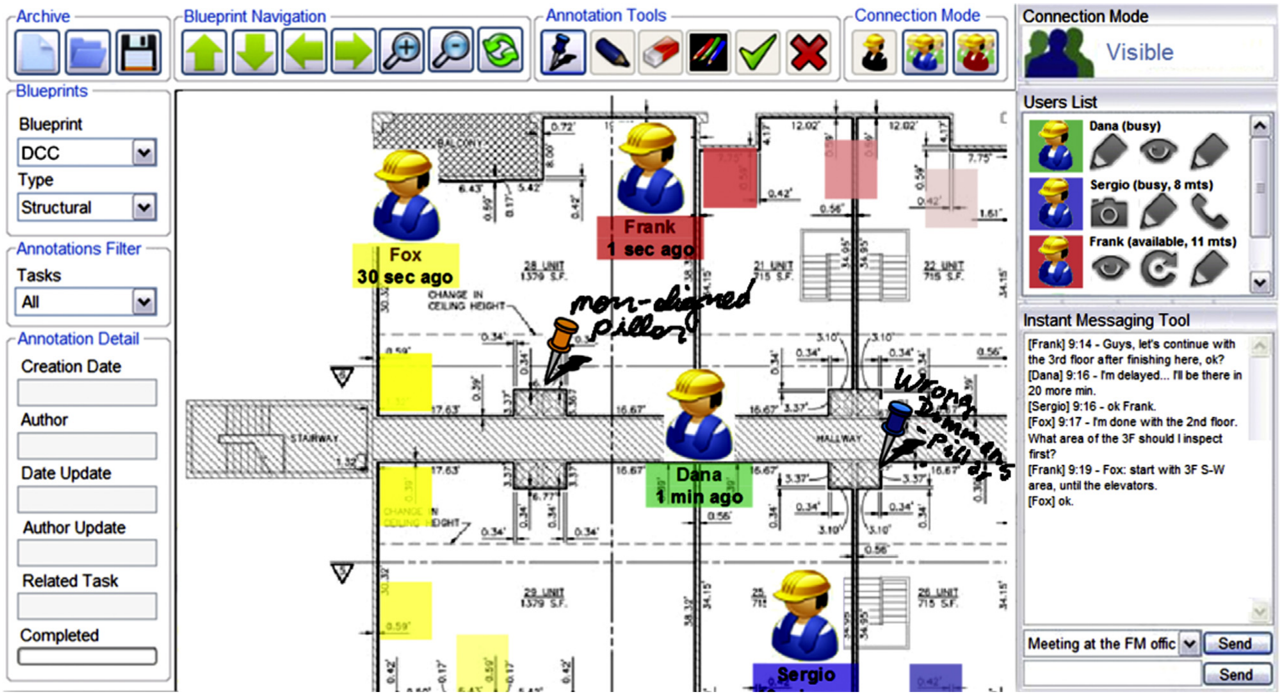
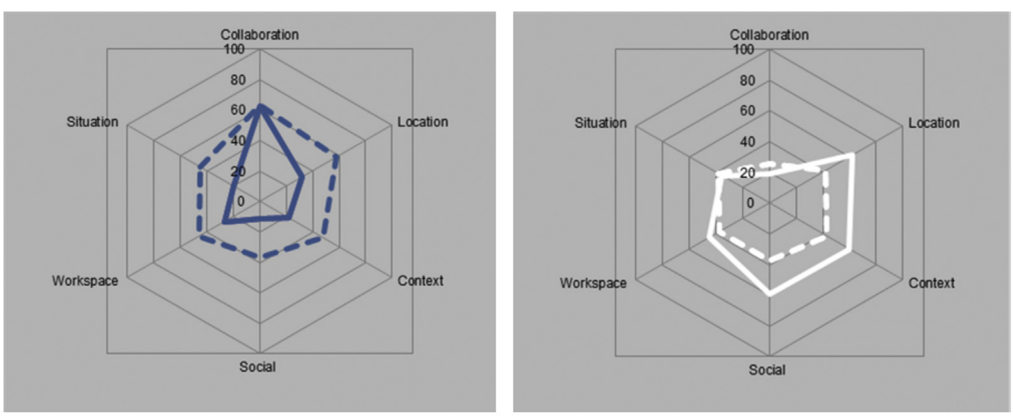


Fig. 10. New COIN user interface.



