Collaboration Support for Mobile Users in Ubiquitous Environments

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1 Introduction

The idea of supporting collaboration with computers goes back to the work done by Douglas C. Engelbart. In his seminal demonstration in 1968 [1], he introduced and demonstrated remote collaboration between two persons through sharing computer screens and using audio-visual communication channels over a network.

However, it took almost twenty years before the vision introduced by Engelbart was taken further. Approximately at the same time period when ubiquitous computing research was taking shape in research laboratories around the word, CSCW (Computer Supported Cooperative Work) was also emerging as a research field concerned with the role of (networked) computers as mediators of the interactions taking place among people. CSCW can be described "*as an endeavor to understand the nature and requirements of cooperative work with the objective of designing computer-based technologies for cooperative work arrangements*." [2]. The first CSCW conference was held in 1986 in Austin, Texas, USA [3]. In the early years, focus of research within CSCW has mainly been on supporting geographically distributed actors. This effort aimed often at providing virtual spaces that could promote collaboration by promoting mutual awareness, communication, and coordination, even when lacking the everyday natural modalities of interaction. Though the designed support has been mainly intended for distributed workers, different studies of cooperative settings made apparent that collaboration is very "physical". Our actions and interactions in the physical space constitute an important resource for the smooth and seamless conduct of collaboration in small groups [4]. Other research efforts also pointed out the need to support mobility of co-workers and the

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risk of binding users to desktop applications that support distributed but not mobile work [5]. In addition, collaboration happens not only in meeting rooms but also in hallways, coffee corners, streets, libraries etc. These properties, albeit obvious, has shown to pose challenging requirements to support technology.

Research in the field of Ambient Intelligence (AmI) and related fields of ubiquitous and pervasive computing shares many of the goals of CSCW with respect to natural and seamless interaction with ICT. We will investigate these common goals in this chapter. Although CSCW researchers have traditionally acknowledged the role of physical embodiment in collaboration, limitations of technology have prevented researchers from creating solutions that can fully support these properties of collaboration. Ambient intelligence supports an important part of human behaviour in general, and collaboration in particular, through its focus on physical spaces, physical resources and their technological support.

Our research agenda for *ubiquitous collaboration* is set to take advantage of research results in CSCW and AmI in order to create better solutions for supporting natural collaboration in co-located or distributed groups. In this chapter we will investigate some properties of collaborative work in small groups. We will provide a survey of some existing systems and platforms that support aspects of ubiquitous collaboration. We will later introduce the concept of a *human grid*, which we use to underpin our research on platforms for ubiquitous collaboration. We will outline Ubicollab, an open source platform that is being developed from ground up with a focus on supporting distributed ubiquitous collaboration.

2 Characteristics of Collaboration

Our focus in this chapter is on collaboration that happens in small groups of up to 10-15 people. Collaboration of course happens also in larger groups and organizations, but this type of small-scale collaboration has been studied extensively in CSCW, and its research problems are closely related to HCI and AmI. A number of theories have been proposed and used to analyze the subject of small groups using technology, and to propose improvements to such technological support. It is an ambitious goal to summarize and compare the various theories and we will not attempt at a thorough analysis here. However, we believe it is easy to observe a set of characteristics that are identified in most of collaboration theories and studies. The characteristics that we are interested in are those that lie directly in the intersection between CSCW and AmI. In this section we take a closer look at these characteristics.

2.1 Collaboration and Shared Context

In day-to-day collaboration scenarios we can distinguish among three types of information exchange mechanisms among collaborating parties [6]:

- Intentional communication: Information contained in explicit utterances that are exchanged between the participants. This includes both verbal and non-verbal (e.g. gesture) communication.
- Feedthrough: Information that is mediated through artifacts involved in collaboration. For instance, rearranging documents on a table might give a specific signal to collaborating parties.
- Consequential communication: Information that is generated due to the fact that our bodies and our body language are all visible to other parties.

This information is used to create what is called *awareness* in CSCW literature. Awareness can be defined as "*an understanding of the activities of others, which provides a context for your own activity*" [7]. The quality and the effectiveness of collaboration depend on proper access to awareness information by all parties involved. Awareness information relates to what in AmI is referred to as context. Awareness information contributes to create a *shared context* where sharing happens among collaborating parties.

There are a number of theories that have been used to explain cooperative work and inform the design of CSCW systems (see [8] for a discussion of the role of theories in CSCW). These theories propose to structure collaboration according to different criteria. This kind of structuring means that parts of the awareness information (or shared context) become more relevant based on which theory one is considering and what the structure means to the users. Examples of such theories include:

- Activity theory [9, 10]: According to this theory *activities* are the center of attention for collaborating individuals. An activity is an analytical collective phenomenon that consists of a *subject* (a person or a group with a motivation), an *object* (being produced or manipulated by the activity) and *tools* (used to mediate the relation between the subject and the object). Based on this model, shared context should emphasize the activities that the users are involved in, the users' relations to tools and objects, and the temporal development of these relations.
- Social worlds [11]: Social words is a theory initially developed by the sociologist Anselm Strauss. The locale framework was later developed to bridge the social worlds theory of Strauss into a more informative theory for technology development [12]. According to these theories, collaboration is structured within *social worlds*, or locales, and is carried on in a series of *actions* embedded in interactions. Interactions are carried out by *interactants* (individuals or groups or societies) who have their own identity, biography and perspective. Collections of interactions are the basis for *trajectories* that guide the development of social worlds in various ways.
- Distributed cognition [13]: A theory focusing on the representation of knowledge "*both inside the heads of the individuals and in the world*" [14]. This theory is a further development of cognitive theories which mainly focused on knowledge representation in brain. The unit of analysis here is not an activity or a social world, but a *cognitive system* composed of individuals and artifacts.

In this perspective, distributed cognition treats collaboration from a systems theory perspective: all pieces in the cognitive system are equally important for successful completion of collaboration.

- Situated action [15]: This theory is probably the one that imposes least structure on shared context. The assumption is that any structuring or planning of a collaborative effort and related context is a rationalization that can be done afterwards and not a priory to the effort. The unit of analysis in situated action theory is a *setting* that is contained in an *arena* [14]. A setting is the relationship between an individual and his/her surroundings (the arena). This means that relevant context is totally dependent on the individual (or group of individuals) who is currently relating to available context. Context that is important in one setting might be of no value in other settings.

