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Supporting Effortless Coordination: 25 Years of Awareness Research

Tom Gross
Human-Computer Interaction Group, University of Bamberg, Kapuzinerstr. 16 96047 Bamberg, Germany (Phone: +49-951-8633940; Fax: +49-951-8633945; E-mail: email@tomgross.net)

Abstract. Significant progress has been made in awareness research in Computer-Supported Cooperative Work over the last 25 years. This survey addresses awareness and effortless coordination—that is, how a mutual understanding in distributed teams can be gained and maintained, while still keeping the team members' coordination efforts to a minimum. I characterise the origins of awareness and its ethnographically-informed and the technology-oriented roots, and discuss the notion of awareness. I review technical solutions for awareness support—both in applications as seen by users, and in base technology as seen by developers. Design tensions in awareness research and solutions are identified. A discussion contrasts awareness as seen from a users' activity and effort perspective versus awareness as seen from a systems' support and automation perspective.

Key words: awareness, coordination, computer-supported cooperative work, survey, history

1. Introduction

The evolution of awareness research within Computer-Supported Cooperative Work (CSCW) over the last decades goes hand in hand with the evolution of the field per se. It manifests itself in progress in the basic understanding of awareness as well as in the development of concepts and technology of awareness support.

The field of CSCW aims to achieve a deep understanding of work and other types of social interaction and to develop adequate technical concepts and tools for social interaction in groups and communities. The term *Computer-Supported Cooperative Work* was coined by Irene Greif who organised the first workshop in 1984. Greif (1988, p. XI) writes that CSCW is 'computer-assisted coordinated activity such as communication and problem solving carried out by a group of collaborating individuals'. More recently, Schmidt (2011, p. VII) writes that: 'the development of computing technologies has from the very beginning been tightly interwoven with the development of cooperative work' and that 'over the last couple of decades computing technologies are also and increasingly being developed and used for coordinative purposes'. These CSCW technologies are often referred to as groupware. The term *groupware* was defined by Johnson-Lentz and Johnson-Lentz (1982) as computer-based technology that supports social group processes.

Awareness support is an essential part of groupware. Lynch et al. (1990, p. 160) make this point very clearly in their early characterisation of groupware and

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awareness, writing: 'groupware is distinguished from normal software by the basic assumption it makes: groupware makes the user aware that he is part of a group, while most other software seeks to hide and protect users from each other. [...] software that accentuates the multiple user environment, coordinating and orchestrating things so that users can see each other, yet do not conflict with each other.' The term coordination here is seen from a rather broad perspective and can be defined as Malone and Crowston (1990, p. 358) suggest: 'the act of working together harmoniously'. Research into awareness has been conducted for more than two decades now and many concepts and systems have been developed. Schmidt (2002, p. 285) points out: 'not surprisingly then, the concept of "awareness" has come to play a central role in CSCW, and from the very beginning CSCW researchers have been exploring how computer-based technologies might facilitate some kind of "awareness" among and between cooperating actors'. In CSCW there has been a long intellectual debate on the *term* awareness per se and whether it should be combined with other terms such as group awareness (cf. Schmidt 2011 for a recent overview). I will provide a discussion on the basic notion of awareness in the next section.

Awareness plays an important role in *many areas*—in addition to CSCW and groupware in a traditional sense—it is, for instance, also penetrating Social Software and Social Media. Social Software refers to technology that typically offers flexible support for multifarious activities and types of social interaction for diverse social settings ranging from small groups to large communities. It aims to scale up for any social setting. The term *Social Software* has been around since the end of the 1980s, but it has become widely known only recently with the advent of Web 2.0 technologies. It puts special focus on the Web as a platform, collective intelligence and wisdom of crowds through peer production and social recommendations of contents, cooperative software development, in addition to a rich user experience through novel user interface concepts and base technology (O'Reilly 2005). Here awareness mechanisms have emerged that are often similar to those of traditional groupware. For instance, the shared editors of Google Documents (Google Inc. 2012), which allow users to edit text or spread sheets collaboratively, provide mutual information on each user's activities and changes to the shared document—much like traditional group editors in CSCW. Another example is Facebook, which in its current version provides a picture collage entitled 'Friends on Chat' that shows users pictures of their Facebook friends who are online at the same time (Facebook Inc. 2012).

Whether it is information on co-workers' activities such as in Google Documents or information on the online co-presence of friends as in Facebook, both are examples of widely used awareness support that is rooted in a *long tradition* of awareness research. In CSCW, awareness ranges from general information of who is around (e.g., Gaver et al. 1992) and detailed information about each others' attention (e.g., Ishii and Kobayashi 1992) to work-oriented information on each others activities (e.g., Dourish and Bellotti 1992) and changes to shared workspaces and documents (e.g., Gutwin and Greenberg 2002). An early awareness study by Dourish and Bellotti (1992) on the positive effect of awareness information on users' successful cooperation was an important initial step for awareness research. They examined awareness in group editors in a case study on the use of the group editor ShrEdit. Dourish and Bellotti (1992, p. 107) write: 'awareness of individual and group activities is critical to successful collaboration'. I will provide a more systematic overview of technical support for awareness information in the subsequent sections.

Comprehensive *surveys* of awareness research have been published that offer many details and perspectives on awareness (e.g., Gross et al. 2005; Rittenbruch and McEwan 2009; Schmidt 2011). Gross et al.'s (2005) survey targets at what the authors call 'user-centred awareness'; the authors write: 'an increasing number of computer-supported cooperative work (CSCW) software systems try to provide users with awareness information… However, most of these software systems are designed from a feature-oriented, rather than a human-oriented, point of view'. The survey reviews features of awareness support and contrast them with the awareness terminology and the concepts of social science. As Rittenbruch and McEwan (2009) write: 'Gross et al. (2005) provide a comprehensive analysis of awareness approaches, but their main focus is on the terminology'. Rittenbruch and McEwan's own survey takes a historical perspective on awareness support. While the authors provide an interesting account of workplace studies and their findings with respect to the way workers accomplish mutual awareness with co-workers, their main contribution is a systematic overview of technology to support awareness. The book by Schmidt (2011) provides—besides a comprehensive overview of the notion of awareness—a thorough discussion of two sides of awareness research: the technology-oriented side where awareness is often seen as technology providing information to users, and the ethnographically-informed side where awareness is often seen as the outcome of an activity of a user.

In an earlier publication Schmidt et al. (2002, p. III) critically remarked that 'despite the growing interest in awareness, and the recognition that it is of critical importance to the successful development of systems to support cooperative activity, research remains fragmented…'. Furthermore, despite the importance, the flipside—that is, the additional *effort* that is required from users to achieve awareness—needs to be considered. If users are in the same physical location, they can display and monitor each other's communication and activities and this takes little or not effort as Schmidt writes: 'cooperating actors mutually heed what each other is doing and do so effortlessly and without interrupting ongoing work because they (normally) know the work…' (Schmidt 2011, p. 25). However, if the users are in different locations they rely on technical mediation of awareness information and on the proper interpretation of this mediated information. In the latter case it is important for technology to mediate information appropriately and to avoid 'additional effort on the users' side for capturing and presenting the information' (Gross and Prinz 2004, p. 285).

This survey addresses the concept of effortless coordination—that is, the question whether and how team work can be coordinated and a mutual understanding in the team can be gained and maintained, while still keeping the team members' coordination effort to a minimum. Despite the fact that—as has been stated—awareness support can now be found in many areas including everyday Social Media, this survey focuses primary on awareness research in CSCW and groupware. The path of this survey is from the origins of awareness research via the past and present technological possibilities to design tensions of awareness research that all relate to effortless coordination and finally to a discussion of awareness. Despite the interdisciplinary nature of CSCW and awareness research, one survey cannot do full justice to everything that has been published on awareness in full detail—so, while this survey also covers literature on how people achieve awareness, its primary contribution is on the conceptual and system design side. In the next section I address the origins of awareness in CSCW in the ethnographically-informed and the technology-oriented roots of awareness, and discuss the notion of awareness. I then review technical solutions for awareness support—both in applications as seen by users, and in environments and concepts as seen by developers. An elaboration on design tensions in awareness research concerning availability, privacy, conventions, phase-specifics and domain-specifics then follows, before a discussion elaborates on the tension between awareness as seen from a users' activity and effort perspective versus awareness as seen from a systems' support and automation perspective. Finally, I offer a summary of the paper in the conclusion.

2. Origins of awareness in CSCW

Awareness research has a long tradition stemming from several roots, and despite this tradition there is no generally agreed definition of the term awareness. In this section I report on the two principal roots of awareness research in CSCW: early ethnographic studies of mutual awareness of actors, and early explorations of technological support for awareness information. Based on these early findings I then discuss the term awareness.

2.1. Early ethnographic findings

There are two early and ground-breaking studies of cooperative work, where the subtleties of the social interaction in teams and the role of mutual information among team members have been carved out: the study of the London Underground Control Rooms, and the study of the London Air Traffic Control Centre.

Heath and Luff (1992, 1996) conducted an early investigation of cooperative work in *London Underground Control Rooms*, where, for instance, on the Bakerloo Line a person acting as Line Controller (LC) and a second person acting as Divisional Information Assistant (DIA) cooperated intensely. The authors showed that—and gave many examples of how—these two people cooperated and exchanged information with each other and with their environment. Heath and Luff (1992, p. 76) write: ‘despite important differences in the formal specification of the responsibilities of the Controller and DIA, the various tasks they undertake rely upon extremely close collaboration. Indeed, Control Room personnel have developed a subtle and complex body of practices for monitoring each other's conduct and coordinating a varied collection of tasks and activities. These practices appear to stand independently of particular personnel, and it is not unusual to witness individuals who have no previous experience working together, informally, implicitly, yet systematically coordinating their conduct’.

An important aspect to note is that the LC and DIA have to react to problems that occur during emergencies. Often they need to make complex adaptations such as rescheduling trains where they do not have time for conversations to inform each other. Thus they use special mechanisms and implicit codes. Special time-efficient practices of intentional *display* are used to keep the other informed that were found by the authors are talking out loud, and directing the other’s attention through sounds. These practices were applied by the Controllers in situations, where their task at hand did not require any verbalisation. At the same time the colleagues used *monitor* practices to maintain awareness of the overall situation and the others by watching the other’s actions, and by listening to the other’s conversations with third parties while still performing their own activities. Newcomers to the control room cannot learn these subtle and complex practices theoretically, but need to engage with them as apprentices.

The study of the *London Air Traffic Control Centre* produced new insights into the cooperation that takes place in radar suites (Bentley et al. 1992; Harper et al. 1989). Each radar suite basically has a chief controller, two radar controllers, and two assistants. As in the above example of the interaction between LC and DIA, cooperative work is based on implicit coordination among the people involved. Bentley et al. (1992) provide an example in which the handover of a plane between sectors happens without communication, unless when there are exceptions (e.g., if the flight speed is not as planned). Harper et al. (1989, p. 82) write on mutual awareness in team work: ‘the team work required in the Mediator system was based on an elaborate division of labour. Specifically, this division of labour allowed controllers to concentrate solely on controlling; that is, maintaining separations, controlling ascents and descents, etc.; whilst the coordination of traffic between and with neighbouring sectors, preparing flight strips, etc. was largely done by assistants and, where circumstances demanded, by crew chiefs’.

These two studies highlight the bigger picture of each team member’s awareness in terms of an overall understanding of his or her circumstances, including the situation of the colleagues—they are not limited to showing that awareness is in many settings essential for successful coordination, but rather that it goes beyond static and constant information and involves on the one hand careful attention to on-going events and actions and on the other hand subtle production and communication of information to each other. They also show that awareness is more internal and implicit in the users’ heads rather than visible in the environment. Yet at the same time the practices that users apply are independent of individual actors. Finally, these studies also show that the effort of displaying and monitoring awareness information should be low enough so it can happen in the background and does not interfere with the other activities of the actors.