(a) Positive scores comparison (b) Negative scores comparison

Fig. 11. COIN 2.0 review (dotted line) vs. COIN 1.0 review (solid line).

technique?), the second evaluator mentioned "*I learnt two things. The first one is that it is possible to have a clear view of the awareness support provided by an application spending a reasonable effort. The second one was that choosing correctly the awareness elements to improve, we can produce a general improvement for the application*". The first evaluator also mentioned that he learnt "*the relevance of discussing the discrepancies. Otherwise I never would have realized the importance of user roles*". That point was raised by the reviewing team that was not interviewed as well.

The answers to the last question (do you think the result is worth the evaluation effort?) indicate the technique is worthy. The second reviewer said "in these six hours I have collected enough information for working in the tool improvements for at least one year". The first evaluator concluded "the evaluation was time-demanding and some parts of the process were stressful, but seeing the results I'm sure that it is worth it".

5.3. Analysis of Dropbox

As another instance of analysis we studied Dropbox version 1.1.23 for Windows and Mac OS X. This is a well-known application used mainly to share files through the Internet. Dropbox implements shared folders that are accessed without restriction by a list of invited users. It should be clear that this is not a formative evaluation since we are not the Dropbox developers and we will not evolve the tool. Furthermore, the application may not be precisely classified as "collaborative". Nevertheless, we wanted to observe whether the proposed analysis method could provide insights as to what Dropbox would need to be oriented more strongly toward supporting collaborative activities.

5.3.1. The analysis process

As in the two previous cases, two reviewing teams independently studied the tool and completed the checklist. The evaluators were software engineers who regularly design software and also utilize Dropbox to support their activities (i.e. Dropbox users).

After the reviewing process, both teams performed the consensus meeting; Fig. 12 shows the obtained results. Such results show a situation similar to the COIN analysis, where the users' requests for awareness support overcome considerably the capabilities provided by the system. In the case of Dropbox this result is

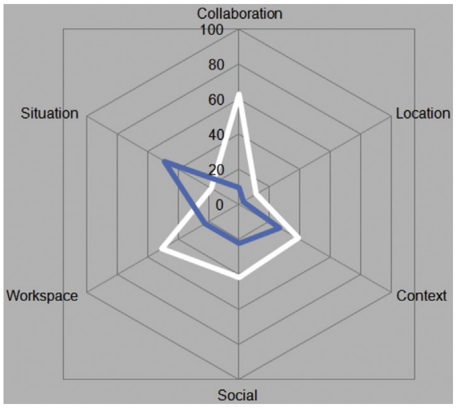


Fig. 12. Dropbox review (dark line: positive scores; clear line: negative scores).

predictable and it has a simple explanation. This tool was designed as a general purpose application, and the reviewers are evaluating it considering Dropbox as particularly designed to address collaborative processes; that is the main reason for such discrepancy.

The time spent in the reviewing process was 84 min for the first team and 76 for the second one. The consensus meeting lasted 34 min. Next section presents and discusses the weaknesses of Dropbox according to these evaluators.

5.3.2. Analysis of the scores

Analyzing the total negative scores indicated in the matrix (Fig. 13 – tag “A”) we can identify four awareness categories having an unsatisfactory support: *collaboration*, *context*, *social* and *workspace*. Concerning the *collaboration* awareness category, the main requested feature was a buddy list (or similar construct) to inform others who is online and offline, and also what they are doing (tag “B”). Concerning *context* awareness, the reviewers identified the need to implement more complex virtual spaces (something better than a shared folder) to allow performing more interesting collaboration processes (tag “C”). They also indicated the need to incorporate users' roles and privileges (i.e. the *practice* and *background* design categories), because in the current Dropbox implementation all users with access to a shared folder have the same rights on the resources contained in it (tag “D”). Depending on the activity supported by the tool, the lack of support for these design elements could be a serious limitation, affecting *context* and *social* awareness (tags “D” and “E”). Similar to the previous cases, implementing services to support users roles and privileges we may improve the awareness support in various categories (tag “F”).