The above theories are not the only ones, but illustrate the various focus on shared context, or awareness information, that is demonstrated within CSCW. These theories, through defining a system of concepts such as activity, social world, cognitive system, and setting, put different emphasis on what is considered important context. Although the sources of shared context are the same, the way this colleted information is grouped, presented and emphasized is different. In particular we can see the following differences in the theories:

- Their emphasis on goal and purpose: Activity theory has the largest focus on goal and purpose. An activity cannot exist without a purposeful subject who has an agenda/goal. Social world theory has a focus on goals at a larger scale or higher level (i.e. related to culture, identity), while distributed cognition and situated action are unclear about the importance of goals [14]. Goals and purpose are similar to user intent in AmI [16] and are quite challenging to model or acquire as context.
- Their flexibility in defining context structures: The situated action theory is most flexible with respect to context. According to this theory the emphasis on the different parts of the context is relative to the individual and the setting, and cannot be defined a priory. Therefore frameworks and systems need to be highly dynamic and flexible with respect to their context models [17]. The other models provide various levels of predefined structuring of context, but none are agnostic with respect to this structuring.
- Their emphasis on embodied action: This dimension will also be discussed later. Here it suffices to say that the different theories have different emphasis on how physically embodied the actions performed by individuals or groups are. Again, situated actions theory seems to be completely embodied in the physical settings. This means the way the physical environment (the settings) behaves during interactions with individuals or groups is the main determinant of how well collaboration is performed. Distributed cognition is quite similar to situated action, while the other theories put increased emphasis on the non-physical, i.e. the goal, motivations, culture, identity etc.

CSCW and AmI have clearly overlapping interest in studying context. In AmI context often relates to information about an individual's situation rather than information exchange among group members: "*Context is any information that can be used to characterise the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves*" [18]. While the information that constitutes context in AmI seems to be similar to awareness information in CSCW, the way the information is structured and used is often different. In CSCW, as demonstrated by the discussed theories, context is almost always relative to a group of people rather than individuals. Moreover, while in most AmI research context is used by the technological system to infer actions on behalf of the individual, in CSCW context is often used not only by the technological system but also by other group members as well [19].

2.2 Embodied Interactions and Artifacts as Resources

One important characteristic of natural collaboration, similar to any type of natural interaction, is that it is embodied in 3D physical spaces. The importance of this embodying is widely acknowledged both in CSCW and in AmI. The seminal paper by Harrison and Dourish [20] discussed the importance of space (in three dimensional sense), and place as referring to how we use spaces as resources: "*Space is the opportunity; place is the understood reality*". Some characteristics of 3D space according to [20] are: relational orientation and reciprocity, i.e. the fact that we share common points of reference in the same space (e.g. "down", "up", "left"); proximity and action, i.e. the fact that our actions are limited to our physical proximity; partitioning, i.e. the fact that distance and physical obstacles can be used to partition the physical room; and presence and awareness, the fact that physical space contains information about people and signs of their activities.

Mark Weiser put equal emphasis on embodying in physical space in his definition of ubiquitous computing, and tried to differentiate it from virtual reality: "*Indeed, the opposition between the notion of virtual reality and ubiquitous, invisible computing is so strong that some of us use the term 'embodied virtuality' to refer to the process of drawing computers out of their electronic shells. The virtuality of computer-readable data – all the different ways in which it can be altered, processed and analyzed – is brought into the physical world.*" [21]. In fact, the majority of the research in AmI and ubicomp draws upon the same idea that users are located in a physical world constituted by 3D spaces.

Not only the spaces we reside in, but also the artifacts contained in these spaces are essential resources for both CSCW and AmI, albeit with a different focus. In AmI, artifacts are largely regarded as specialized computer-human interaction resources that can provide greater degree of affordance and "calmness" than e.g. a desktop computer. Artifacts, such as "tabs, pads and boards" in [21] are used in AmI as a way of making technology disappear by making the interaction as natural as possible. A similar approach has been followed in HCI through e.g. tangible user interfaces [22].

In CSCW, artifacts play a widely acknowledged role as coordination mechanisms in small and large groups [23, 24], and as externalized knowledge [13], to name a few. All major CSCW theories include a notion of artifacts in different forms [14]. Affordance of physical artifacts, both at interaction and at collaboration level, has been studied. Physical artifacts are flexible, tangible, customizable, and portable [25]. In addition they improve collaboration by being predictable, supporting peripheral awareness, and enabling implicit communication [24].

2.3 Mobility of People and Resources

Mobility of people and resources is a common concern for AmI and CSCW. The role that mobility of people plays in collaboration has been documented well in the CSCW research literature also before mobile technologies were widespread [5, 26, 27]. In a study of a product design team, Bellotti and Bly [26] could document that only around 10% of the studied group members' time was spent at their desktop. The rest of the time was spent in meeting rooms, other colleagues' offices, model shops etc. Luff and Heath observed that micro- and macro-mobility helped individuals in London Underground to "*overhear and oversee the contributions of others, whilst rendering their own activities visible [to others]*" [5]. The role of mobility in informal communication is also well-documented [27]. In short, people move frequently in order to meet other people or access resources that are not available locally.

Being able to move freely while using technology is a prerequisite for making technology disappear. In fact, mobility research can be regarded as a precursor to AmI research [16] and mobility is regarded as one of the key enablers for AmI [28]. Mobility in AmI is related to both people and resources. A large amount of research in AmI and ubicomp is related to dynamically connecting people and resources as they move from one location to another.

2.4 Physical Distribution of People

The original idea of CSCW was to provide technological support not only for co-located groups but also, and maybe most crucially, to geographically distributed groups. Physical distribution is a reality of today's businesses, and poses hard challenges to CSCW systems. The type of rich interaction that is possible in face-to-face scenarios is reduced considerably when using technology as mediator [29]. Additionally, a number of studies show that informal communication, i.e. the type of unplanned opportunistic communication that is crucial for smooth coordination and cooperation, is severely reduced when people reside in geographically distributed spaces [26, 27].

Focus on physical distribution and related support for collaboration has been scarce in AmI research. Some research has studied how artifacts are used in shared spaces [30, 31], but this line of work does not consider how remote collaboration can be supported using shared artifacts.

2.5 Flexibility and the Need for Tailoring

Flexibility generically refers to the property of a system that makes it modifiable to satisfy new or changing needs of its users. Flexibility is a core aspect of cooperation support and it has been studied in relation to different dimensions. No two groups work in the same way. There are variations in knowledge, processes, preferences, task complexity etc.