2.2. Early technologies to provide awareness information

The Cognoter was a very early meeting room system aimed at facilitating face-to-face meetings of small groups with an interesting focus on users and their mutual awareness (Stefik et al. 1987a' b; Tatar et al. 1991). Stefik et al. (1987b) provide an insightful discussion of design issue with respect to supporting cooperation and problem solving in groups. They (1987b, p. 44) write: 'the fact that a writing technology allows only one person to enter text at a time enforces a kind of shared focus (i.e., a focus on that person's actions) that maintains a common context for the group' and 'shared focus is achieved by means of reference to common objects. Cognoter's goal, as with a chalkboard, is to enable participants to refer to common objects through various kinds of efficient reference such as deixis (deixis means referring to something either verbally (e.g., 'the grey house across the street') or by pointing)'. Tatar et al. (1991) further elaborate on the shared focus and on deixis. They provide interesting details on the users' utterance and pointing, while the authors found challenges with respect to shared reference to shared objects as well as with respect to following the changes to objects by others. In (Stefik et al. 1987a) the authors introduce the concept of *What-You-See-Is-What-I-See* (WYSIWIS) of the Cognoter as the coupling of the user interfaces of multiple users' computers. The authors (1987a, p. 149) write: 'in "strict" WYSIWIS, everyone sees exactly the same image of the written meeting information and can see where anyone else is pointing'. In relaxed WYSIWIS the system provides private and public windows that are not synchronised and offer parallel activities.

Overall, the research on Cognoter has identified several aspects of computer support for awareness that to this day have not been completely solved. In fact, it brought up *design tensions*, where it is very hard or sometimes impossible to find the one solution that meets all requirements. Design tensions 'conceptualise design not as problem solving but as goal balancing. They draw explicit attention to conflicts in system design that cannot be solved but only handled via compromise.' (Tartar 2007, p. 415). The design tensions here are concerned with the adequate presentation of awareness information in a way that it is perceivable by users at adequate effort (as a prominent example: Daniel J. Simons won a Nobel prize for analysing the phenomenon of change blindness). Examples from the Cognoter research are handling screen space and windows and coupling screens and windows between users, finding the granularity of updates and propagating changes of a user to the others, following updates and changes made by another user on the own screen, and using tele-pointers for remote gestures in the full group or sub-groups. Also the need for dealing with one's own and one's co-worker's focus, leading to shared focus in some situations of close cooperation, needs to be taken into consideration in the design of awareness support.

2.3. The term awareness

Interestingly none of the early and path-breaking publications from the previous two sub-sections used the term awareness. In fact, defining the term awareness has been a *challenge* for the CSCW community. As Schmidt (2002, p. 287) writes: 'the very word "awareness" is one of those highly elastic English words that can be used to mean a host of different things. Depending on the context it may mean anything from consciousness or knowledge to attention or sentience, and from sensitivity or apperception to acquaintance or recollection'. The author provides a thorough discussion of the notion of awareness and concludes (2002, p. 292): '"Awareness" is not the product of passively acquired "information" but is a characterisation of some highly active and highly skilled practices'.

These active *practices* are addressed by Gutwin and Greenberg (2002), who developed a 'descriptive framework of workspace awareness for real-time groupware'. The authors combine their own experience with developing real-time groupware applications with Neisser's (1967) perception-action cycle. This cycle is used to explain that awareness is maintained as follows: the humans' existing knowledge directs their exploration of the environment through sampling, and this in turn modifies the existing knowledge.

Dourish and Bly offered an *early definition* of awareness in (Dourish and Bly 1992, p. 541) and point out that awareness is a basis for further social interaction and should therefore also be maintained over distance: 'awareness involves knowing who is "around", what activities are occurring, who is talking with whom, it provides a view of one another in the daily work environments. Awareness may lead to informal interactions, spontaneous connections, and the development of shared cultures—all important aspects of maintaining working relationships which are denied to groups distributed across multiple sites' and 'we wished to extend the notion of "awareness" outside a single physical location, and thus support awareness for distributed work groups. Such groups, by their nature, are denied the informal information gathered from a physically shared workspace and the proximity, which is an important factor in collaboration between colleagues'.

In a different publication, in the same year, Dourish and Bellotti offer a *narrower definition* (1992, p. 107): 'awareness is an understanding of the activities of others, which provides a context for your own activity. This context is used to ensure that individual contributions are relevant to the group's activity as a whole, and to evaluate individual actions with respect to group goals and progress. The information, then, allows groups to manage the process of collaborative working'. They (p. 112) continue by stating that awareness 'is fundamental to coordination of activities and sharing of information, which in turn, are critical to successful collaboration. Awareness plays a number of key roles. First, high-level awareness of the character of others' actions allows participants to structure their activities and avoid duplication of work. Second, lower-level awareness of the content of others' actions allows fine-grained shared working and synergistic group behaviour, which needs to be supported by collaborative applications'.

The term awareness has been *combined* with several other words but with similar overall meanings. For instance, Borning and Travers (1991, p. 13) use the term *shared* awareness as: 'distribution of general information about the environment, both physical and social. Such information includes who's here, what they are doing (if they want this to be known), whether they are available for interactions and what's happening in the common areas'. And Gaver et al. (1992, p. 28) use the term *general* awareness to denote: 'the pervasive experience of knowing who is around, what sorts of things they are doing, whether they are relatively busy or can be engaged, and so on. Neither planned nor involving a great degree of interaction, this sort of awareness acts as a foundation for closer collaboration—one of the reasons that physical proximity is a highly accurate predictor of collaboration'. Some other examples are: 'mutual awareness' (e,g., Rittenbruch and McEwan 2009), and 'workspace awareness' (e,g., Gutwin and Greenberg 2002).

So, the term awareness has not been defined and used consistently. Yet, overall it is important to note that awareness is a user's *internal* knowing and understanding of a situation including other users and the environment that is gained through subtle practices of capturing and interpreting information; and this awareness information partly exists in the environment, and is partly provided by awareness technology.

2.4. Summary

These three strands of early awareness research—ethnographic studies, technological explorations, and terminological discourse—have identified some profound design tensions of awareness support that to the present day have been challenging awareness researchers. I will come back to these later (especially the trade-off between awareness information notification and disruption, and between awareness information and privacy).

While the above terms and quotes only reflect a small portion of the definitions of awareness in CSCW, they still provide *important aspects* of awareness that are essential for our understanding of awareness in the remainder of this paper: awareness involves skilful and prolonged activity of the perceiving person and it can involve a person actively seeking another person's attention and emitting information; awareness information in a broader sense refers to a general overview about one's social and material surrounding and awareness information in a narrower sense refers to a shared frame of orientation in a team. Mutual awareness can facilitate initiating and leading conversations. At the same time the borders between awareness and communication are fluent—for instance, when a person directs another persons' attention to something.

In the remainder of this paper I depart from these early findings and glance at technical solutions for awareness information support, in order to then discuss some core design tensions of awareness research.

The *bulk* of awareness research has traditionally been published in the CSCW journal (i.e., the Computer Supported Cooperative Work - Journal of Collaborative Computing and Work Practices published by Springer-Verlag (*JCSCW*)) and in Human-Computer Interaction (HCI) journals (mainly in the International Journal of Human-Computer Interaction published by Taylor & Francis (*IJHCI*), and in the Transactions on Human-Computer Interaction published by ACM Press (*TOCHI*)) as well as at CSCW conferences (mainly in the ACM Conference on Computer Supported Cooperative Work (*CSCW*), the European Conference on Computer Supported Cooperative Work (*ECSCW*), and the International Conference on Supporting Group Work (*Group*)), but also in HCI conferences (e.g., ACM SIGCHI Conference on Human Factors in Computing Systems (*CHI*)). Fitzpatrick and Ellingsen (2012) in their comprehensive survey on CSCW research in healthcare use the same publication venues (i.e., JCSCW, CSCW, ECSCW, Group, CHI)—for this survey I just added IJHCI and TOCHI, since for an awareness survey they are also highly relevant. I analysed the JCSCW, IJHCI, and TOCHI journals as well as the CSCW, ECSCW, Group, and CHI conference proceedings for the last 25 years with respect to their contribution to awareness research.

Besides this selection of publication venues, the perspective underlying the *scope* and *classification* of this survey needs clarification. I would like to emphasise that, despite the fact that in the subsequent two sections I will provide an overview of technology to provide awareness information, the primary focus is not on the respective technology and its features, but rather on insightful concepts underlying these prototypes and systems. The next two sections present awareness support from the perspective of end-users functionality and of a technological concept and technology respectively.

It is important to depart from this insight into technology in order to gain a better understanding of the feasibility for realising awareness support. After that, Section 5 on key design tensions of awareness research will identify and discuss central and complex questions of awareness research that emerged and evolved over the last 25 years. This will then be used as a basis to discuss if and how the gap between the ethnographically-informed and the technology-oriented side can be bridged towards effortless coordination.

3. Concepts and technology above the surface

This section presents awareness concepts that are part of awareness technology for end-users (i.e., above the surface from an end-users' perspective). Based on insights from the research underlying this survey as well as classifications from existing awareness surveys (e.g., Gross et al. 2005; Rittenbruch and McEwan 2009; Schmidt 2002) I divide the prototypes and systems into coexistence awareness and cooperation awareness. Coexistence awareness refers to concepts and systems for providing users with information on each other's presence and availability; and cooperation awareness clusters concepts and systems for providing background information on users' activities in collaborative working environments and changes to shared artefacts. Please note that, as has been emphasised before, the border between awareness and social interaction such as communication and cooperation are not always clear-cut, and prototypes and systems often do not only provide concepts and functionality for the one or the other. Still, for the purpose of this survey, I want to discuss remarkable examples of specific awareness support and will therefore only present spotlights on isolated concepts or features relevant for awareness research, and neglect others not directly relating to awareness.

3.1. Coexistence awareness

Coexistence awareness can be seen as users' mutual person-oriented information on each other. Media spaces and collaborative virtual environments are the most prominent examples of this category in terms of early concepts and follow-up conceptual discussions.

3.1.1. *Media spaces*

Media space systems provide permanent connections between two (or more) sites via audio and video in order to provide general awareness of who is around as a basis for chance encounters. Media spaces have a long history in CSCW and are excellent examples of early and on-going awareness research (see also the edited book by Harrison (2009)).

The *Palo Alto-Portland Link—Video Wall* (Bly et al. 1993) system linked the Palo Alto Research Centre (PARC) in Palo Alto, California, with the PARC in Portland, Oregon, and was among the first media spaces. It was reported that awareness played a major role in the users' feedback. Bly et al. (1993, p. 34) write: 'although seemingly the most invisible, the use of the media space for peripheral awareness was perhaps its most powerful use'. The advantage of this use was that people had an overview of others' presence and activities without being forced to start a conversation. Technically, at both sites public areas were equipped with cameras, monitors, and speakers as a basis for permanent audio and video connections.

Constant awareness systems also aimed at providing coexistence awareness, but compared to the original media spaces had additional functionality. Early examples of this type of system were Polyscope, Vrooms, and Portholes. The *Polyscope* system (Borning and Travers 1991) was developed at Rank Xerox Research Centre in Cambridge, UK, and aimed at providing general awareness information to facilitate social encounters over distance. It showed a window with a two-dimensional matrix of frame-grabbed video images of other users' offices. The observers could specify the camera inputs they want to use and the update intervals of the images. The observed users could control the amount of information captured about them, which ranged from no information, to short text messages, to manual video (i.e., users could manually take and share pictures), and to automatic video (i.e., users could define an interval in which pictures were regularly taken). Additionally, users were informed about the capturing and could decide which feedback they wanted, ranging from no feedback to names of the observers, to video connection with the observer. The *Vrooms* system (Borning and Travers 1991) was a successor of Polyscope and offered improved functionality for ease of use. In order to make the handling of privacy and symmetry specifications easier, the metaphor of virtual rooms (vrooms) was introduced. Vrooms were places where symmetrical social interactions and conversation could take place and which were displayed as windows with video images. Users who entered a room were aware of each other while co-present, just like in a real room. Different versions of Vrooms support text messaging as well as audio and video conferencing of co-present users. The *Portholes* system (Dourish and Bly 1992) provided long-distance awareness via a video connection between the Rank Xerox Research Centre in Cambridge, UK, and the Xerox Palo Alto Research Centre in Palo Alto, California. The connection across continents allowed users to be aware of who was around. The system showed several images of different places of either site in a single large window, which was updated every ten minutes.