The *workspace* awareness, which is affected by several already identified design elements (tag “G”), is the category with the lowest scores. According to the evaluators, Dropbox would have to implement *task* awareness mechanisms to support any collaboration process that requires more than simple file sharing.

After analyzing the awareness report, participants identified the three main aspects of Dropbox that would need to be improved to provide collaboration support: (1) the visibility about users' presence and availability, which would impact the *collaboration*, *social* and *workspace* awareness, (2) the support for user roles and privileges that would allow more suitable file sharing mechanisms, and impact various awareness categories (but mainly the *social* awareness), and (3) the visibility about the users activities, which is not currently supported by Dropbox. This last aspect will contribute to improve the *workspace* awareness.

The analysis of the awareness report and the identification of the main issues took 47 min. Next we present the feelings of the reviewers who participated in this process.

5.3.3. Evaluators feelings

This activity was performed in the same way than the previous analysis processes. Concerning the first question (*did the technique help you to understand the strengths and weaknesses of the application in terms of awareness support?*) both participants answered ‘yes’, but they realized that Dropbox was not particularly designed to support the activities that they were performing using the tool. One evaluator also mentioned that “*although the technique is useful to identify Dropbox limitations, it does not make sense to analyze an application that we are not able to change*”. Concerning the second question (*what exactly did you learn about this application design after applying the technique?*), the same evaluator indicated “*I have learnt that a simple and limited application can be successful if we use it just in the most favorable scenario*”. The second evaluator mentioned that “*after this evaluation I realized enormous potential of Dropbox as a collaboration platform*”. The responses to the last question (*do you think the result is worth the evaluation effort?*) both participants indicated the technique is clearly useful to identify limitations in the awareness support, but they would like to use it to analyze an application that they can improve.

6. Discussion

Aspects of collaboration are becoming quite natural in various types of applications used by large groups of people. Popular current examples include Wikipedia, Doodle, Google Maps and Docs, Facebook, LinkedIn, Dropbox, Twitter and Zoho. This clearly indicates that collaboration support is being subsumed with other features in all types of applications.

This trend has taken CSCW out from the research laboratories into the market, where broad socio-technical concerns such as awareness, context, social interaction or media effects may have to fight for the engineers' attention against more focused technological problems. We recently had the opportunity to evaluate the use of one of the aforementioned tools by a large group of users in a collaborative scenario, just to find out that the tool does not support several features that have been researched for many years (Antunes et al., 2011).

Thus, from our point of view, questioning whether and how CSCW knowledge accumulated in the laboratory is being transferred to the market has become of paramount importance. The research described in this paper contributes to this discussion. The awareness checklist codifies a large amount of CSCW expertise about awareness support, thus helping software designers reflect on the awareness support their application should provide. The checklist points out positive and negative factors in a very ample range of awareness and design categories. The awareness types and the design elements come from an extensive review of the CSCW literature. Therefore, all of the awareness types and design elements will not be relevant to every application. However, the checklist provides application designers with many aspects of awareness to consider adding into a design. On the other hand, we make no claim of checklist completeness: future research may add design elements not considered in the current version. This consideration was included in the checklist, as an opportunity for evaluators to add additional awareness elements that the application they were evaluating had, or should have (Appendix B). However, none of the evaluators felt the need to add any element. Naturally, we do not claim that this proves checklist completeness.

We studied which elements of the checklist are present in available software – both software discussed in this article (Dropbox, COIN, MobileMap) and other collaborative applications (Whatsapp, SecondLife, Foursquare). This exercise is presented in Appendix C. We wanted both to explore whether the checklist captured awareness elements present in existing software, and to see if any