Flexibility has been identified as a core issue in the adoption of media-spaces, i.e. systems providing a permanent audio and video link across two or more locations. Experiences with the adoption of an early system developed by Xerox show the importance of a system that can be tailored to adapt it to specific needs and conventions within a group of users [32]. This allows developing new functionalities that are relevant to the group and to develop and make explicit conventions about the group accepted usage of the system, for example concerning privacy. Flexibility has also been recognized as core with respect to support for managing task interdependencies, see e.g. [23, 33]. Flexibility allows in this perspective to adapt to local or global, temporary or permanent, changes in the way the work has to be coordinated. In addition there is a need to tailor to the preferences of individual users. This need is shared with many AmI applications that generally focus on the need for personalization. It is also important to point out that, especially in ubiquitous environments, systems must be flexible with respect to the technical context of use since they operate in environments that might be very different in terms of offered services and high dynamics [34]. Consider for example the technical complexity that is associated with the simple scenario of a person that is moving from one room to another, using a personal device to access services offered in the newly entered room.

Given the need for flexibility along different dimensions, it is often impossible to identify a set of predefined configurations that users or groups can select from. This has led to re-thinking the way systems are constructed, supporting the development of systems as composition of simpler services, often offering tools to empower users in the tailoring and programming of the support that they need. Seminal in this perspective in the area of CSCW is OVAL. This system was allowing users to create their own configurations of components and in this way define radically tailorable groupware systems fitting to their environments [35]. RAVE was also supporting tailorabily by allowing users to re-define the behavior of buttons and share the developed code within groups of users [32]. More recently, different research efforts have focused on identifying basic concepts and services that can be composed by users to create complex applications, also addressing the specific needs of end-user development of cooperative systems [36]. On the other hand, end user tailoring and programming has been identified as one of the major challenges also in AmI [37, 38]. In this perspective, the interests in the CSCW and AmI are rather complementary, the first focusing more on group issues and the second on flexibility with respect to the technical environment and personalization.

3 Existing Technology in Support of Ubiquitous Collaboration

The CSCW research field started when mobile and ubiquitous technologies were not commonplace. Although sociological and ethnographical studies of groups showed clearly the need for ubiquity and physicality, initial technologies were often bound to the desktop and tried to simulate natural interactions in different ways. For instance, a number of CSCW frameworks and systems tried to simulate the properties of the physical space in form of virtual spaces [39, 40]. Additionally, the seminal work on media spaces in Xerox PARC [41] and other related work tried to use multimedia channels such as audio and video to extend these properties of physical space beyond physical distances. A number of early awareness systems used ubiquitous computing technologies to support informal impromptu communication [42].

As a result of the interest in applying sociological theories to design, a number of CSCW systems were informed by specific theories. Social worlds and the locale framework were used to implement Orbit [43], a flexible desktop-based groupware. Situated action, pointing out the problems connected to defining and formalizing plans, has inspired a number of systems that provide flexible means of interactions rather than attempting a formalization of work [44]. Key in supporting collaboration in these systems is the provision of means to promote awareness. For example, room-based groupware such as TeamRooms [45] and related shared workspace awareness systems [6] support a high level of flexibility and tailorability with respect to context modeling (albeit all in virtual rooms). Activity theory has also inspired research in CSCW and, to a more limited extent, the development of a number of systems, as for example a technological framework called ABC [46] with support for ubiquity in hospital work.

Within the area of AmI and ubicomp the issue of collaboration support has been addressed by a few of systems. The Speakeasy platform and the Casca collaborative application built on top if it [47] supported peer-to-peer setup of group areas, and allowed users to connect to physical resources using resource discovery mechanisms. The Interactive Workspaces project [48] focused on physical resources such as shared displays and projectors in meeting rooms, and collaborative interaction with these. Another system called BEACH (Basic Environment for Active Collaboration with Hypermedia) [49] was used to implement the concept of roomware, which are room elements with integrated information technology such as interactive tables, walls, or chairs. A number of systems have also been developed lately focusing on the use of shared physical displays in public spaces and how these can support collocated or distributed collaboration [50, 51]. Experiences with this type of systems pointed out that their design and deployment arise a number of challenges in terms of hereogeneity and dynamism of the environment, robustness and interaction techniques [34]. Physical interfaces have also been suggested as a way to promote embedded interaction and phidgets (physical widgets) are provided to support their rapid development [52].

In the area of mobility we can see a recent popularity in making conventional groupware applications mobile. This can be regarded as a first step in the right direction, although most of these mobile groupware applications are merely a miniaturized version of their desktop ancestors. This means that specific requirements for mobility are yet to be supported. The use of location and sharing of other simple context information is also supported in some of these systems [53].

The proliferation of mobile and ambient systems targeting groups shows an increasing interest in supporting ubiquitous collaboration. As outlined in the review above, there is an increasing awareness of the need to develop frameworks and platforms to provide developers and users with flexible and tailorable tools. The work described in the following sections falls within this line of research. *UbiCollab* is a platform for the development of ubiquitous applications to support cooperation among distributed users. The platform is based on the core notion of *Human Grid*. The Human Grid is a unifying implementational concept that has been developed based on the study of existing theories and systems. This concept will be outlined in the next section, and an initial implementation of UbiCollab will be described using a simple example application.

4 Human Grid as a Unifying Concept for AmI and CSCW

The concept of a *human grid* [54] constitutes our vision of ubiquitous collaboration. A human grid denotes a collection of (geographically distributed) users and the resources each of them has available in their physical vicinity. Figure 1 shows an instance of a typical human grid. A human grid exists for each collaborative activity that a group of users is engaged in. The individuals in a human grid are connected to each other using communication technologies. The resources each user wishes to use in the collaboration are also connected to the human grid using communication technologies. Interactions among the users are supported using the resources and the communication across physical spaces.

The core part of a human grid is the *collaboration instance* (for short CI, shown in the middle of Figure 1) and its human *participants*. The CI acts as a shared context for collaboration. Information in a CI can be grouped and represented according to the needs and the habits of the users. A CI can contain shared information organized in different ways in order to support different views of collaboration. For instance, a CI can represent an activity, a social world, a locale, a cognitive system, or a setting.

Participants of a CI will physically inhabit *collaboration spaces* (for short CS). Collaboration spaces represent physical spaces (such as offices, streets, homes) where CI participants reside in the course of their collaboration with other participants. A CS can be used in a human grid as a resource for collaboration. A CI participant becomes an *inhabitant* of a CS when he/she physically enters that CS. It is up to the CI participants to decide how they want to represent and use their collaboration spaces in a human grid.