Social browsing systems, in contrast to constant awareness systems, allowed users to actively explore online worlds. The CRUISER system and the RAVE system were early examples. The *CRUISER* system (Root 1988) allowed users to browse virtual worlds that were constructed, populated, and organised independently of the physical world. Based on the metaphor of virtual hallways, users could jump to specific places, follow specific paths, or walk randomly in the virtual world. Users who met in the virtual world could start conversations. The *Ravenscroft Audio Video Environment* (RAVE) system (Gaver et al. 1992) supported functions for social browsing such as background viewing (monitoring a selected public area via video only for general awareness), glances (a three second one-way connection), video phone calls (short-term conversation initiated by one partner and accepted by the other), and office sharing (long-term conversation initiated by one partner and accepted by the other). Privacy was protected with similar means as applied in CRUISER—office sharing was always reciprocal and as backgrounds only public areas were allowed. Users could control the access to their private views and specify the system reaction to another user's initiative. RAVE was deployed at the Rank Xerox Research Centre in Cambridge, UK, building. Over time more control over privacy became necessary. A privacy service allowed specifying all users who were allowed to use a certain service (e.g., all users who are allowed to glance into a specific office). Furthermore, notifications were implemented that informed users about observers. Feedback could be displayed as text messages on the monitor or spoken messages, which were played over the audio network.

More recent media space research continued to bring up interesting results. For instance, the *TimeLine* system (Nunes et al. 2007) added asynchronous awareness information to a media space—that is, not only supported a real-time connection between two or more sites, but also provided a video history trace. Users could take this trace and get miniature overviews of the video stream in order to better understand patterns of the behaviour of users at the other site; they could change the granularity to get either detailed information or a coarse overview; and they could go back in history. Despite these interesting conceptual ideas, the system also had its limitations. The authors (Nunes et al. 2007) report that users of TimeLine raised issues such as voyeurism and surveillance. The *MagicWindow* system (Kim et al. 2007, p. 110) used the concept of a 'co-present media space to support awareness between an office occupant and observers in the public area outside the office'. Awareness information was provided as a video stream on a monitor that was mounted on the wall outside an office. The video stream had different levels of fidelity—a blur filter could be used to reduce details and protect the office inhabitants' privacy, or if the inhabitants wanted, full details could be shown. The users outside the office could then see what was going on in the office and decide if they wanted to enter the office. The 'Occupant Presence Timelines' provided visitors in front of the office with awareness information on the presence of users in the office throughout the past hours.

Thus overall media spaces started as full-fledged permanent audio-video connections that bridged the distance between two sites via providing peripheral awareness information. Later media spaces added functionality for privacy, reciprocity, and more flexible connection and disconnection among users. The research on constant awareness systems showed the observed users' needs for feedback and control—where feedback refers to the requirement that the observed users should be informed about the fact that they are being observed and what is being observed, and where control refers to the requirement that the observed users should be able to have an active influence on what is being captured about them and presented to others (Bellotti and Sellen 1993). Social browsing systems provide interesting results with respect to the role of awareness and its role in facilitating chance encounters and adequate timing of starting conversations. The later media space research provided thoughtful technological refinements in finding a compromise between providing information to observers while maintaining privacy of the observed persons (e.g., with different levels of fidelity and blurring).

3.1.2. *Collaborative virtual environments*

Collaborative virtual environments provide a shared three-dimensional online space that represents users graphically as avatars and allows them to interact with each other via text, audio, or video. Two early prominent examples were the DIVE and the MASSIVE systems.

The *Distributed Interactive Virtual Environment (DIVE)* system (Benford et al. 1995) was a virtual environment that users can enter with a standard desktop PC, but also with a head-mounted display or a projected display. Online users could communicate in real-time with audio and video. Awareness embodied online users in the system as simple T-shaped avatars called blockies, or more complex anthropomorphic bodies with movable arms and heads and texture mappings of photos. Thus users could identify other users by their specific blockies or personal photos, and they could immediately see their position and orientation in the shared space. Awareness of a user's activity on an object was displayed as a line connecting the respective user and the object (Benford et al. 1995). Furthermore, DIVE users could draw on a shared whiteboard application, meet and communicate and share documents on a conference table.

The *Model, Architecture and System for Spatial Interaction in Virtual Environments (MASSIVE)* system (Greenhalgh and Benford 1995) was a virtual reality conferencing system based on the DIVE system. Like DIVE it also supported multiple online users and provided text, audio, and video channels. MASSIVE added concepts for supporting users with diverse hardware to participate in the online world: MASSIVE offered a full-fledged three-dimensional virtual world with 6° of freedom for users' navigation, and at the same time it provided a light-weight text terminal client where users could go online and were presented with a schematic overview of the virtual world in pure ASCII characters. In the fully-fledged version users were embodied as three-dimensional blockies, and in the lightweight version users were represented as single characters. Since each user's technological equipment influenced their capability for social interaction (e.g., the capability for audio and video conferencing depends on the shared technological infrastructure, but also on each individual's personal hardware and software equipment), MASSIVE provided feedback on equipment (e.g., a user with audio equipment is represented with ears added to the blockie).

Thus collaborative virtual environments were similar to media spaces with respect to providing co-presence information to users. However, while media spaces provided audio-video connections between real persons in real rooms, collaborative virtual environments provided an abstraction of users and allowed them to move and meet in virtual worlds. While media spaces have the advantage that they capture real users and users are shown online without effort because they are captured in their every-day environment, collaborative virtual environments have the advantage that users can position and present themselves whenever and wherever they want and this way influence their online appearance independently of their real appearance. According to Goffman it is a very basic human need to influence and manage one's own appearance in front of others (Goffman 1959). Additionally, MASSIVE brought up a discussion and solutions with respect to the requirement that for awareness support to be successful, users need to have a common technological basis (e.g., for sound awareness users need microphones and loudspeakers). This is common in today's technology—for instance, in the 'Friends on Chat' list mentioned above that shows users pictures of their Facebook friends who are online at the same time (Facebook Inc. 2012) there are mobile phone icons next to online users who are online via a mobile phone and not a computer; and as an other example Skype clients show a camera icon for each online user who has a camera for video conferencing available on the smartphone or computer they are online with (Skype 2013).

3.2. Cooperation awareness

Cooperation awareness can be seen as users' mutual information on their activities—either as background information in a collaborative working environment, or as foreground information in a cooperative application. In the former shared workspaces are prominent and widely used in practice, while for the latter group editors constitute great advances on the early Cognoter research.

3.2.1. *Shared workspaces*

The *BSCW* system (Bentley et al. 1997) was an early shared workspace system that provided users with an environment for sharing documents and other types of artefacts, and it is still available. Similar to local file systems and to many shared workspaces systems that came later, the BSCW was structured into workspaces and folders. Users could easily create them, and invite other users to access them. Underlying it was a complex rights management system. The interesting part from an awareness perspective was that it had awareness both inside and outside the system. Once users had logged into the system they could navigate their workspace and folder structure, similar to a local file system, but with added visualisations for awareness information (in particular, awareness in the folder and file list was visualised via icons that showed user activity such as visits to folders, creation of new files, or updates to existing files). The BSCW system generated a workspace activity report that provided awareness information outside the system. Every 24 hours an awareness service generated and mailed users a report on all activity to all workspaces, folders, and files where the respective user had access. As a result users did not need to log in to understand what was going on inside the workspace system. Some interesting extensions have been developed for BSCW. For instance, the *AwarenessMaps* visualised awareness information in a shared workspace: the PeopleMap provided user-centred information on present and active users in a workspace facilitating real-time interaction among active users; and the DocumentMap gave a visual overview of locations of and changes to shared documents allowing users at a glance to see the folders with high or low activity (Gross et al. 2003).

Later, other systems such as Microsoft SharePoint (Microsoft Inc. 2012) emerged and provided similar awareness functionality. Additionally, some of the more recent systems for document sharing such as DropBox (Dropbox Inc. 2013) and others are increasingly offering awareness information on 'events'—that is, user activities.

What is interesting to see from early systems such as the BSCW is that users had extensive possibilities to specify their interests on the awareness information they wanted to receive inside and outside the system. Providing *inside* awareness information can help users when they are actually working in the respective environment with the artefacts contained; and *outside* awareness information allows users to stay in the loop while working in a different environment. Another interesting finding was that it was not always the high activity that was relevant and important for users, but rather it was sometimes important to notice things that should have occurred but did not (e.g., low activity in areas of the DocumentMap provided information on missing uploads to shared workspaces).

3.2.2. *Group editors*

The *GroupDesign* editor (Beaudouin-Lafon and Karsenty 1992) was an early, yet elaborate, cooperative drawing tool that allowed a group of users to draw and manipulate graphic objects together in real-time. When a user was actively manipulating an object, the system marked the object with a busy icon with the colour of the active user. After the operation was completed the object smoothly changed its position or size (or whatever had been changed) as the user had wanted it to. GroupDesign used a relaxed What-You-See-Is-What-I-See (WYSIWIS) coupling mechanism—that is, all users could have different views of the same diagram. Modifications caused audio feedback on all users' computers, so users were also aware of activities outside their field of view. In the localisation mode users received a miniature overview of the whole diagram with the current views of the others shown as rectangles. Besides relaxed WYSIWIS, the strict WYSIWIS mode allowed users to closely follow each other's actions. The time-relaxed WYSIWIS allowed for privacy, and users' modifications only appeared on the other participants' windows after an explicit commit action.

The *ClearBoard* system (Ishii et al. 1994) was a drawing tool for two users—therefore it was sometimes referred to as pairware rather than groupware. Its glass board metaphor of 'talking through and drawing on a transparent glass window' (Ishii et al. 1993, p. 349) meant that both users had the impression of drawing on a transparent surface, where the drawn objects were shown on the surface and the drawing partner was shown in the background. This design allowed the combination of mutual gaze awareness of both users and at the same time workspace awareness about the status of and changes to the shared drawing artefact. Ishii and Kobayashi (1992, p. 526) rightly point out that prior to ClearBoard 'there has been no system that fulfils both of the following two requirements: (1) a contiguous space that includes both shared drawings and user image, and (2) eye contact'. As a side comment, the evolution towards the final ClearBoard system can be seen as a blueprint for user-centred design of awareness concepts and technology—over several years technology starting with TeamWorkStation-1 and TeamWorkStation-2, and then moving on to ClearBoard-1 and ClearBoard-2 has been developed, thoroughly tested with users, and refined (Ishii et al. 1993).

Several other early group editors provided related functionality—for instance, the Quilt editor (Leland et al. 1988) was similar, but additionally had explicit user roles, and the GROVE editor (Ellis et al. 1991) additionally allowed concurrent user actions.

All group editors shared the function of primarily providing task-specific awareness information for users who are collaboratively editing documents. More recent group editors—such as Google Documents (Google Inc. 2012) that were mentioned above—provide similar awareness information on co-workers' activities. GroupDesign is an example of a group editor with interesting concepts for diverse modes of coupling distributed user interfaces with different granularities of update information and different types of timings; and it is an excellent example of soft locks, where users are able to work concurrently, but receive awareness information on each others' activities, so they are aware of the concurrency. ClearBoard is a rather unique example of early awareness support for both person-oriented information on users' mimics and work-oriented information on the status of and changes to a shared artefact.