#	Design category	Design features	Positive						Negative					
			Collaboration	Location	Context	Social	Workspace	Situation	Collaboration	Location	Context	Social	Workspace	Situation
1	Availability	Availability							32	6.4		4.0	4.5	
2	Communication	Communication mode							8.1	1.8		1.3	1.0	
3		Network connectivity							8.1		0.8	0.8	0.7	
4		Message delivery												
5		Message delays												
18	Navigation	Virtual places									5.3	2.2	2.4	
19		Virtual topology								1.1	5.3	2.0	1.4	
20		Map views		1.6	5.3	1.3	2.6	1.7						
21		Viewports												
22	Virtuality	Group objects	0.8		4.2	1.5	3.1							
23		Public objects			4.2	1.2	2.9							
24		Virtual attributes												
25		Virtual relationships		1.1	4.2		0.9							
26		Virtual constraints									4.2		1.5	
27	Practice	Roles							3.2		4.2	13	1.7	2.6
28		Activities												
29	Background	Privileges									4.2	13	1.7	2.6
30		Group history			2.4	13	1.4	1.9						
31	Task	Who							1.1		1.2	1.2	3.7	0.9
32		What							0.8		1.5		3.7	1.4
33		Where							0.9	2.0	1.1		3.7	1.4
34		When							1.1		1.2		3.7	1.4
35		How									0.9		3.7	1.6
36		Task history												
42	Interdependence	Paralell activities							1.2		0.9	0.8	5.6	2.1
43		Coordinated activities							2.2		1.2	1.2	5.6	2.3
44		Mutually adjusted activities							2.2		1.5	1.3	5.6	2.1
45		Access control							1.2		5.3		1.8	
		Total positive / Total negative	9	3	27	22	22	49	62	11	39	42	51	18

Fig. 13. Partial view of Dropbox awareness report.

awareness elements were missing from the checklist. We found that within these seven applications 40 (out of 54) elements were present, and no new elements were missing from the checklist. It is important to note that 14 elements were not immediately apparent in the reviewed applications. This is natural, as we only reviewed a fraction of all possible applications, and some of the elements (e.g. eye-gaze cues) are very specific and may pertain to other domains, with more specialized needs.

The checklist also offers an engineering approach to articulate the relationships between design requirements and implementation requirements, allowing engineers to explore what-if scenarios. It may not be as useful as a clear-cut theory, which for instance could give estimates of effort, usability or success/failure, but nevertheless contributing with a practical and explicit mechanism to tune the design features to the information people need in their collaboration.

We identified two main analysis strategies that developers may adopt: (1) comparing different design iterations, focusing on deltas rather than absolute scores; and (2) doing what-if simulations of different design decisions, using deltas to evaluate their impact. As such, the checklist approach may be useful in its intended analysis of design features.

Of course since one aim of the checklist is to provide across-the-board guidelines for system designers, it is best suited to those who do not have much experience with CSCW, although it can also be useful as a reminder for experienced CSCW designers. Our experience developing the checklist and interacting with the participating CSCW experts also raised the problem that it may be difficult to describe the awareness design elements to participants with no experience at all in CSCW. The various iterations of the checklist tried to improve clarity and insight, but further research actions may be necessary to improve it.

We also note that the checklist adopts a fixed benchmark, seeking to obtain 100% scores in all defined criteria. However, often the software engineers just seek acceptable solutions for their particular context, which may turn the review of all design elements unnecessary. Also, incorporating additional awareness elements may produce information overload, as users' attention is limited, thus developers must find a suitable tradeoff. This means it may not be optimal in this sense to obtain a score of 100%.

We have done some preliminary experiments with an alternative checklist that adjusted the review to the application context. This gave the evaluators the possibility to remove some design categories from their analysis and still obtain 100% scores in the evaluation. However, we observed the obtained results turned quite difficult, if not impossible, to compare different applications and different designs. It also made it more difficult to understand how far a particular design is from the optimal (since the optimal becomes a moving target). As a consequence, we opted for the fixed benchmark.

Regarding the 100% scores, we emphasize that our goal is not having development teams incorporating unnecessary awareness features in their applications. Quite on the contrary, evaluators are expected to analyze which design features are adequate to their application context and make that explicit in the checklist, in this way adjusting the analysis of a tool to a particular collaboration scenario and not assigning negative scores to features that are not needed in the application use scenario. This means that in most realistic situations the obtained scores may be well below 100%. However, as we found out in practice, basing the construction of what-if scenarios on a fixed benchmark allows comparing very different design options.