Each CS can contain physical and digital *resources* that become available to the human grid once a CI participant inhabits a CS. Typical resources in an office environment include projectors, whiteboards, printers, and file servers. In a home environment resources might be TVs, media servers, electrical equipments such as lamps, heaters etc. Although resources are owned by individual CI participants, a participant can allow other participants in the human grid to use and control his/her resources. For instance, in an office setting a participant can use projectors in multiple meeting rooms to show a presentation to all the CI participants.

Resources in a human grid are deployed for collaboration using *applications*. Applications implement the collaboration logic necessary for each CI. A simple application in an office-related CI might be a slide presentation application that will use a set of resources such as projectors, microphones, speakers and file servers located in various CSs. In addition to implementing collaboration logic, applications are responsible for what we call *publication* and *actualization* in a human grid. Publication and actualization are the mechanisms that help implement shared context. Ambient information collected from various CSs (using resources as sensors) is *published* to a CI by applications. For instance, a presence application might publish

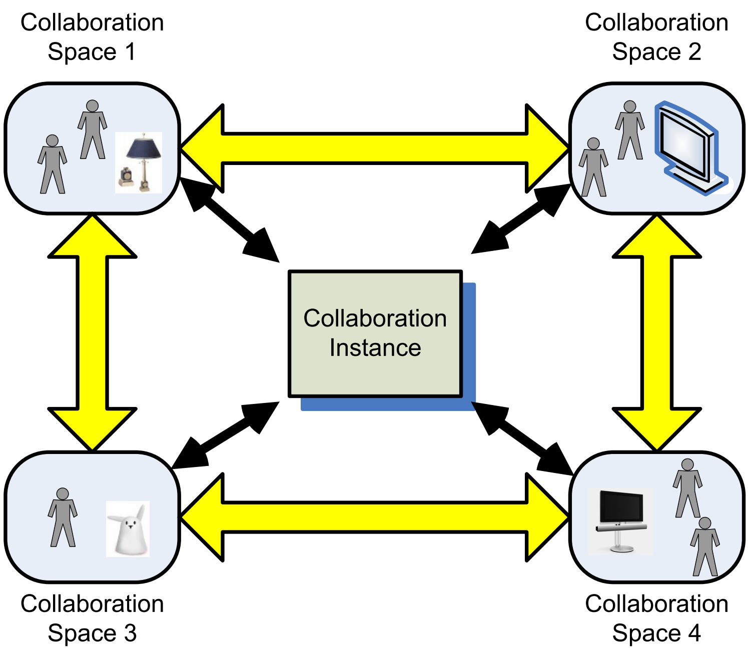

Fig. 1 The Human Grid

the state of a light sensor (a resource) in an office (a CS) into a CI. This published information can be used by other application to *actualize* actions. In this case, the fact that the light is off might trigger an action such as locking the door.

In the next section we will present a simple application that is prototyped in order to demonstrate the human grid concept. This application is implemented on top of our experimental platform called UbiCollab. UbiCollab will be described later.

4.1 The Example of UbiBuddy

One of the most popular collaborative applications nowadays is the buddy list. A buddy list application provides a "live" list of close friends (buddies) and information about their online status (often called awareness, availability or presence information). As buddies go online and offline, the user is notified through peripheral notices. These notices can remind or motivate the user to initiate an informal, opportunistic communication with his/her buddies, or just keep an eye on their activities. Communication is often done using text messages (often called instant messages) and in recent versions more and more through audio and video channels. Each user can control his/her availability to others by personalizing the application.

UbiBuddy (see Figure 2) is an enhanced buddy list application implemented using the human grid concept. UbiBuddy tries to address some shortcomings of available buddy list applications:

- *Limited support for collaboration context* - Generally buddy list applications are built assuming flat social networks, i.e. individuals are either available to all their buddies or to none of them. UbiBuddy, on the other hand, allows individuals to define multiple buddy groups (in form of CIs) and switch among these groups. Each of these groups represents a separate human grid with specifically associated participants (buddies). Individuals can enter and exit buddy

Fig. 2 UbiBuddy integrates with physical artifacts and devices surrounding its user

groups instead of going totally online or offline. A user can e.g. decide to be online/available to a group of his/her colleagues in a specific project, and be offline/unavailable to all his/her other colleagues.

- *Limited support for mobility* - Support for mobility in conventional buddy list applications normally means running the application on mobile devices. This in general means that the same exact functionality is provided through smaller keyboards and screens. In most cases the main advantage of providing peripheral notices about buddies is lost because the application is often not in continuous line of sight anymore (as opposed to when running on a desktop computer screen) but is in user's pocket. Some of these applications also provide location awareness in terms of individuals' positions fetched from their mobile device. In UbiBuddy mobility of individuals is supported by allowing participants in a buddy group to define collaboration spaces (CSs) using meaningful information. UbiBuddy users will see each other as being at "home" or in the "office" instead of as being a "dot on the map". In addition, peripheral notices are supported through directing information in a buddy group to various resources available in a CS (see also next point). For instance changes in a user's online status can be actualized by turning on/off a lamp in the living room (see Figure 2.C).
- *Lack of connection to the physical context* - Conventional buddy list applications not only have a limited array of output channels for displaying presence and availability information, but also a limited set of input sources for collecting information about users' context (often limited to keyboard and mouse activities). By using the concept of a resource in a human grid, UbiBuddy can use physical resources in users' surroundings as both sensors and displays of presence information (Figure 2.C). For instance, turning the light off in a user's bedroom can set the user's availability to offline.

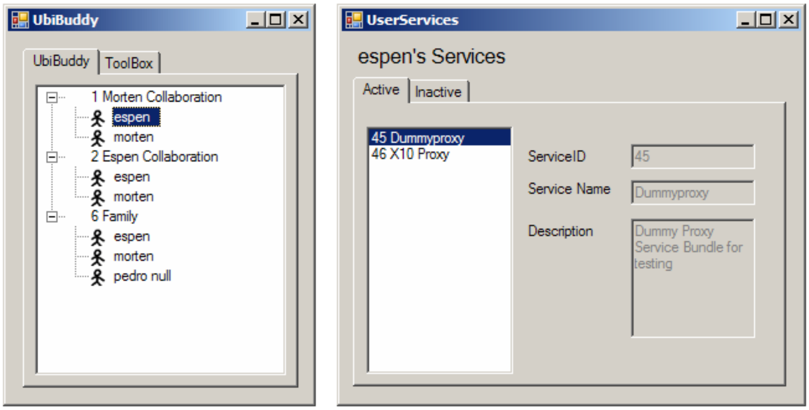

Fig. 3 UbiBuddy main window and context details window

UbiBuddy is implemented as an application on top of our experimental platform called UbiCollab. UbiBuddy's GUI is very similar to a normal buddy list but with some significant differences:

- The main overview window, which is shown when the user starts UbiBuddy (see left side of Figure 3) gives an overview of all the buddy groups that a user has set up, and an overview of who else is online in each group. The user can also use this window to manually control own availability in each group.
- The buddy group details window, which is shown when the user clicks on a group in the main window. Once in this window, the user can see more details about the group such as a list of all participants, their location and the resources they have shared in the group.
- The buddy details window (see right side of Figure 3), which allows a user to see more details about a specific buddy, e.g. what CS each buddy inhabits and which services each buddy has shared in that group.