3.3. Summary

In this section several examples of coexistence awareness and cooperation awareness were presented. The coexistence awareness support with media spaces and collaborative virtual environments introduced classical awareness support for users' mutual information on each others' presence and availability. The cooperation awareness support with shared workspaces and group editors presented some examples of systems that provided core concepts for working together—typically, more loosely in shared workspaces, and more closely in group editors. There are a huge variety of shared workspace systems and group editors—the examples were chosen to illustrate the conceptual challenges they raise and the solutions they offer. Overall these system examples highlight interesting issues and solutions for awareness research in order to balance users' benefits and efforts:

- Providing mutual person-oriented information can facilitate chance encounters even over distance. Providing awareness information, especially if it is personal information, should always keep in mind the privacy concerns of users; providing users with feedback on the information captured and the means to control it are good solutions as is reciprocity to avoid lurking. Technical manipulations of the mediated information—such as blurring—can also reduce the trade-off between awareness information and privacy. Alternatively, technology can allow users to have abstract representations in the system that they can manipulate in order to control their virtual appearance. Abstractions also facilitate the participation of users with heterogeneous hardware and software equipment.

- Providing mutual information on artefacts and activities on artefacts often relies on users' actions captured as events in the system. Users should be able to specify their interests (which in many current systems is done in terms of events or event types). Users should have detailed awareness information in the cooperative system, but also have the possibility to receive awareness information outside of the system with the advantage of staying in the loop and not entering the system if the required events have not yet occurred. Technical support for cooperation and awareness during shared activities should allow for various levels of engagement from low engagement with relaxed coupling of user interfaces and low-fidelity awareness information to high engagement with strict coupling of user interfaces and high-fidelity awareness information. Soft locks can allow, yet provide information about, concurrency, which is sometimes preferable over locking some users out. Multimodal (e.g., audible, visual) notifications should be offered.

4. Concepts and technology beneath the surface

This section addresses awareness research with respect to the users' effort for producing and maintaining awareness in the following subsections: The first subsection 'Base Technology' contains 'Awareness Information Environments' that give a background on how technology can provide a basic infrastructure for capturing, storing, and distributing information on users' activities across distance; 'Sensing Technology' that discusses how technology can be used in a mixed-initiative approach to combine automatic sensing of data and inferring on a user's specific situation with manual overriding by users if needed; and 'Awareness Information Presentation' that shows how technology can be used to bring awareness information to users' attention on the computer screen and beyond. The second subsection 'Modelling Awareness' presents various approaches—including the famous spatial model—to discuss and add semantics from a users' perspective as a basis for structuring awareness information in the technical systems. The purpose here is to give some impression of the underlying processes of awareness support, in order later in this paper to have a better idea on the feasibility of technological awareness support.

4.1. Base technology

The base technology for awareness support needs to capture, store, and present awareness information to users. Here we address awareness information environments, sensing technology, and presentation tools, all of which show the possibilities and limitations of technology with respect to awareness support.

4.1.1. *Awareness information environments*

Awareness information environments—also known as event notification infrastructures—can be seen as the basic technological building blocks if users should get awareness support beyond individual applications. They capture data from various applications and other sources and present awareness information in diverse styles such as with tickertapes or pop-up windows on the computer desktop. Their event processing is similar to the one of shared workspaces mentioned above. Subsequently, I glance at the Khronika system, the NESSIE environment, and the AWARE architecture to exemplify this idea. They were based on sensors, indicators, and infrastructures. Sensors captured data on events triggered by users or the environment before sending them to an event data server. Indicators then presented awareness information to interested and authorised users.

The *Khronika* system (Lövstrand 1991) gathered data about events from various clients, stored them in its database, and distributed notifications to interested and authorised users. Its event daemon monitored events, classified by means of attribute-value pairs and stored events with their attribute-value pairs including their respective start time and duration. Interested users could subscribe to event types. If a new event matched a user's interests, the user received a notification. The access and privacy control of Khronika to the individual events 'wanted to avoid the complexities of a fully fledged group protection system and settled instead on what I thought of as a relatively bare minimum: read access of events are controlled by an explicit access control list and write (change/delete) access is limited to the event's owner' (Lövstrand 1991, p. 272). So despite the fact that the mechanisms were quite straightforward, in this system the users could negotiate awareness via technical means were the awareness information producers could specify what they wanted to be captured and shared, and where the consumers could specify what they were interested in.

The *awareNESS envIronmEnt (NESSIE)* (Prinz 1999) had similar concepts—it also had sensors, events, and a central event server. Additionally, NESSIE also strived for: 'open, extensible protocols for the interaction with the environment; light-weight sensors and means for an easy realisation of new sensors; configurable set of indicators and means for integrating new indicators; integration with web-technology to provide a high level of interoperability' (Prinz 1999, p. 395). For end-users it was easy to integrate their own awareness displays (e.g., lightning for visual notifications, or sounds for acoustic nonfictions). NESSIE addressed the challenge of users' effort for specifying their interest with a concept of shared interest profiles, where users could specify their preferences and then share their preferences with others (e.g., people who joined the team and did not want to make the specification effort).

The *AWARE* architecture (Bardram and Hansen 2010) is a more recent example, which aimed at providing awareness information in a hospital. This architecture addressed four dimensions of 'context-based workplace awareness': social (i.e., information on the colleagues at work), temporal (i.e., the flow of activities over time including past, presence, future), spatial (i.e., the situation at specific local and remote locations), and activity (i.e., information on actions and their context). The AwarePhone application, which was developed together with clinicians, was a smartphone application that reduced the number of interruptions by providing a contact list with extra information on the contacts' personal status, activity, and location. The AwareMedia system provided support for large-scale awareness and communication. It had publicly available interactive displays in various places of the hospital, which provided an overview of the coordination room, individual people at work, the operation room, as well as a schedule of operations with cancelled operations, scheduled operations, on-going operations, and finished operations. The system was deployed in a hospital and received positive feedback from the employees.

Overall awareness information environments were considerable advances in awareness support beyond individual applications. They already provided some structure for the event data they captured and some functionality for leveraging on this structure to subscribe to events. Khronika was the first example of a complex infrastructure and already had concepts for presenting awareness information selectively according to users' interests. NESSIE in several respects followed the approach of Khronika, but also had valuable conceptual aspects that are highly relevant for awareness research. For instance, it identified the need that users who get feedback and control of what is captured about them and also about which awareness information they want to receive want support for specifying their preferences. Easy means for end-users to integrate their own notifications (e.g., playing their own sounds and pieces of music) was highly appreciated. Designing for low disruption is an important aspect of awareness support. Today, most cooperative systems rely on producing, distributing, and reacting to events in one way or another.

4.1.2. *Sensing technology*

Sensing technology is essential for awareness support. Its important lay in its capabilities to capture data and allow users to influence the capturing in the interest of privacy. Yet, it is not the primary focus of attention in the CSCW community. Here I introduce an excellent example of hardware developed to explicitly sense availability and unavailability of users.

The *Lilsys* system (Begole et al. 2004) collected data from users and their environment in order to determine users' availability. The system was a single unit that hid all technical details and featured a range of sensors capturing keyboard and mouse activity; motion, light, and sound sensors; as well as a door sensor and a phone sensor. The presence of a specific person could then be inferred from a combination of the data of the motion and sound sensors. A user's degree of availability was inferred from a combination of the data of the sound, door, and phone sensors. The Lilsys was connected to the Awarenex awareness and communication system and each user's degree of availability was shown as an icon next to their name in the contact list of the mobile Awarenex client. Lilsys had an on- and an off-toggle, and could be deactivated at anytime. An override timer allowed users to override the detected degree of availability and to manually set a period of unavailability. A user study showed that—despite the accuracy of the system and the important possibilities to switch the system off or manually override the availability status—users had some issues with the fact the other users ignored their unavailability status. Begole et al. (2004, p. 514) write: 'finally and most importantly, users report that interruptions still occur even when the strongest unavailability icon is indicated, regardless of topic or urgency'.

Thus although earlier systems such as Khronika and ENI also had both software sensors capturing data from the digital realm and hardware sensors capturing data from the real environment of the users, the interesting aspect of Lilsys was that it combined complex hardware sensors and inferrencing software and at the same time came in an aesthetically pleasing shape, and allowed end-users to override the system's inferences from the data. It was one of the rare systems that even before capturing and storing data about the user, allowed the user to influence the capturing. In fact, many systems do capture and store information on users, and only allow users to influence the distribution of the captured information to other users.

4.1.3. *Awareness information presentation*

The awareness information presentation is an important part of any awareness supporting system. Several of the early awareness information environments already included interesting solutions for the presentation of awareness information. Basically awareness information can be presented on the user's computer desktop or in the users' environment. Some later results are worth introducing; here I focus on a toolkit for developing awareness presentations on the graphical user interface as well as ambient interfaces.

The *Multi-user Awareness UI (MAUI)* toolkit (Hill and Gutwin 2003, 2004) provided widgets that visualised awareness information on a graphical user interface (GUI). It was targeted at software developers who wanted to develop software for the presentation of awareness information. From a technical perspective the MAUI toolkit supported the sharing and coupling of the GUI on the widget layer (between the screen and window on the one hand, and the view and model on the other hand). It could overlay menus, sliders, and buttons, but also text fields with transparent awareness information of remote users. In terms of the event flow, the toolkit could capture user events, as well as store and transmit them in a feed through to the GUI of other users.

Ambient interfaces, also known as ambient intelligence, go beyond the GUI and present awareness information in the users' physical environment. They also work with sensors in the users' digital and real environment and adapt the environment accordingly (Gross 2006). Interesting conceptual challenges that emerge here are the levels of granularity and of abstraction that technology can sense the environment and its users (e.g., only sense the presence of a user group, or also infer that this group is having a brainstorming session). The *Tlatoque* system (Cornejo et al. 2012) suggests the concept of ambient awareness to present awareness about the extended family's whereabouts on displays in the everyday world. The first version of the system acted as a passive display, where the user could not make any input. User feedback and wishes for functionality for user input led to the second version of Tlatoque, where elderly people could share information with their relatives via the system. This was an interesting finding and corroborates the distinction that Gross makes between the commonly known ambient *displays* for presenting information and ambient *interfaces* for interacting with the system (Gross 2006). Overall, contact between the family members increased. Cornejo et al. (2012, p. 32) write: 'the ambient awareness gained through the use of Tlatoque enhanced older adults' face-to-face interactions, as they were aware of family members' life, dynamics and interests'. The authors continue to suggest helping the elderly to share information automatically: 'what we need are solutions that instead of requiring an older adult to decide what to share take advantage of an environment furnished with sensors capable of detecting what relevant information is worth sharing. […] Also, privacy concerns might arise when enabling the automatic sharing of information even though this information could be important for relatives'.

The *Proactive Displays* (McDonald et al. 2008) system used RFID technology to identify individual participants of conferences and large wall-displays to present awareness information. The *AutoSpeakerID* showed the name and affiliation of a participant asking a question; the *Ticket2Talk* showed the topics on the display about which an active user wants to talk; and the *NeightbourhoodWindow* gathered and presented the unique and shared interests of conference participants. McDonald et al. (2008, p. 16:29) conclude that 'the data we collected indicate some success in creating greater awareness and interaction opportunities within the conference community. However, they also show we were less successful in seamlessly meshing with the common practices at the conference'.

Informative art systems are ambient displays that present awareness information in the users' physical environment in an 'aesthetic and artful style' (Ferscha 2007, p. 287). They translate the status and changes to sensor data into colours, shapes, abstractions, etc. in computer-generated pictures that are projected on the wall (e.g., a Mondrian-style picture can be used as the basis, and changing colours and sizes of objects can indicate new documents and changes to documents in a shared workspace).

Overall ambient interfaces are particularly suited to situations where non-essential information is presented at the periphery of the user's attention. They have the advantage of reducing disruption, but at the cost of users sometimes missing the presented information. Toolkits such as MAUI allow rapid prototyping, which is important for exploring technological concepts with end-users. The ideas for automation of Cornejo et al. with respect to future versions of the Tlatoque system bring up the issue of reducing users' effort through automation while at the same time leaving the onus on the users. Both the Tlatoque system and the Proactive Displays are examples of awareness support for information that is not purely work-related. The examples used—and especially the informative art systems—also highlight the importance of the aesthetics of ambient interfaces. Again it needs to be stressed that there are many other examples, with the ones presented picked to illustrate concepts behind this type of awareness support.