We also observe that the cost of implementing a particular design feature could have been equated in the checklist. This somehow reflects the same preoccupations that we have found in the software quality community, where the effort to implement the software components is commonly considered (along with other criteria such as organizational importance). Further empirical work is necessary to understand if such additional complexity gives actual benefits to the checklist users.

Still, considering the limitations of the proposed approach, we note that the awareness checklist does not substitute proper usability evaluations. The checklist may give some indications to software designers about which features may be lacking or inadequately implemented in the system. Nevertheless, in the case of inadequate implementations, it does not identify the specific deficiencies. Also, the checklist does not provide detailed feedback about the usability and usefulness of the features.

In order to finish our discussion of the current limitations, we note that awareness support is just one aspect of CSCW research. Therefore the proposed checklist does not aim to inform about all problems and challenges they may encounter when incorporating collaboration support in their applications. However, awareness is one important facet of the problem, especially when highly interactive and interdependent tasks are involved, such as the ones discussed in two of the case studies presented in the paper. Future work might focus on extending the checklist to other CSCW concerns, for instance integrating it with other methods evaluating CSCW support.

We finish the discussion highlighting some positive contributions from this research. The first one we consider is derived from the analysis of the state of the art. This paper provides a framework disentangling the main constituents of awareness and their relationships with design elements. We believe this framework may help software engineers who are not experienced with CSCW perceive the socio-technical nature of their implementations and align their strategies with the best practices. The proposed checklist also provides these people with a fast mechanism to compare different applications and check design consistency. Although limited in scope, the case studies described in this paper gave positive indications about this feature.

At a more theoretical level, this research also contributes to elucidate how different design elements are related with different awareness functions. Departing from a set of correlations theoretically derived from the related literature, we probed several CSCW experts about additional correlations. The obtained results confirm our initial perception that the relationships between design elements and awareness are rather complex. Certainly more input from CSCW experts will allow improving the precision of the correlations table.

7. Conclusions and further work

Awareness is an important component of collaborative technology that helps users conducting interaction processes, orchestrating their activities and ultimately achieving their shared goals. In this paper, we have studied the analysis of awareness support starting with the basic concepts of formal technical reviews.

We developed an awareness checklist helping software designers inspect the quality of awareness support in applications that are under development or evolution. The checklist items were defined based on an ample review of awareness research that allowed us to identify 54 design elements contributing to six different types of awareness. Of course, the engineer is not forced to incorporate all these design elements in a certain application; he/she can use this checklist to ponder the benefits of a certain design element and the implementation of a certain type of awareness.

The correlations between design and awareness elements were defined according to theory and practice, incorporating the views of CSCW experts. The awareness checklist allows quickly obtaining hints on the quality of awareness support supplied by an application by simply inquiring about how effectively some key design elements have been supported. The awareness checklist serves to obtain positive and negative scores, both contributing to inform people about which design areas require major interventions. The awareness checklist also serves to define quality metrics, control the development processes and benchmark various applications. The awareness checklist was used to inspect three applications, and the obtained results suggest that the checklist is useful to provide a review of an application's strengths and weaknesses regarding awareness support. As mentioned above, the checklist results should be combined with usability test results.

Next steps in this initiative consider performing additional reviews in different conditions (e.g. at other points in the software lifecycle, with other stakeholders) in order to accurately and empirically determine the validity and reliability of the proposed checklist.

Acknowledgements

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Appendix A. Definition of design elements