In addition, a number of generic UbiCollab tools and applications are integrated in UbiBuddy. These tools are common to all UbiCollab applications and allow individuals to create and manage CIs (see Figure 4), CSs, resources and applications. More information on these tools will be provided in the section on UC architecture.

To summarize, UbiBuddy demonstrates the human grid concept by defining buddy groups as CIs, while physical resources are used as sources and displays of presence information in a manner true to AmI and ubicomp. Collaboration spaces are used to locate users and resources, and to publish and actualize presence information in the correct way. The logic to handle changes to the availability of buddies (e.g. going offline for colleagues when at home) is done by UbiBuddy itself, which is implemented in form of an application.

In the following sections we will provide a short analysis, using UbiBuddy as an example, of how the concept of human grid supports the various characteristics of collaboration discussed earlier.

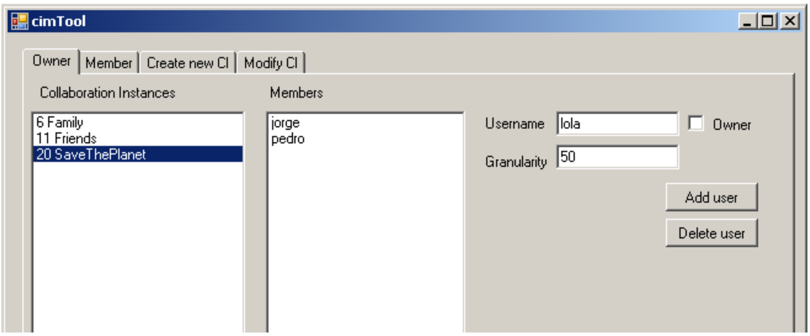

Fig. 4 CI Manager GUI

4.2 Shared Context in Human Grid

Shared context in collaborative work can take different forms. In the case of UbiBuddy, for instance, shared context is limited to sharing of availability information about the members of a buddy group. Although the basic idea in most scenarios is to make information available to all collaborating parties, the nature of this information, the way the information is organized, presented etc. varies greatly. As we have discussed earlier, different collaboration theories (and the systems developed based on these theories) structure and emphasize shared context in different ways. The concept of a collaboration instance tries to capture this variety by providing the basic sharing mechanism without presuming specific structures. Beside some basic administrative information, applications have full control over what information is shared in a CI and how this information is structured/presented. CI in this way can be regarded as a common information space [55] in the sense that the content and the format of this content or "packaging" of the information is defined by the participants. Of course this puts greater demand on supporting the process of agreement and social construction of meaning among the participants. Additionally, flexibility is needed at the application level in order to easily manipulate such information.

4.3 Embodiment in Human Grid

Human grid supports embodiment by both defining the concept of a collaboration space (CS), and allowing the inclusion of people and (physical) resources in these spaces. Using CSs helps promote embodiment in two ways. First, individuals are able to define meaningful representations of familiar spaces (e.g. "My home") and even create a shared meaning for a CS used in a human grid (e.g. "Babak's home"). Second, information about whereabouts of individuals can be used to adapt system behavior, as envisioned in many AmI scenarios. For instance, in UbiBuddy, a participant's online status can automatically be set to offline whenever that participant inhabits the CS "My home".

Resources in a human grid are also used to strengthen embodied action. In UbiBuddy, a participant in a buddy group might control his/her availability by turning on or off the lights in his office. Additionally, associating resources to collaboration spaces allows for some degree of automatic reconfiguration of available resources. This means that, in the example above, the light switch is a resource that might be available only in the office, while at home other resources are used to signal the same action (e.g. turning on or off the TV). This access to resources can be automatically adjusted, and information provided to the users[1].

[1] Note that in UbiCollab we also implement two default collaboration spaces called "Body" and "Web". The Body CS includes all resources that the user carries with her (e.g. mobile phone, portable music player) and are normally available to the user everywhere. The Web CS includes all web services and similar online software services that are available on the internet, and thus can be used everywhere.

4.4 Mobility in Human Grid

Mobility is supported by allowing users to move from one CS to another, and continue to use their applications without any interruptions. Applications are associated with CIs. This means, as long as individuals are participating in the same CI, their applications will have access to the proper resources in emerging collaboration spaces as they move from one CS to another.

In cases where CSs are predefined, such as "home" or "office", mobility in human grid is similar to nomadic mobility where collaboration happens in familiar spaces. In order to support more spontaneous mobility in unfamiliar spaces we have defined a special CS called "Body". The Body space is used to contain resources that the user carries with her/him, i.e. portable resources. Additionally, in our UbiCollab platform we are also working on supporting the rapid creation of temporary spaces that will further facilitate full mobility beyond nomadic scenarios.

4.5 Support for Physical Distribution in Human Grid

Geographic distribution is inherently supported in human grid by assuming that participants in a CI inhabit collaboration spaces that are by default disjoint. Shared context contained in the CI is one way by which inhabitants of different CSs communicate with each other. Depending on the application area, necessary shared context is distributed among CSs by applications publishing and actualizing information. Additionally, we assume that different levels of communication will be supported by direct communication among the resources that reside in different CSs. For instance, a video camera in one CS might be connected to a TV screen in another CS. This kind of communication can potentially have a high level of dynamism and media richness. Moreover, resources in distant CSs can be controlled by remote participants. For instance, the inhabitant of one CS can use a screen in a remote CS in order to display a document.

The way shared physical resources and artifacts are used in distributed collaboration is an open research topic. Empirical research and observations are needed in order to both learn how people will choose to utilize such possibilities, and how the affordances of such resources need to be changed in order to better support these collaboration scenarios.