4.2. Modelling awareness

The above examples of base technology illustrate the technological progress for awareness support. However, with more awareness technology becoming available, huge amounts of data can be captured and stored. Increasingly the question arose of how to structure awareness information in order to selectively provide awareness information according to the respective user's needs. Subsequently, I summarise solutions that were offered including the space model as well as the other awareness models conceived for this purpose.

4.2.1. *Spatial model*

The *spatial model* came up early in awareness research—it played an outstanding role in collaborative virtual environments and beyond, particularly because it inspired many subsequent models. It interpreted each computer as a space or a set of spaces, through which users can move and interact with other users or with objects. It aimed to leverage users' everyday experience in the real world, where proximity and distance influence and constrain the possibilities for interaction with each other and with artefacts.

Benford and Fahlen (1993, p. 110) write that the spatial model adopted: 'a "spatial" approach where people employ the affordances of virtual computer space as a means of control' and that this spatial approach was of a 'highly intuitive nature' and the authors describe its advantages as follows: '…from a more abstract standpoint, space affords a number of important facilities for collaboration including awareness at a glance; support of ad-hoc as well as planned interaction; use of body language and other social conventions in conversation management; flexible negotiation of access to resources (e.g., queuing, scrumming, and hovering), and structuring, navigation, exploration and mapping of large-scale work environments'. Thus users' positions, orientation and movement in the space was used to facilitate easy conversation management and adequate scaling of mutual awareness information as in a real space, where, for instance, the distance between two people and their orientation influences whether and how they can perceive each other (e.g., can see each other, can hear each other).

The spatial model offered an insightful analytical perspective on awareness in three-dimensional systems and included *key concepts* such as medium, aura, focus, and nimbus (Benford and Fahlen 1993). The *medium* was the connection among users and between users and objects; as a communication medium it could be text, audio, or video. The *aura* structured the virtual world and was defined as 'the sub-space which effectively bounds the presence of an object within a given medium' (Benford and Fahlen 1993, p. 112). The aura surrounded each object and moved as the object moved through space. Interaction between two objects was only possible if they approach each other and their auras intersect. Furthermore, the aura was medium-dependent—that is, an object's aura could vary in size and shape between different media. The *focus* and *nimbus* of objects influenced their level of awareness. It depended on the observer's *focus* determining whether the observing object was aware of the observed object as well as on the observee's *nimbus* determining whether the observed object was aware of the observer. Furthermore, awareness could vary between specific media and was not necessarily symmetrical between objects involved. Benford and Fahlen (1993, p. 112) define that 'the level of awareness that object A has of object B in medium M is some function of A's focus on B in M and B's nimbus on A in M'.

These general concepts need to be adapted for the respective cooperative system that wants to provide awareness based on a spatial model. The calculated awareness level is used for various purposes such as for controlling the volume of an audio channel, or for establishing a video connection automatically when a certain awareness threshold is reached. Already in DIVE and MASSIVE, the spatial model influenced awareness in any kind of medium: in audio connections awareness influenced volume, in video connections awareness influenced size and granularity of the graphical representation, and on text interfaces various kinds of text messages indicated the level of awareness. Later, Rodden (1996) refined the model and also applied it to non-spatial applications. Also Metaxas et al. (2011) extended it.

The spatial model has triggered some *intellectual debate*. Most prominently, it has been reflected on by Harrison and Dourish in their paper RI-Place-in Space: The Roles of Place and Space in Collaborative Systems' (Harrison and Dourish 1996). Here the authors discuss pros and cons of spatial models, and write: 'observing the way that space structures actions and interactions—the "affordances" of space (Gaver 1992)—many designers have used spatial models and metaphors in collaborative systems.' and in the 'spatial model of interaction' the 'awareness of each other, and opportunities for interaction, are managed through spatial extensions of their presence' (Harrison and Dourish 1996, p. 67). Later in the paper the authors emphasise the importance of place in space: 'places, not spaces, frame appropriate behaviour' and 'places have social meaning' (1996, p. 73f). They conclude that 'in everyday experience and interaction, it is a sense of place, rather than the structure of space, which frames our behaviour. Our sense of place is a cultural or communally-held understanding of the appropriateness of styles of behaviour and interaction' (1996, p. 75).

In the follow-up publication Dourish (2006) does not actually contradict the earlier paper, but writes that 'one reason for recounting, above, the intellectual history of the original ‘place’ paper is to account for some of its omissions’ (2006, p. 300). He observes that ‘in the decade since Re-Place-in Space was published, the questions of space and place have only become more relevant to CSCW research and practice. Mobility, the encounter with technology in different social settings, the need to understand contexts, the ability to transform spaces through the introduction of technology, the emergence of ‘locative media’—these and any number of other changes have both made space more relevant to CSCW, and CSCW more relevant to space’ (2006, p. 306).

Thus overall the notions of space and place—despite the their debate—offer wide-ranging advantages with respect to scaling awareness information automatically according to user behaviour. As the quotations indicate, the notion of affordance is used throughout the presentation of the spatial model and its discussion. Norman made the notion of affordance popular in the field of Human-Computer Interaction, and defined it as: ‘properties of the thing, primarily those fundamental properties that determine just how the thing could possibly be used…a chair affords (“is for”) support and, therefore, affords sitting.’ (Norman 1988, p. 9). In turn Norman took the notion from Gibson, who originated the term, writing: ‘the affordances of the environment are what it offers…what it provides or furnishes, either for good or ill. The verb to afford is found in the dictionary, but the noun affordance is not. I have made it up.’ (Gibson 1986, p. 127). Similar to the notions of space and place, the notion of affordances also has stimulated discussion. For instance, the questions of whether all or which kinds of objects can have affordances, and whether affordances are just in the objects or also in the user’s mind or only emerge in the user’s interaction with the object have triggered long debates. I do not have room here to pursue this background, as it would involve tracing its origin in the Gestalt Psychology of Koffka of the 1930s or even earlier in Lewin’s term Aufforderungscharakter (sometimes translated as invitation character or valence). In summary, however, it is this Aufforderungscharakter—literally the nature (of an object) that calls for specific behaviour—that is important for the design of awareness support. As Gaver who applied the notion of affordances to cooperative systems points out: ‘making affordances perceptible is one approach to designing easily-used systems. Perceptible affordances are inter-referential: the attributes of the object relevant for action are available for perception.’ (Gaver 1991, p. 81).

4.2.2. *Further awareness models*

Later awareness models were mostly grounded on the spatial model and provided sophisticated approaches for modelling entities in the world, and their relations, and their events. Subsequently, I summarise the awareness models of AETHER, MoMA, ENI, AREA, and locales.

The *AETHER model* (Sandor et al. 1997) can be seen as an extension of the spatial model; the concepts of aura, focus and medium were also used, although in a slightly modified manner. This model did not need the notion of events; instead it defined the relations between objects with a semantic network and its notion of time allowed the specification of validity of objects and relations over time. Change in validity of relations, the expiration of relations, and the marking of objects as invalid all constituted events. In contrast to the spatial model the aura was not directly connected to a person, but lays in the semantic net—that is, it was in the relations and not in the objects. Media were augmented with a percolation mechanism—each medium could consume aura and focus and therefore increase or decrease aura or focus.

The *Model of Modulated Awareness (MoMA)* (Simone and Bandini 1997, 2002) was based on a reaction–diffusion metaphor. Simone and Bandini (1997, p. 359) motivated their metaphor by a comparison with nature: 'in the natural world many phenomena have been described in terms of two basic principles: reaction and diffusion. Reaction referred to phenomena where two or more entities came in contact in some way and modify their state in consequence of this fact. Diffusion implied the existence of a space where the involved entities were situated. Reaction–diffusion referred to situations in which the entities modified their state together with their spatial position'. MoMA also had the notion of space, which was populated by entities. Users were seen as entities who engaged in tasks and who were interested in signals. Whenever two or more entities made contact their state was modified. Entities could produce and consume awareness through fields. Both the entity that emitted the awareness and the entity that consumed the awareness could influence the awareness produced or captured respectively.

The *Event and Notification Infrastructure (ENI)* (Gross and Prinz 2003, 2004) of the TOWER environment was a context-based model of the previous NESSIE that adapts to the respective users. It was used for a user study to analyse communalities among and differences between project teams. Events were the basis for the processing of the awareness information and the context information in in a project management and work setting. The context module and the situation module of the ENI server were responsible for the context processing. The context module analysed the attributes of incoming events and compared these attributes with the context descriptions in the context database. If all or some attributes matched, the context module attached a context attribute to the incoming event (e.g., `event-context=ProjectX`). On the other side the situation module analysed the attributes of the events a user produced through her specific behaviour and tried to reason about the current work context of the respective user. The system could then compare the user's current work context with the incoming events' context of origin and provided the user with information that was important in her current situation—that is, the ENI server sent the respective events to the users' indicators.

The *AREA system* (Fuchs 1999) provided a cross-application notification service based on a semantic model of awareness and involved the concepts of users, artefacts, and events. It described situations as relationships among objects, where objects were either single persons and single artefacts, or groups of people and sets of artefacts. Users could specify which events and artefacts they were interested in and when and to what level of intensity they wanted to be informed.

The *locales framework* (Fitzpatrick et al. 1995) was the awareness model of the WORk, Locales and Distributed Social worlds (wOrlds) system. The notion of locales was based on the theory of action by Strauss (1993). Locales aggregated resources that facilitated interactions and contained users and tools. Conceptually, people could meet in locales. The wOrlds system, therefore, provided a communication channel via audio and video connection as well as visual awareness information of each visitor's presence. All users had their personal home locale. User could navigate between locales, and even stay in multiple locales at the same time. While, finally, it could be combined with the Elvin event notification service (Fitzpatrick et al. 2002). Elvin included a tickertape that received automatic input from the event service or manual input from users and provided awareness information. Fitzpatrick et al. found interesting effects of making information publicly available: despite the fact that the authors report on a scenario, in which software developers benefited from information on the work progress and status of their fellow developers their 'communicative nature of their actions' when checking in software (2002, p. 464), it is comparable to the display and monitor practices in the control room as described above.

Overall, these awareness models provided good support for structuring awareness. They were based on precise models with close correspondences to the parts of the reality they modelled, as well as a clear mapping to real events and situations. However, the modelling effort was quite high and typically these models did not adapt to changes in the modelled part of the reality.

4.3. Summary

In this section some background on underlying patterns of awareness support with respect to base technology and modelling awareness was given. Base technologies in awareness information environments showed how the overall processing and storing of awareness data works and illustrated it with prominent early examples. Sensing technology was exemplified using one example—Lilsys, which demonstrated that any awareness support strongly depended on sensing capabilities of the underlying technology and that it was important that end-users received feedback and controlled it. Awareness information presentation provided technological examples for bringing awareness information to the users' attention on graphical user interfaces and in the users' physical environment. Modelling awareness started most prominently with the spatial model that led to considerable debate on the notion of space and place, and also stimulated further awareness models such as the AETHER model, the MoMA model, ENI, the AREA model, and the locales. They all provide excellent contributions in finding ways to represent users, activities, and environments. The following points can be distilled from them:

- Awareness information environments are typically based on hardware and software sensors that capture event based data. This approach is very generic and makes it possible to integrated new technology easily, also for end-users. However, the means for end-users to express their interests are limited. The users' need for feedback and control on what is captured about them has been discussed at the end of the previous section; yet, the concept of shared interest profiles to leverage on synergies between users' specifications is an interesting design idea. Identifying and addressing challenges concerning the disruption of awareness information recipients is a central requirement to effortless awareness support.
- Sensing technology should provide adequate combinations of hardware and software sensors as well as inferrencing concepts to get a better impression of the overall picture. Privacy concerns should not only be considered when dealing with sending and presenting information, but when dealing with capturing information. Furthermore, systems should provide suggestions that users can always override—either for a specific single moment, or as a general rule.
- Awareness information presentation should be explored with early user participation. Information can be provided on users' screens, but also in the users' physical environment. Therefore, toolkits that allow fast prototyping are well suited. Besides the objective presentation of facts, ambient interfaces and especially informative art can be used to present awareness information in aesthetically pleasing ways. The type of awareness display should fit the users' information need and context.
- Awareness models are important for structuring awareness information. Often the models—most prominently the spatial model—combine complex mechanisms for processing awareness information internally with easy abstracts for end-users. Here the technological strengths and weaknesses of the base technology as well as the affordances offered to the users need to be considered.