Category	Design category	Design element	Definition
Collaboration	Availability	Availability	It is concerned with whether people are in the same physical place or not (Johansen et al., 1991), who is online/offline (Lauwers and Lantz, 1990; Schmidt, 2002), and their virtual availability, e.g. participants may be virtually co-located (physically distributed but accessible through high-quality audio/video links) or remote (physically distributed and with low-quality communication links) (Rodden and Blair, 1991)
	Communication	Communication mode	It refers to the way in which group members interact: synchronously, asynchronously, or in a mixed way in which both types of communication are supported (Rodden and Blair, 1991)
		Network connectivity	It indicates if the network is connected/disconnected (Ferreira et al., 2011)
		Message delivery	It indicates if a message has been delivered to the group or not (Ferreira et al., 2011).
		Message delays	It gives an indication about the time messages take to be delivered to the group (Ferreira et al., 2011)
Location	Spatiality	Cartesian locations	It labels space with Cartesian coordinates, therefore defining relationships between locations in terms of their coordinates with respect to an origin position (Dix et al., 2000)
		Topological locations	It is used when location is defined in relation to other objects that are "near", and not in an absolute way (Dix et al., 2000)
		Distances	It refers to physical distances between objects (Dix et al., 2000)
		Orientations	It refers to where elements in spaces are oriented toward (Dix et al., 2000)
		Range of attention	It maps the attention and presence of elements in spaces through focus (objects you are aware of) and nimbus (objects aware of you) (Rodden, 1996)
	Mobility	Location modality	It characterizes the movement of users in three categories: a user may be working while visiting (different places for a significant period of time), traveling, or wandering (locally mobile) (Kristoffersen and Ljungberg, 1998)
		Level of mobility	It refers to whether the device is fixed (not mobile), mobile (may be moved) or autonomous (moves under its own control) (Dix et al., 2000)
		Relation with other devices	It refers to whether a device is free (independent), embedded (part of another device), or pervasive (belongs to the environment) (Dix et al., 2000)
	Physicality	Physical constraints	It refers to the limitations of the physical space where the collaboration takes place, e.g. walls (Harrison and Dourish, 1996)
		Physical places	It refers to the notion of what a community uses a particular space for; i.e. what is expected and considered as appropriate behavior defines a place inside a space (Harrison and Dourish, 1996)
		Physical topology	It refers to the structure and complexity of the physical environment where the collaboration takes place (Harrison and Dourish, 1996)
		Physical attributes	Context includes physical characteristics such as temperature and weather conditions (Pascoe et al., 1999)
Context	Navigation	Virtual places	Virtual spaces may accommodate several places such as meeting rooms, chat rooms and recreational places (Snowdon and Munro, 2000)
		Virtual topology	Connectedness between virtual places (Harrison and Dourish, 1996)
		Map views	It provides map-views of shared workspaces for distributed groups (Dourish and Bly, 1992; Gutwin and Greenberg, 1999)
		Viewports	It provides views into shared workspaces for distributed groups (Dourish and Bellotti, 1992a,b)
	Virtuality	Group objects	They are objects managed by a shared repository. At the most private stage, individual work is performed on objects that are controlled by and prominent to one participant while being hidden to others. At the semi-public stage, individual work is performed so that others can monitor it (Arvola, 2006)
		Public objects	They are objects shared by group members in a workspace (Greenberg et al., 1999). At the public stage, participants can work jointly on the same objects (Arvola, 2006)
		Virtual attributes	They are attributes of virtual objects (Convertino et al., 2005)
		Virtual relationships	They are relationships between virtual objects (Convertino et al., 2005)
		Virtual constraints	They are constraints between virtual objects (Convertino et al., 2005)
Social	Practice	Roles	It is awareness of individual responsibilities and roles assumed by individuals in groups (Carroll et al., 2003)
		Activities	It is awareness of others' plans and goals in complex, long-term endeavors (Carroll et al., 2003)
	Background	Privileges	They are access permissions for shared workspaces by end-users (Haake et al., 2004). They define a new way to think about the space and what one can do there–a new spatiality of access, presence, and interaction (Dourish, 2006)
		Group history	It is the history of how a group works together and interacts, including e.g. individual users' knowledge and expertise (Cecez-Kecmanovic, 2005)

Appendix A (*Continued*)