4.6 Flexibility and Tailoring in a Human Grid

The concept of human grid is an acknowledgement of the fact that technology-based collaboration support needs to be flexible enough in order to fit into emerging and dynamic scenarios. A human grid does not make any strict assumptions about the type of collaboration that will happen. It presumes only the very basic properties that are common to most types of collaboration and supported by the majority of collaboration theories discussed earlier. More detailed description of each of these properties is left to the specific application of human grid in various collaboration domains. E.g. the type of resources and spaces used in collaboration will vary from one human grid to another, and the information sharing needs of various groups will be different.

On the other hand, the vision of ambient intelligence assumes a level of pro-activeness in order to help users get rid of the routine tasks involved in everyday activities. To this end, the concept of human grid provides a number of features that we might call "adaptability primitives" (i.e. the concepts of CI, CS, resources, and applications). These features don't implement pro-activeness per se, but allow pro-active applications to be implemented effectively. The underlying technological platform that will implement the human grid concept will play a central role in providing this flexibility to application developers, and at the same time allowing the level of pro-activeness desired for each application domain. The following sections will describe the overall architecture of our experimental platform that is used to implement a proof-of-concept human grid environment.

5 Implementation of Human Grid: The UbiCollab Platform

The concept of human grid is being implemented in form of an experimental platform called UbiCollab[2]. In UbiCollab, multiple human grids are realized inside a peer-to-peer network called a *UbiNetwork* (See Figure 5). Each peer in a UbiNetwork is called a *UbiNode*, and belongs to one UbiCollab user. The UbiNode plays the role of an identifier for the user, and also contains the UbiCollab platform. UbiNodes are typically mobile devices (PDAs in the current implementation of UbiCollab). Stationary UbiNodes are also possible, and typically belong to users who are not mobile but who provide online community services to a UbiNetwork.

Each UbiNode communicates directly with the resources in the physical space where its owner resides. Resources are discovered using UbiCollab's resource discovery mechanisms (see below). Resources are external to UbiCollab and use their own native communication protocols. They are therefore accessed within UbiCollab using *Proxy Services* (described shortly). Proxy Services are similar to drivers in an operative system (e.g. printer drivers). They run on the user's UbiNode and implement a uniform way of communicating with the various resources.

UbiCollab's functionality is implemented in form of independent services called *Platform Services*. Platform Services run on the user's UbiNode and communicate with their peers on other UbiNodes in the UbiNetwork.

[2] www.ubicollab.org

5.1 UbiNode Overall Architecture

UbiCollab platform is fully deployed on each UbiNode, as shown in Figure 6. The UbiCollab Platform Services are implemented as independent modules that reside in a container on user's UbiNode (rectangles in the left side of the UbiNode in Figure 6). Independent here means that they can be installed and used by their own, without requiring the other Platform Services in order to function. Each of these Platform Services implements a part of UbiCollab functionality. The pentagons in the right side of the UbiNode in Figure 6 denote the Proxy Services that each UbiCollab user will have to install in order to access external resources. The left side of the UbiNode is called the *platform space*, and the right side is called the *user space*. The current implementation of UbiCollab uses OSGi (Open Services Gateway initiative[3]) as container. UbiCollab platform services are deployed as OSGi bundles (bundles are java files that implement services in OSGi). OSGi supports dynamic deployment (i.e. runtime installation or upgrade of bundles) and provides an easy way to export services using web standards. Dynamic deployment means that not only new versions of Platform Services can be installed in runtime, but more importantly Proxy Services can be installed on the run as users encounter new resources in their physical surroundings.

UbiCollab currently consists of the following Platform Services, each of them implementing a part of the human grid concept:

- CI manager: Responsible for creation and maintenance of Collaboration Instances.

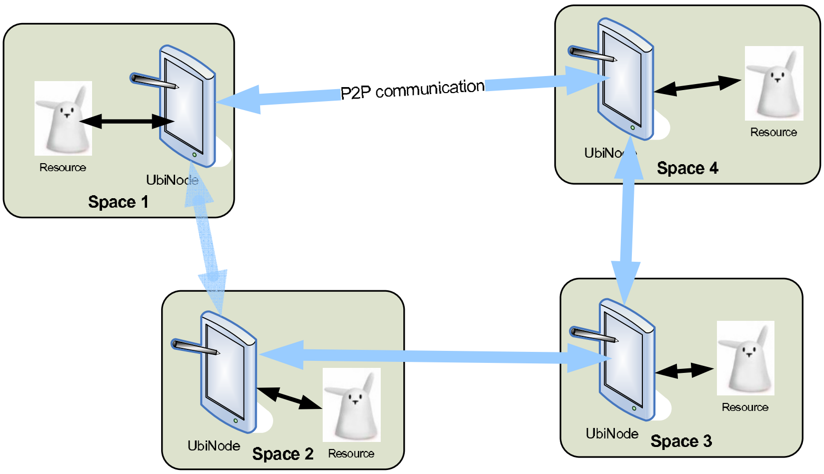

Fig. 5 A sample UbiNetwork with four UbiNodes

[3] www.osgi.org

- Session Manager: Responsible for implementing a runtime environment for the applications.
- CS manager: Responsible for creation and maintenance of Collaboration Spaces.
- Service Domain (SD) manager: Responsible for maintaining and managing the user's Proxy Services.
- Resource Discovery (RD) manager: Responsible for finding external resources.
- Identity manager: Allows users to create multiple virtual identities to represent themselves in the platform and when using external resources.

The following sections will describe briefly each of UbiCollab's Platform Services.

5.2 Collaboration Instance Manager

The main job of the Collaboration Instance Manager (CI Manager) is to make sure that the information in a CI is always up-to-date for all human grid members, and that only members of a CI can access this information. This is shown in Figure 7. In this figure, each UbiCollab user Tom, Jan, Dennis, Robert and Lisa have their own UbiNode with CI Manager installed on it. Jan and Tom are members of a CI called "Golf club". CI Manager makes sure that any information Jan or Tom publish into the CI is synchronized with the UbiNode of the other participant. CI Manager communicates with CI Managers of other participants in a peer-to-peer fashion. Information in a CI is stored as files in a standard file and folder system. This means that applications have full flexibility in storing any information they need in a CI.