5. Design tensions of awareness support

This section discussed four design tensions that emerge from the basic desire to mimic mutual awareness for effortless coordination over distance.

In this paper, so far, Section 1 motivated the important role of awareness research in CSCW. Section 2 characterised the ethnographically-informed as well as the technology-oriented roots and gave first hints on the gaps between them. On the one hand early ethnographic studies investigated how awareness is achieved in an effortless manner through careful attention to on-going events and actions as well as the subtle production and communication of information. On the other hand early technologies for providing awareness information suggested mechanisms for coupling user interfaces and remotely displaying actions and changes to shared artefacts. Section 3 and Section 4 gave an impression of the evolution of awareness research—mainly from a conceptual and technological perspective. Section 3 glanced at the achievements and open challenges for providing person-oriented and artefact- and activity-oriented, and Section 4 exemplified the technological evolution and status quo with respect to sensing, processing, and presenting as a well as structuring and modelling awareness information.

Awareness is a *dynamic construct*—that is, a process rather than a point in time. As Schmidt (2002, p. 292) puts it: 'competent practitioners are able to align and integrate their activities because they know the setting, they are not acting in abstract space but in an material environment which is infinitely rich in cues … They understand the processes and the issues, they know how activities intersect, they know what probably will happen and what might happen, they expect things to happen and other things not to happen, they anticipate what will happen next, they are in the rhythm, they monitor for indicators of what is expected to happen, and so on'. In a different publication Schmidt explains: 'work is a highly social phenomenon. The subject of the production process, human kind, is a zoon politikon. Human adults entering the workforce of society arrive fully equipped with language; logical categories and inference rules; concepts and other developed cognitive structures; general and domain-specific knowledge acquired in the process of socialisation; ideological notions such as moral and aesthetic norms, beliefs, prejudices, etc. These abilities (and, in some cases, liabilities) are of a profoundly social nature' (Schmidt 1991, p. 75). This holds true for any type of work—as Bannon and Schmidt point out (1989, p. 361): 'replacing the term "cooperative work" with that of "group work" or defining the former by the latter does not help much'.

So in order to understand awareness and provide awareness information over distance, it is important to take these findings into account: work is fundamentally social and requires actors with multifarious social skills. As we have seen in the previous sections technological concepts and systems cannot and do not always meet these requirements. In face-to-face settings people have great social skills—that cut across awareness research and have been touched on throughout this paper—especially with respect to mutual availability, privacy, conventions, and tailoring awareness to the respective situation. As we will see in the following four subsections, developing concepts and systems for distributed settings that compensate for the lack of physical presence and the social skill that are engaged there, entails considerable design tensions with respect to (1) managing availability, (2) dealing with privacy, (3) establishing conventions, and (4) tailoring awareness to the respective situation.

5.1. Availability

The *first design tension* where a complex interplay of human practices and technological support is essential for successful coordination at low effort is the mutual availability of users. As Berlage and Sohlenkamp (1999, p. 207) point out: 'awareness… allows users to coordinate and structure their work, because they can see what others are working on. Additionally, it enables users to check the availability and accessibility of others, providing a base mechanism for establishing communication'. Yet there is a *trade-off* that was identified by Hudson and Smith (1996, p. 249): 'the more information one receives about others, the greater awareness of them is possible. However, at the same time, the more information one receives, the more likely it is to disrupt normal activities or consume too many resources'. So awareness support for availability has the potential to facilitate flexible social interaction over distance, but has also carries the danger of interrupting users and increasing their overall effort.

Part of the complexity of dealing with user's availability results from the fact that users often do not have just one task at hand, but are required to work in multiple cooperative work settings *concurrently* and to switch between them. In fact, writing on multiple and collaborative tasks, Johnson et al. (2003, p. 277) point out that: 'the activities that now need to be understood and supported by design include multiple and collaborative tasks. They do not always have single, clear goals, they often lack discrete start and end points, and sometimes the multiple goals are incompatible. Tasks are frequently carried out in parallel, with various levels of interleaving and interruption. People perform the same task with the same technological support in different ways, depending upon their social context, and the degree of cooperation and collaboration. Collaboration introduces overheads for managing the collaboration, which have to be traded off against gains in efficiency of the task itself'.

Working concurrently over *distance* adds more complexity—especially with respect to estimating each other's availability. In a study comparing users self-attributed availability with the other users' estimation of availability, a discrepancy between the two could be found (Avrahami et al. 2007). This discrepancy is partly due to the fact that technology has an influence on the perception of availability of remote colleagues. As Avrahami et al. (2007, p. 51) write: 'people have developed a variety of conventions for negotiating face-to-face interruptions. The physical distribution of teams, however, together with the use of computer-mediated communication and awareness systems, fundamentally alters what information is available to a person considering an interruption of a remote collaborator'. The results show, for instance, that the social engagement of the persons had a strong influence on misjudgement of their availability—in both ways: when the person to be contacted was interacting with another person their availability was more frequently over- as well as under-estimated than in a situation without interaction. Phone use led to over-estimation of the interruptibility (i.e., the phone users perceived themselves as less interruptible than the watching persons thought); and the closed door led to an under-estimation of interruptibility (i.e., the persons in closed rooms were more interruptible than the other people outside thought). So it is sometimes difficult for humans to adequately judge others' availability.

Another interesting facet of the effect of the computer-mediation of awareness and communication on users' behaviour is the way users deal with and *handle their own availability*. In a study on the use of instant messaging (Hancock et al. 2009) it was found that the fact that users sometimes feel overexposed to their online contacts leads to the fact that in some cases users start deceiving others about their actual availability. Hancock et al. (2009, p. 518) write: 'understanding the role of deception in managing interpersonal awareness and interactions is a critical part of the larger problem of providing awareness information within geographically distributed work and social groups. […] One key factor undermining these vital interactions in distributed groups is the difficulty in determining who is available to interact at any given moment, or maintaining a sense of interpersonal awareness'. The study was based on self-rating of the message contents and showed that out of 6,996 messages sent during the study 685 contained lies. And out of the 685 lies 132, about one fifth, were identified as butler lies, defined as (2009, p. 517): 'using deception to manage social interaction an awareness by avoiding a new conversation ("Yeah, sorry, I gtg. I'm studying with a friend."), smoothly exiting an ongoing conversation ("Okay, back to work I go."), or explaining other communication behaviour ("hey I just got your call. my phone wasn't with me.")' (TG: spelling and capitalisation from original). The butler lies were used evenly among participants—no difference of age, gender, or IM experience was found.

Some approaches have applied *technology*—mostly machine learning approaches—to allow the system to judge users' availability. For instance, in (Nagel et al. 2004) the experience sampling method was used to prompt users for their own availability and at the same time the system analysed via various sensors the overall state of the users' environment at the moment. Regression analyses showed different relevance of aspects of the users' environment with respect to judging availability (e.g., activities such as writing email, or watching television had a much stronger relevancy than the time of the day or other activities such as cooking). The *FeedMe* system (Sen et al. 2006) uses machine learning techniques to determine moments when to present *alerts* and when to postpone alerts. In a related paper it is even claimed that 'this article presents a series of studies that quantitatively demonstrate that simple sensors can support the construction of models that estimate human interruptibility as well as people do' (Fogarty et al. 2005, p. 119). While this claim might be justified when looking at a specific setting at a specific moment in time, it seems very ambitious when regarding the dynamic nature of social interaction in the course of which availability management can be seen as an on-going negotiation of borders among the people involved.

Another approach that seems more promising in the task allocation between users and technology is to use technology to make simple and reliable analysis of user behaviour and present clear-cut rhythms that can then be interpreted by users. For instance, the *Awarenex* system (Begole et al. 2002) that was already introduced above received an interesting extension for data extraction and visualisation in order to provide awareness on work *rhythms*. In a visualisation called the Actogram the users' activities on the computer were monitored over 10 months and aggregated to show typical online and offline rhythms. For instance, it became clear that a specific user typically began work between 8:00 and 9:00, had lunch breaks between 12:00 and 13:00, and left the office between 17:00 and 18:00. It also revealed that the user typically left earlier on Thursdays (i.e., between 15:00 and 16:00), but would sometimes go online later that day (i.e., after 17:30).

As these latter examples of technology-centred approaches show, more awareness research needs to be done. In fact, Chen et al. (2010, p. 1:1) point out that 'data mining and data analysis have a long history in human-computer interaction', but at the same time 'using such analysis to improve the responsiveness, user fit, and functionality of interactive systems has not been explicitly synthesised even though it has been a persistent interest in HCI'.

Summarising this availability discussion, the following issues and requirements for awareness and coordination with respect to availability can be identified:

- Solid concepts for availability to avoid interruption are required
- Both social availability for interaction with other users and personal availability for notifications on awareness information are important
- Concurrency of activities and multitasking play a central role and need to be understood better by means of empirical studies
- Users practices in estimating availability—especially over distance—need to be better understood by means of empirical studies
- It is critical to have appropriate task allocation between users and technology—while technology has the potential for reducing user effort through atomisation, users should nevertheless have enough flexibility for negotiating their availability

5.2. Privacy

The second *design tension* is the antagonism between sharing awareness information and maintaining privacy. This *trade-off* has—similar to availability, also—been emphasised by Hudson and Smith (1996, p. 249) who write: 'in fact, we believe there is a fundamental trade-off between providing awareness information and preserving privacy. In general, the more information transmitted about one's actions, the more potential for awareness exists among those receiving the information. Yet, the more information transmitted, the more potential for violation of one's privacy exists'. The authors (1996, p. 249) also point out that privacy can be more challenging in remote CSCW scenarios than in collocated situations: 'privacy has been widely recognised as an important issue for media spaces. In a shared physical space we have a well-established set of social protocols for dealing with issues of privacy. For example, the distinction between a public and a private space is normally immediately clear, and most adults know how to adjust their behaviour for each with little effort. However, in a virtual space, it is often the case that the normal cues of public versus private spaces are absent'.

There are *technical concepts* and systems to address this trade-off between awareness and privacy in CSCW.

For instance, the *Awareness Mechanism* based on a sophisticated document model and ghost operations in (Ignat et al. 2008) allowed the system to compute and visualise awareness information on changes to documents in various parts and on various privacy levels. The different privacy levels provided users options such as no privacy (i.e., all activity on a shared document is fed through), mask the user (i.e., the operation is carried out and shown in the shared document, but anonymously), or mask changes and their effect (i.e., the operation and its effect is only visible to the local user and hidden from others). Where operations were transmitted and presented, the system gave feedback on concurrent actions and stimulated discussions among users to resolve them.

Another example is the *Privacy Grounding model* (Romero et al. 2012) that wanted the users of the system to develop a common understanding of their privacy intentions. For this purpose the model provided signals for grounding. An example that the authors (2012, p. 10) use is the following: 'if someone initiates communication even after the recipient has blurred her video to represent unavailability, the recipient could explicitly signal her meaning of unavailability intended by the blurred video, which grounds the recipient's unavailability and how it affects the recipient's responsiveness'.

There has also been research on technical solutions for privacy protection on the Web. For instance, in The *Privacy Bird* system (Cranor et al. 2006) was not targeted specifically at CSCW and awareness, but provided an interesting approach to simplifying the process of specifying and applying privacy settings that can be complex and cumbersome to users. It was based on the Platform for Privacy Preferences of the World Wide Web Consortium (W3C) and followed the eight principles of the Organisation for Economic Cooperation and Development (OECD) guidelines for the protection of privacy. The client of the system compared the P3P policies of Web sites with the user's personal preferences and gave simple recommendations whether the user should visit a specific Web site or not. While P3P failed with respect to its immediate adoption, the basic principle of specifying and declaring the intended use of information absolutely addresses the trade-off between information needs and privacy.