Category	Design category	Design element	Definition
Workspace	Task	Who	It is related to social aspects of belonging to a group, e.g. the collaborators' presence and frequency of activity (Carroll et al., 2003)
		What	It is related to the ongoing actions, e.g. the focus of activity and interaction with resources (Carroll et al., 2003)
		Where	It is the part of the workspace collaborators are viewing or working on (Carroll et al., 2003)
		When	It is the moment-to-moment information about users' actions (Carroll et al., 2003)
		How	It is related to the nature of activities, e.g. role assignment and modification of shared plans (Carroll et al., 2003)
		Task history	It concerns preserving an extended log of collaborator actions on shared task-relevant resources over time (Carroll et al., 2003)
	Interaction	Feedback	Feedback is required by humans to achieve their goals by approximation, comparing the obtained outputs with a reference (Meadows, 2009)
		Feedthrough	Feedthrough is necessary to bring information about the other's actions, allowing the individual users to make decisions based upon what the others are doing (Hill and Gutwin, 2003)
		Backchannel feedback	Backchannel feedback is necessary to convey unintentional information indicating that the listeners are following the speaker (Rajan et al., 2001)
		Eye-gaze cues	Eye-gaze cues may be detected through mechanisms such as eye trackers to convey eye contact, and may be used to represent attention, e.g. to regulate multiparty conversation (Vertegaal et al., 2003)
		Voice cues	It is the use of voice loops to overhear others' communications (Gutwin and Greenberg, 2002)
	Interdependence	Parallel activities	Parallel activities are generally independent, or sequential, and can therefore be carried out with less need for coordination (van de Ven and Delbecq, 1976)
		Coordinated activities	Activities are coordinated when they are specified according to a pre-determined plan (van de Ven and Delbecq, 1976)
		Mutually adjusted activities	Activities are mutually adjusted when a user modifies his own work according to others' activities (van de Ven and Delbecq, 1976) They correspond to very fine-grained coordination of actions in space when people are together (Brewer and Dourish, 2008)
		Access control	Access to places can be constrained by access rights defined by an administrator (Haake et al., 2004)
Situation	Understanding	Events	It is related to the perception of events in light of pertinent operational goals (Endsley, 1995)
		Actions	It is the information that is relevant to tasks and roles (Endsley, 1995)
		Resources	It concerns the consideration of supply and demand of resources (Endsley and Garland, 2000)
		Critical elements	It concerns the perception of the elements in the environment within a volume of time and space (Endsley, 1995)
		Meanings	It concerns the comprehension of the meaning of the elements in the environment (Endsley, 1995)
		Future scenarios	It is the projection of near-future status of the elements in the environment (Endsley, 1995)
	Sensemaking	Individual	It refers to an individual interpreting, understanding, reflecting and making sense of an event (Cecez-Kecmanovic, 2005)
		Distributed	It refers to knowledge that is decentralized: distributed throughout the organizational environment, and how users can make sense of it (Cecez-Kecmanovic, 2005)
		Collaborative	It refers to sharing and creating meanings and knowledge and achieve mutual understanding in a group, with the purpose to accomplish collective sensemaking (Cecez-Kecmanovic, 2005)

Appendix B. Awareness checklist

Scale	
O	Adequate implementation
–	Neutral/not relevant
X	Inadequate implementation

Please assess if/how the following design features have been implemented in your application. Use this 3-point scale.