CI Manager provides the following API towards UbiCollab applications:

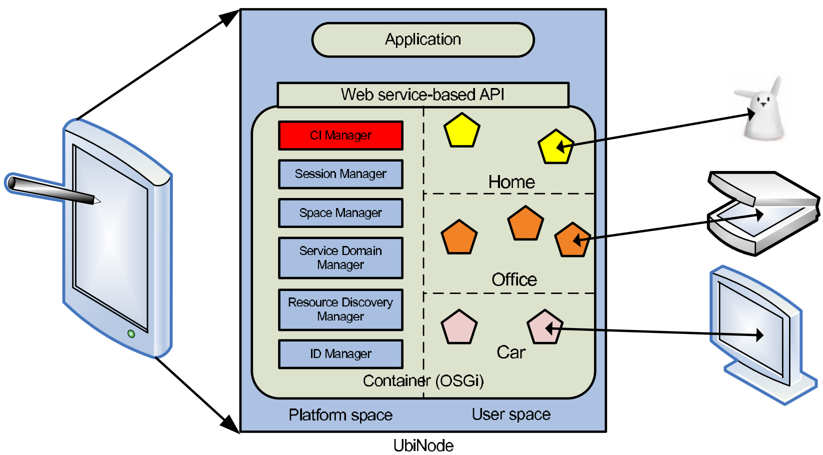

Fig. 6 The architecture of a UbiNode

- CI Management: Allow users to create, delete, rename and annotate CIs, and to invite and remove members from a CI.
- Information publication: Allow applications or users to write information (files) into a CI. This information is then synchronized with CI Managers of other CI participants.
- Change notifications: Once CI information is changed by one CI participant's application, other applications are notified about the change.
- Participant lookup: CI Manager uses peer discovery in order to find the CI participants within the UbiNetwork. Currently JXTA's[4] lookup mechanisms are used for this, but we can think of scenarios where more restrict registry-based lookup can be implemented.

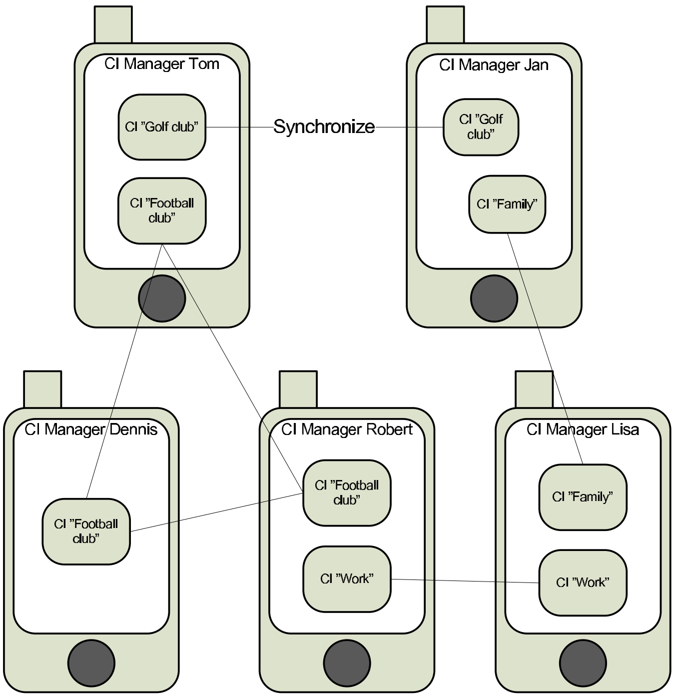

Fig. 7 CI Manager and synchronization of CIs

[4] JXTA (www.jxta.org) is a java-based peer-to-peer framework that is used in the current implementation of UbiCollab.

5.3 Session Manager

Applications in UbiCollab are realized as a combination of Proxy and Platform services. The specific combination of these services is specified in form of an *Application Template*. Application Templates are XML-based declarative information and are handled by the Session Manager. The user runs an application by providing the Session Manager with a link to the application's template. Session Manager then creates a Session for the application and takes care of allocating needed resources to the application. Additionally, Session Manager is also in charge of handling user mobility by switching to new resources as they become available due to users moving from one space to another [56].

5.4 Collaboration Space Manager

Collaboration Spaces (CS) are representations of bounded physical locations that users normally reside in. Space Manager provides an API that allows users and applications to perform the following:

- CS Management: Define and manage CSs by tagging physical coordinates. Coordinates can be detected automatically using a position sensor, or users can enter coordinates manually. Users can then annotate these definitions based on a flexible internal CS model.
- Locating users: CS Manager can return a user's current location. The location is identified by either providing the CS Manager with the GPS (Global Positioning System) coordinates for the user (acquired e.g. automatically through a GPS sensor, or entered manually) or by the user manually setting an existing CS as his/her current location. CS Manager then returns zero or more matching CSs that indicate to the applications where the user is. Automatic acquisition of location is tried out in form of Bluetooth-enabled GPS sensors that are discovered and installed in each user's Service Domain (see below for Service Domains).
- Location-tagging of resources: CS Manager is used to tag newly discovered resources with a CS tag. This is useful for embedded resources such as a projector or a printer in a meeting room. CS tags for resources are used to provide context-aware access to Services that are physically available to the user.

CS Manager also defines two default CSs for its user: a Web Space for online services (such as a file sharing service) and a Body Space for wearable devices (such as MP3 players or GPS sensors carried around by the user).

This set of simple location-based services allows UC applications to know where each user is and what resources each user has access to. The level of automation can be varied from full automation using various positioning services to fully manual by the user entering all the information. CS Manager has an associated management GUI to allow users manually adjust and change CS-related information. In addition, we are working on defining a standard CS exchange format in order to allow users exchange their CS definitions. This can be a useful functionality in situations where a number of standard "rooms" are defined. For instance, a user entering a museum can download a predefined set of CSs with extended information about the rooms in the museum.

5.5 Service Domain Manager

Resources in UbiCollab denote external resources such as devices, artifacts, and web services. In UC, the process of making these resources available to the applications is called *Proxy Service installation*. Proxy Service installation is analogous to installing a driver (e.g. printer) on a laptop computer. In Figure 6 these Proxy Services are shown as pentagons. An installed Proxy Service resides in user's Service Domain (SD) and can be used by applications through its API. A Proxy Service might also implement additional functionality such as a local client GUI, security and logon mechanisms. The SD Manager in UC provides a set of functions to make the accessing and management of the SD easy for both the user and the applications:

- Proxy Service installation: An external resource can be installed as a Proxy Service in the SD by providing the SD Manager a URL to its Proxy Service code. SD Manager will then download the Proxy Service code and add it to the user's SD. The URL can be entered either manually or using the Resource Discovery Manager (see below).
- SD maintenance: Proxy Services can be deleted (when not needed anymore), and the user can change their associated meta-data. Such meta-data includes the location of the resources (i.e. the Collaboration Space), and additional information such as human-understandable descriptions.
- Sharing of services: SD Manager allows users to assign user name and password to Proxy Services (see also ID Manager below), assign different levels of access to the Proxy Services, and create a secure URL to these that can be included in a Collaboration Instance. In this way other users in a CI can access and control.