Also in the field of *Ubiquitous Computing* where sensing technology is omnipresent, considerable research on privacy has been published. For instance, Iachello and Abowd (2005) suggest asking the following questions when designing and developing technology that involves sensing person-related data: legitimacy of the application purpose for the future users; appropriateness of the sensing technology according to legal and social standards; and adequacy of the concepts and functionality developed and evaluation of their impact on future users' privacy.

Summarising the privacy discussion here and privacy issues from earlier sections of this paper, the following issues and requirements for awareness and coordination with respect to privacy can be identified:

- Social interaction over distance can lead to new challenges for users, since traditional social protocols with respect to privacy in face-to-face situations can not always be applied
- Privacy principles should be set up and guide the design of awareness technology. Observed users need feedback (i.e., information about the fact that they are being observed and what is being observed) and control (i.e., active influence on what is being captured about them and presented to others). Reciprocity where all observers are also observed and the same information is captured and presented to each other is for many situation highly adequate, but it needs to be better understood by means of empirical studies
- Users practices in dealing with privacy and the levels of privacy for different types of data—especially when mediated via technology over distance—need to be better understood by means of empirical studies
- Further technical concepts for extracting and masking information on users and their activities need to be developed that can provide the observer enough orientation for mutual coordination, yet do not reveal information that the observed user wants to keep private
- Despite the potential for technological support for privacy, it is critical to have appropriate task allocation between users and technology—especially providing users with enough flexibility for negotiating their privacy

5.3. Conventions

Conventions are agreements in a team on how to behave. Supporting conventions has inherent *design tensions*, since they often emerge and evolve over time and need to find a delicate balance between individual freedom and shared arrangements and shared orientation in a team.

In an early study on the role of awareness in cooperative work settings, Mark et al. (1997) examined the influence of awareness on the emergence and evolution of *conventions* in distributed teams. They (1997, p. 254) defined 'conventions for a groupware system to be rules or arrangements established in the group, common and accessible to its members, that users need in order to cooperate effectively with the system'. The study analysed the cooperative work of 12 users over 6 months and led to interesting findings with respect to awareness support for conventions: peripheral awareness should provide non-obtrusive guidance and orientation in the group and its conventions; contextual awareness should allow for individual work styles and provide information that is relevant for the respective task at hand; and mutual awareness should via shared awareness profiles encourage the use of the same awareness configuration and thus the same information in the respective situation. In a different publication on the same study, Mark (2002, p. 359) further elaborates on conventions: 'conventions are built upon a foundation of some degree of common ground among actors. Before actors can cooperate, or even communicate, establishing a common ground is essential. Common ground is cumulative, being developed as actors share experiences. It must be reciprocal—each much assume that the other possesses it … Members of the same social group, or people who live and work in proximity, share a considerable degree of common ground … A critical factor for the emergence and functioning of conventions is the information available that communicates social, behavioural, and environmental aspects of the group. This information is the raw material for forming conventions'.

In a recent publication on the role of awareness with respect to common ground Convertino et al. (2011) studied the adoption and use of three different prototypes providing awareness in an emergency management planning scenario. The authors found that awareness on the mutual activities of the users could stimulate the establishment of conventions and reduce the communication effort. For instance, they found that with awareness support the length of the turns in communication decreased, which they interpret as higher communication efficiency. The authors conclude that awareness support is vital for supporting common ground over distance; where 'common ground results from exchange of content and mutual checking and signalling understanding: "I know that you know that I know what"' (2011, p. 22:29). They, finally, even claim that well-supported distributed work can lead to better awareness than collocated work: 'more generally, we have argued that members of mediated groups may develop enhanced mutual awareness of each other due to the additional cognitive work they do to establish and maintain awareness… Thus an overarching design goal has been to articulate, facilitate, and enhance what is already good about distributed and computer-mediated environments, with the corresponding design objective to create a tool that increases distributed group performance beyond that of a face-to-face group'.

The following issues and requirements for awareness and coordination with respect to conventions can be identified:

- Concepts for conventions need to respect its emerging and evolving nature and changes over time—conventions are often based on common ground and common ground in teams is a dynamic construct, where group members create and maintain a growing mutual understanding

- Users practices in dealing with conventions—especially with respect to mutual awareness over distance—need to be better understood by means of empirical studies (e.g., issues of loose and tight coupling and mutual feedback on the coupling mode)
- Concepts need to adapt awareness information over time—with the emergence and growth of common ground and conventions the need for both explicitly displaying the own status and activities and monitoring the others' states and activities can be reduced and therefore also the need for awareness support can change or go down
- Concepts need to help new-comers catch up with already established conventions—the emergence and evolution of conventions can lead to complex agreements in groups that are not easy to grasp by new members of a group; awareness support should therefore help users entering the field

5.4. Tailoring

The fourth and final *design tension* addresses the challenge of providing strong generic concepts and technologies that have the potential to span across time, distance, and domains, but still can be tailored to the respective circumstances.

Luff et al. (2008) conducted a study of a team and its work in surveillance centres in London Underground and found a range of practices that the team members use in order to maintain awareness. Besides the general practices found, the authors also made interesting discoveries concerning *domain-specific* awareness needs. They reported on a study of the operations room of the London Underground stations, where the staff had eight to ten CCTV monitors displaying video images selected from sometimes more than 100 cameras. So with this amount of input sources the process of maintaining awareness of the passengers in the station was of a complex nature. The staff had to take care that no problems occurred, and to analyse passengers and identify irregularities in their appearance or behaviour. As the authors write (2008, p. 418): 'some of these everyday practices for awareness rely on noticing the "strange" from apparently "normal appearances"'. When problems occurred, the staff needed to react quickly and systematically. Luff et al. (2008, p. 431) concluded that: 'the complex array of practices and reasoning for maintaining awareness provides a fundamental resource for the day-to-day operation of the service; indeed the travel arrangements and working days of hundreds of thousands of passengers a week rest on a seemingly delicate body of tacit procedure and convention'. Thereby the practices of maintaining awareness on the team members and at the same time on the platform were quite complex.

With respect to CSCW and awareness research they point out that the fact that ethnographic studies shed light on highly specific and contingent settings requires that the insight gained from studies and for the design of awareness technology is highly specific. This result was in contrast with existing awareness technology that—according to the authors—very often aim at providing generic solutions. The authors (2008, p. 431f) write that: ‘the kinds of technical solutions that we considered in this article are distinctive to those usually discussed within CSCW that aim to support awareness. Technologies such as media spaces, collaborative virtual environments, and awareness systems available on personal workstations tend to be designed to support generic tasks, supporting a range of distributed activities and drawing upon a broad conception of awareness. […] However, designing generic awareness systems has proved fraught with difficulties… The technologies they require need to be designed for their highly specific activities and requirements’. And finally, they (2008, p. 433) write: ‘awareness technologies, particularly those that seek to support distributed tasks, can focus unduly on the dissemination of information to remote colleagues, for example, about an individual’s current activities. …the means by which these are provided become obtrusive in a collaborative activity rather than supportative’.

Strongly related to conventions that emerge and evolve over time is the fact that many teams go through different phases and need *phase-specific* awareness information.

Under the label of *Awareness of Collaboration* (Leinonen et al. 2005) a study analysed the work of a distributed team and how they maintained awareness for 3 months. Awareness of collaboration was defined as to ‘how team members perceive their collaborative work in relation to their shared goals and the process of collaboration’ (2005, p. 304). A working model for distributed collaboration with four phases was suggested: negotiation of the aim of the project (including a shared goal, conditions for collaboration, rules for coordination); working on the shared task (including phases of individual work and of shared attention); summarising the project (including joint activities of looking at earlier project phases); and evaluating the project (including a group reflection that facilitates awareness of the collaborative activity). The study contained 19 people from three continents and the object of the real teamwork was to create guidelines for an upcoming company merger. The team used a Web-based shared workspace system providing an asynchronous discussion forum as well as workspace awareness. The qualitative study investigated how the working model supports awareness of collaboration. The open-optioned questions of the questionnaires gave interesting insight into awareness of collaboration, which can be put into three categories. The awareness of the possibilities for collaboration was seen positively and most team members had the impression that they had on-going support from others. The awareness of the aim of collaboration left some points open; for instance, some answers raised the issue of a lack of a shared aim. And, finally, the awareness of the process of collaboration was seen positively as the team followed the four phases of the model. The authors (2005, p. 316) conclude that: ‘awareness of collaboration is more than awareness of some technically constructed environment where individuals work together. […] In the awareness of collaboration, both content and social processes should be included'.

The following issues and requirements for awareness and coordination with respect to domain- and phase-specifics can be identified:

- Concepts for domain-specific semantics of awareness information can help observers to distinguish regular information from extraordinary information; overall we need technologies with a generic and reusable software and hardware architecture that still support context-specific designs
- Users practices in team of different domains—especially with respect to dealing with team stages over distance—need to be better understood by means of empirical studies
- Availability, privacy, and conventions should be analysed with respect to their domain- and phase specifics and allow teams in their respective situation to tailor them to their needs

5.5. Summary

This section revisited awareness research from a user's perspective and identified and discussed four design tensions with respect to availability, privacy, conventions, as well as tailoring. All four illustrate that bridging the gap between the subtle user side and the automated technology side is difficult, but can lead to success. The issues and requirements identified should help designers of future awareness support.

Overall, it is essential to keep the *multifarious nature* of awareness in mind—with respect to diverse users, diverse needs, diverse situations, and diverse social, political, and technical contexts. After all, awareness and its facets are a social construct, as, for instance, the study on deception in instant messaging shows it is not only about hard facts. Awareness is often ephemeral. Furthermore, awareness is not a single-user construct about individuals and their surrounding world, nor a single-user to single-user construct about two or more individuals participating in some shared activity, but a genuine group concept. In order to illustrate this thought, take group recommender systems as an example: they are all called *group* recommender systems since they involve multiple individuals. Typically, it involves collecting information from individuals (either through explicit user input or through monitoring of user behaviour) and providing individuals with recommendations. There are only few real group recommender systems that accommodate genuine group concepts that, for instance, provide recommendations not for single users, but for groups of users (Herr et al. 2012).

6. Discussion

The field of CSCW and the awareness research within it has produced excellent results over the last 25 years. Awareness, as has been said above, is a core concepts of cooperative work; as Schmidt (2012, p. 4) points out: ‘multiuser database systems (such as, e.g., airline reservation systems), while enabling cooperative work in the first place by providing shared digital representations, did not provide any kind of support for the necessary mutual alignment among actors (“mutual awareness”)’. Maintaining awareness is a complex and ongoing activity for users and takes effort. Reducing this effort would be highly welcome. However, as has been shown there is a considerable gap between the human achievement of awareness and the technological capturing, processing, and presentation of awareness information. In this section I glance at awareness research in other areas related to mainstream CSCW research.

So far we have reviewed awareness research from within CSCW. Yet awareness has been researched in other related areas as well. Despite the fact that the CSCW community mostly has been sceptical towards *automation*, it is still important not to ignore the progress made in other areas such as HCI and UbiComp. Overall, in HCI and UbiComp the resistance towards automation in terms of adaptability and adaptivity in order to reduce users’ effort has been smaller. Automation in the sense of adaptive and (at least partly) autonomous behaviour of technology has always had its pros and cons; and it has always been and it still is vital to consider both sides. For instance, in UbiComp the vast availability of embedded and mobile technology was used to adapt the systems’ information and functionality of the users’ location and activities. Ambient intelligence—and especially cooperative ambient intelligence—aims to be highly adaptive to groups of users (Gross 2008).