Design features	Questions	Eval.
Availability	The system informs who are the users available to collaborate.	
Communication mode	The system informs whether other users are working online, offline or both.	
Network connectivity	The system informs when the network connectivity is lost or recovered.	
Message delivery	The system informs the user when her/his messages are received by the target users.	
Message delays	The system informs the users about the time spent in message delivery.	
Cartesian locations	The system indicates the physical location of potential collaborators.	
Topological locations	The system informs whether other users are nearby.	
Distances	The system indicates the physical distances to other users.	
Orientations	The system indicates the orientation of other users (e.g. where they are moving toward)	
Range of attention	The system gives cues about the user's center of activity (e.g. what they are looking at)	
Location modality	The system indicates the type of users' mobility (e.g. whether they are wandering, visiting or traveling)	
Level of mobility	The system recognizes the type of device mobility (e.g. whether the device is stationary or moving by a user or autonomously)	
Relation with other devices	The system recognizes whether the device is independent of other devices, embedded into another device (e.g. a car), or spread throughout the environment	
Physical constraints	The system deals with the constraints imposed by the physical environment where it is used	
Physical places	The system has a metaphor for "physical places" (e.g. meeting rooms and cafeteria)	
Physical topology	The system gives cues about the complexity of the physical environment where it is used	
Physical attributes	The system gives cues about the environmental conditions of the place where it is used (e.g. weather conditions)	
Virtual places	The system supports the concept of "virtual places" (different places for collaboration)	
Virtual topology	The system represents the topology of the virtual environment (i.e. moving between virtual places)	
Map views	The system gives an overview of the virtual environment	
Viewports	The system allows users to peek the others' activities	
Group objects	The system allows users to share objects/resources	
Public objects	The system identifies the public objects/resources	
Virtual attributes	The system displays the attributes of objects/resources in the workspace	
Virtual relationships	The system displays the relationships between objects/resources in the workspace	
Virtual constraints	The system gives cues about object/resource constraints (like location or ownership)	
Roles	The system displays the users' roles	
Activities	The system gives cues on the users' current activities	
Privileges	The system informs the user about the others' privileges in the system	
Group history	The system highlights the conventions/protocols agreed by the users to collaborate (e.g. who leads the discussion)	
Who	The system indicates who is doing a particular task	
What	The system shows the activity being performed by a particular user	
Where	The system indicates the place where a user is currently working on	
When	The system informs when a task is being (or was) carried out	
How	The system gives indications on how a task is being (or was) carried out	
Task history	The system shows the sequence of tasks performed over time	
Feedback	The system provides feedback about the user's current actions	
Feedthrough	The system notifies the user about the other's current actions	
Backchannel feedback	The system notifies the user whether the others are following what her/he is doing	
Eye-gaze cues	The system gives cues about where the users are looking at	
Voice cues	The system provides feedback about who is talking to whom	
Parallel activities	The system indicates if the users are doing parallel activities	
Coordinated activities	The system indicates if users are doing coordinated activities (e.g. through a workflow)	
Mutually adjusted activities	The system informs if users are doing mutually adjusted activities (i.e. modifying their own work according to others' activities)	
Access control	The system notifies about who is in control of a shared object/resource	
Events	The system shows the past events that occurred in the collaborative environment as a way to help users understand what is going on	
Actions	The system shows the users' actions over time	
Resources	The system displays the objects' changes over time	
Critical elements	The system highlights the presence of critical issues in the working environment (e.g. events or situations)	
Meanings	The system gives a strategic view about what is going on in the working environment	
Future scenarios	The system gives cues about future situations that may occur in the working environment	
Individual	The system provides information that helps users reflecting over their course of action	
Distributed	The system gives cues about environmental changes that may be relevant for the course of action	
Collaborative	The system provides information that helps users keeping a shared sense of their goals and achievements	
Others	**Please indicate any other awareness element present in the application that has not been included in the checklist**	

Appendix C. Awareness design elements present in some software applications

Design element	Dropbox	Mobile Map	COIN v1.0	COIN v2.0	Whats app	4sq	Second life	Total
Availability	√	√	√	√	√	√	√	
Communication mode	√	√	√	√				
Network connectivity	√	√	√	√				
Message delivery	√				√	√		
Message delays					√			
Cartesian locations		√		√		√		
Topological locations		√		√		√		
Distances		√	√	√		√		
Orientations		√		√			√	
Range of attention				√			√	
Location modality		√						
Level of mobility		√	√	√				
Relation with other devices		√						
Physical constraints								×
Physical places		√		√			√	
Physical topology								×
Physical attributes								×
Virtual places				√			√	
Virtual topology							√	
Map views				√		√	√	
Viewports	√			√			√	
Group objects	√	√	√	√	√			
Public objects	√	√		√				
Virtual attributes					√		√	
Virtual relationships	√	√						
Virtual constraints			√	√			√	
Roles								×
Activities		√		√			√	
Privileges								×
Group history	√	√				√		
Who	√	√	√	√		√		
What				√				
Where		√	√	√				
When		√				√		
How								×
Task history	√					√		
Feedback			√	√				
Feedthrough							√	
Backchannel feedback								×
Eye-gaze cues								×
Voice cues							√	
Parallel activities	√		√					
Coordinated activities								×
Mutually adjusted activities								×
Access control								×
Events	√		√	√				
Actions	√		√	√	√			
Resources	√	√	√					
Critical elements								×
Meanings								×
Future scenarios								×
Individual	√	√						
Distributed	√	√						
Collaborative	√			√				

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