It is important to distinguish *adaptability*, where the users are in control and customise the environment according to their preferences, from *adaptivity*, where the system tries to learn about users and their behaviour and makes suggestions for changes in reaction to them. In single-user systems based on GUIs, adaptability was supported through user customisation, and adaptivity through system recommendations for changes. Later in cooperative systems articulation has been an important topic allowing users to adapt the system according to their respective needs, and adaptivity was supported in some individual systems such as the Coordinator that could analyse email contents and react accordingly (Winograd and Flores 1987). The Coordinator system has been heavily criticised—most prominently by Suchman (1994)—especially for its speech acts and rigid categories. The debate between Winograd and Suchman on this issue stimulated a long discussion among many CSCW researchers, the details of which I cannot go into here. However, I do want to quote Malone’s comment on the debate: ‘I believe the most important lesson from all of this for the field of CSCW is that we need to learn the “art” of applying categories well. On the one hand, we need to avoid rigid or slavish devotion to any particular set of categories; on the other hand, we need to find and support useful patterns of interaction.’ (Malone 1995, p. 38). While the debate at that time was on communication support, this also holds true for awareness research today. To put it simply: if the goal is to reduce users' effort with awareness, we need to automate some part of it.

The *notions of awareness* in CSCW and context awareness in HCI and UbiComp should be compared and the potential for automation of awareness support should be evaluated, but always bearing in mind that we leave users in charge. Yet, the historical and legitimate paradigmatic differences between awareness in CSCW and context awareness in UbiComp should not be forgotten. As Schmidt et al. (2004, p. 221) put it in the introduction to their special issue in JCSCW on Context-Aware Computing in CSCW: 'the understanding of context in CSCW goes beyond the traditional view of context-aware systems discussed in the fields of Human–Computer Interaction and Mobile Computing'.

Chalmers (2004) conducted a thorough review of the notion of context in CSCW as well as in UbiComp. He (2004, p. 223) points out that 'context and awareness are at the core of both CSCW and context-aware computing, albeit with different interpretations with regard to theoretical principles and design practice. An extreme view, deliberately highlighting differences, might hold them as incompatible or conflicting: CSCW focuses on intersubjective aspects of context, constructed in and through the dynamic of each individual's social interaction, and defends against reductionism and objectification. In contrast, context–aware and ubiquitous computing often concentrate on computational representations of context that span and combine many senses and media-rather than the social construction of context in interaction'. Chalmers also pointed out—and this is related to some discussions of the Coordinator system above—that technology should represent work adequately, but also modestly 'without over-formalising, over-simplifying and over-objectifying it' (2004, p. 224).

Edwards (2005) uses an analogous distinction and points out that in context-aware computing information on the users' context is produced and consumed by the system, whereas in cooperative systems this information is produced by the system, but consumed by users. The author continues to point out that besides the differences in the recipients of the information there are also differences in the representation of the data: loosely structured data in CSCW versus highly structured ones in UbiComp. His *Intermezzo* system (Edwards 2005) system built on this basis and provided flexible context support by means of structuring contexts through activity where an active subject performs an action on an object, and representing context in a flexible and rich way by means of an evolvable model of slots, a canonical representation of users, and multivalued data per slot. The *AWARE* architecture that was already introduced above took a similar conceptual approach—it also aimed at combing strengths of CSCW and awareness with concepts from UbiComp. Bardram and Hansen (2010) write: 'this paper introduces the term Context-Based Workplace Awareness to denote the mechanism of establishing awareness about the activities in a workplace based on access to information on work context. In particular, the paper investigates context-based workplace awareness in ubiquitous computing environments designed for hospitals'.

Thus one promising avenue for future awareness information support is to combine human- and machine-readable—that is, rich and structured—representations, as well as original and inferred data. The everyday world of CSCW is ultimately also made up of atoms and bits—or, in other words, cooperative settings have three vital dimensions: space, time, and connection among users that all have aspects that are *machine-readable and -processable*. The notion of *space* has a long tradition in mathematics and physics as well as philosophy (it must be noted here that the notion of space here is not directly related to the spatial model above). Seen from a mechanics perspective, space can and is being measured in common standards such as meters, or GPS coordinates. *Time* as well is very important in mathematics and physics (e.g., in quantum mechanics). It can also and is measured in standardised ways, such as in seconds, minutes, hours, and so forth. Finally, the *connection* between users is at the core of CSCW and awareness and can also be seen from a neutral perspective. Both the technological infrastructure that links users can be analysed and measured (e.g., in transmission rates, and network latency, technical features of audio and video equipment), and social connections have been quantified (e.g., in social network analysis). Any of these three dimensions of CSCW and awareness can be analysed and measured per se and in combinations with each other: for instance, time is often important for analysing and measuring the evolution either of space and place or of social connections. From an awareness perspective the social connection can be seen in space (e.g., as users' absolute positions or users' positions in relation to each other), or in time (e.g., as users' course of interaction with each other), or in space and time (e.g., users' rhythms of social interaction). So it is possible to analyse and measure the objective parts of the cooperative situation and of the awareness, and it is vital to have some basis to start from.

As has been said above, the measurability of some parameters of space, time, and space should not obstruct the fact that *social reality is more than that*. As Husserl stated: humans are embodied in their Lifeworld (2006, p. 3): 'Every I finds itself as having an organic lived body. The body, for its part, is not an I, but rather a spatial–temporal "thing" around which is arranged a surrounding of things that reaches outward without limits. In each case, the I has a limited spatial-temporal surrounding, which it immediately perceives, or, as the case may be, which it remembers in immediate, retentional memory. […] Likewise, the I knows that the currently remembered temporal piece of what exists is only a piece of the endless chain of what exists; a chain that stretches back into the endless past and reaches out into the endless future as well'. And, Heidegger—who did his PhD with Husserl and was inspired by the phenomenology invented by Husserl—writes (1967) that the hammering itself discovers the specific handiness of the hammer. The characteristic of the tool that it discloses itself, let us call it ready-to-hand. This ready-to-hand is in contrast to pure existence, which Heidegger calls 'Vorhandensein' or present-at-hand. So, for awareness research this means that we exist in a cooperative setting as part of a world that has already been there, before we entered it. It also means that the world consists of things and the things are connected with each other as well as with their respective past and future. And, at the same time, at any given moment users only see a part of it, but know of their connections. The tools supporting awareness are most likely not handy from the beginning, but should suggest and support intuitive handling. Furthermore, systems can only provide some information that is hopefully relevant to the respective users—but it is the users with their lived experience who associate the presented information with their personal spatial-temporal mental connections.

Robertson (2002) points out that designers of CSCW technology can achieve a better understanding of cooperation by applying the *phenomenological* stance of Merleau-Ponty to awareness. She (2002, p. 303) suggests: 'for participants in a cooperative process to be aware of anything, it must be publicly available to them. And the public availability of anything is dependent on its perceivability' and (2002, p. 306) 'put very simply, perception is learned, embodied, skilful action. So is awareness. Awareness can never be a "property" of a virtual workspace, nor can any technology "produce" it. Awareness can only be achieved by the skilful activity of participants in a shared space if the resources they have learned to recognise, and therefore understand, are publicly available to them'.

So there is probably not only one truth to this question of human-centred awareness versus technology-mediated mutual information of users. Chalmers offers a compromise when he (2004, p. 231) combines: 'people "do" objectification, conscious reflection and rationalisation, as well as the non-rationalising, intersubjective and bodily activity that makes up much of one's everyday life. We are continually developing new ways of understanding and acting, new objects and processes, and new ways of interpreting what was familiar and everyday. They may begin as starkly detached and objectifying, but as we build up individual and subjective histories of how to relate such new tools and interpretations to the others we use in our lives, they become mundane, everyday and unremarkable: they "disappear" or become "invisible"—for a while'.

Bødker and Christiansen (2006) see an advantage in this oscillation of awareness between foreground and background. They (2006, p. 4f) point out a detailed yet important aspect of user's awareness: 'In order to stay aware of other people, you have to sense their presence as somewhat ephemeral, potentially disappearing. If their presence becomes too habitual, you tend to take them for granted, and you cease to pay attention. On the other hand, if you do not come across them at all, you may forget they are there. In order to stay socially aware, it seems necessary to have people within reach—not always, but at least occasionally'.

This fluent and complex nature of social interaction has also been emphasised by Altman et al. (Altman 1976; Werner et al. 2000) in his analysis of the ways in which humans manage their personal availability and privacy. They (Werner et al. 2000, p. 309) write: 'in dialectic fashion, the opposing processes of accessibility and inaccessibility are in constant dynamic tension and flow as people regulate self-other boundaries over time.' Palen and Dourish (2003) offer a valuable discussion of Altman. They point out that 'the significance of information technology in this view lies in its ability to disrupt or destabilise the regulation of boundaries' (2003, p. 131). According to the authors three boundaries that are important: the disclosure boundary between privacy and publicity, the identity boundary between self and other, and the temporal boundary between past, present, and future. They conclude that 'privacy management is a dynamic response to circumstance rather than a static enforcement of rules; that it is defined by a set of tensions between competing needs; and that technology can have many impacts, by way of disrupting boundaries, spanning them, establishing new ones, etc.' (2003, p. 135), which once again emphasises the dynamic and emergent nature of social interaction, and the limitations of automatisablity.

7. Conclusion

This paper aimed to provide a survey on the awareness research in CSCW over the last 25 years. It glanced at the origins of awareness in CSCW and showed that early ethnographic studies and technology explorations already brought up fundamental insights and questions for awareness research. The term awareness was narrowed down, but no clear-cut definition of awareness was given, since this is considered to be impossible. A detailed overview of concepts and technology for awareness support from a users' perspective was given including support for person-oriented information in media spaces and collaborative virtual environments, and for work-oriented information in shared workspaces and group editors. Additionally, an overview of concepts and technology for awareness support from the inside provided information on base technology such as awareness information environments, sensing technology, and awareness presentation as well as approaches for modelling awareness such as the space model and other awareness models. Design tensions for awareness research with respect to availability, privacy, conventions, tailoring were identified and discussed—particularly as to the question what role technology can play in automation, reducing users' effort to maintain awareness. The final discussion aimed at bridging the gap between on the one side ethnographically-informed insights on the nature of awareness and the users' practices dealing with it and on the other side technology-oriented approaches from CSCW and elsewhere to support users where help with technical means is possible.

Despite its length this survey could not cover all areas of awareness research in full detail. I tried to investigate how people establish awareness, yet the majority of the contents is of a conceptual and technological nature. Furthermore, as has been said in the introduction the emerging awareness support in Social Media (e.g., Facebook) was not the primary focus. Important new questions that emerge with the increasing mediation of awareness information through technology include ways to deal with the fact that in many systems (especially Social Media systems) awareness information is stored persistently as opposed to ephemeral mutual information in face-to-face situations. They also include research into the influence of new technologies (especially wide-spreading Social Media systems such as Facebook) on users' current behaviour and new habits (e.g., Facebook has a long history of both neglecting and addressing users' behaviour and wishes for privacy feature for selectively sharing contents and thereby strongly influencing the behaviour of users). The future relationship between on the one side traditional CSCW and awareness research and Social Media on the other side should have a bi-directional nature: Social Media are and will increasingly be an interesting area for awareness research, especially due to the large numbers of users and their intense use of the technology, but at the same time developers of Social Media can benefit from taking the results of 25 years of CSCW and awareness research into consideration when conceiving new systems and functionality.

Overall, the concept of awareness remains difficult to grasp; as Schmidt points out it is 'used for describing that a particular cooperative activity is successfully aligned and meshed, and that this was accomplished effortlessly and inconspicuously, without conversations, queries, commands, gesturing, emails, or other kinds of interruptive interaction.' (2011, p. 24). Future awareness research can and should—as has been pointed out throughout the paper—address many issues with respect to a better understanding of achieving awareness and effortless coordination in face-to-face situations as well as conceiving and testing novel technology to mimic awareness displaying and monitoring over distance to keep the coordination effort to a minimum. The identified design tensions for awareness research with respect to availability, privacy, conventions, tailoring can be addressed by further development of theory, further empirical studies of the pros and cons of technologically-mediated awareness information; as well as the on-going exploration of technology.

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