5.6 Resource Discovery Manager

Resource Discovery (RD) Manager implements user-friendly mechanisms for accessing and integrating external resources in UC. Discovery of resources can be done in many different ways, and a good number of discovery mechanisms are already implemented by others. In UC we wanted to avoid creating yet another discovery protocol. RD Manager uses so-called discovery plug-ins to enable interaction with native discovery mechanisms. For instance, a plug-in which is already implemented uses an RFID reader pen to read an RFID tag from a resource. All plug-ins return a URL to the Proxy Service code (an OSGi bundle) for the discovered resource. This URL can be passed to SD Manager, which will use it to install the Proxy Service in user's Service Domain.

5.7 Identity Manager

Identity (ID) Manager is a recent module under development for UC. ID Manager is in charge of facilitating personalization and preserving the privacy of UC users. ID Manager allows the user to create a *personal profile*. This profile contains values for various parameters that the user has set for personalizing services. For instance, the printer service will have a placeholder in user's profile with user-set values (such as double-sided printing). The user can also use the ID Manager to create an arbitrary number of *virtual IDs*. Each virtual ID (VID) has a pseudo-name (nick-name) and a password. Each VID provides access to a subset of the personal profile data, in this way allowing for anonymous access and personalization of various services. ID Manager is under development and will be integrated fully in the UC platform. The goal is that all services (Proxy and Platform services) will support VID-based authentication and personalization. ID Manager supports the following functions:

- Profile management: Create and maintain the personal profile, with areas associated to service types that the user normally uses.
- VID management: Create and manage VIDs, and associate VIDs to various services.
- User management: Connect to community services for verification and trust management related to VIDs.

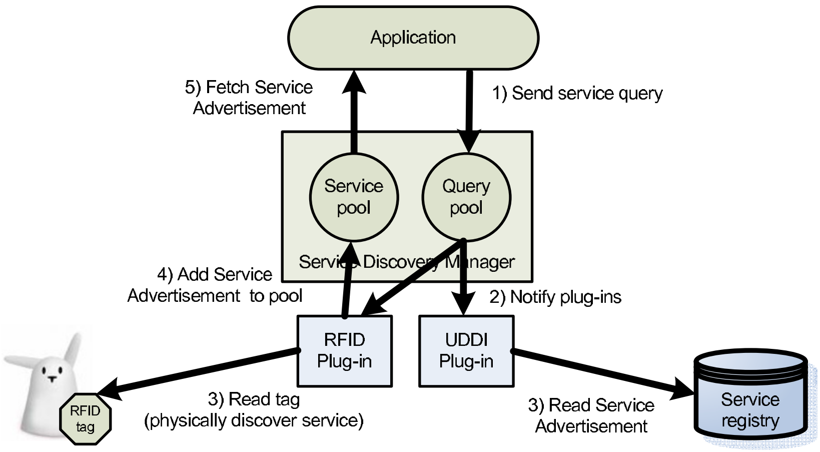

Fig. 8 Various steps in the resource discovery process

6 Conclusions

In this chapter we have discussed the concept of ubiquitous collaboration, and have presented an overview of existing technologies to support it. We have also outlined our own research in this area in form of the concept of human grid and the experimental UbiCollab platform. We have deliberately focused on supporting the "mechanics" of ubiquitous collaboration in UbiCollab. UbiCollab in its current form supports the basic functions. These basic functions (and their robust functioning) are our main short term goal. In the long term we are looking into implementing additional components in UbiCollab. We believe providing an open platform where components can be added and removed freely is necessary for a sustainable platform.

Research in AmI provides a number of advances in technology that are highly relevant to CSCW. On the other hand, supporting social interactions in small and large groups should be considered as a natural development within AmI and ubicomp. We can regard the development from single user (HCI) to multiuser (CSCW) as what will also happen to Ambient Intelligence. In our view future AmI will be some form of "Ambient Collective Intelligence". Some of the important questions to ask in this respect are:

- How can advances in context acquisition and processing in AmI be used in CSCW in order to implement shared context, improve awareness and support group processes? How can theories from CSCW be used to make better and more informed use of available context in AmI?
- How can connected artifacts, such as mobile and embedded devices, be used in collaboration? How can the notion of artifact as studied in CSCW as a resource for collaboration enrich the notion of physical connected objects in AmI? How is meaning created by using shared physical artifacts over geographical distances?
- How can designs and innovations in end user configuration from AmI be used to facilitate adaptation and tailoring of technology to the needs of groups? What does it mean to personalize a shared space? What are the best processes for tailoring shared smart spaces? How will we handle conflicts?
- How can AmI spaces be used from a distance? How can context from one space be shared with another space when groups are distributed across geographical distances?
- How will pro-active AmI technologies behave in a group context?

In our research we treat AmI as fundamentally collaborative. In real life there are very few AmI spaces that are "single user". At the same time, in order for CSCW to support anything close to natural face-to-face collaboration, we need to move away from the desktop and focus on natural physical surroundings of collaborating parties. Ubiquitous collaboration support is a compelling research field and we can already see innovative technologies that aim at addressing this shared challenge.

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References

[1] Engelbart, D.C., English, W.K.: A research center for augmenting human intellect. In: Proceedings AFIPS Fall Joint Computer Conference, San Francisco, CA, USA, AFIPS (1968) 395–410

[2] Bannon, L., Schmidt, K.: CSCW: Four characters in search of a context. In Bowers, J.M., Benford, S.D., eds.: Studies in Computer Supported Cooperative Work. Theory, Practice and Design. North-Holland, Amsterdam (1991) 3–16

[3] Krasner, H., Greif, I., eds.: Proceedings of the 1986 ACM conference on Computer-supported cooperative work. ACM, New York, N.Y., Austin, Texas, December 3-5, 1986 (1986)

[4] Olson, J.S., Teasley, S.D., Covi, L., Olson, G.M.S.: The (currently) unique advantages of collocated work. In Hinds, P., Kiesler, S., eds.: Distributed Work. MIT Press, Cambridge, MA (2002) 113–135

[5] Luff, P., Heath, C.: Mobility in collaboration. In: Proceedings CSCW, ACM Press (1998) 305–314

[6] Gutwin, C., Greenberg, S.: A descriptive framework of workspace awareness for real-time groupware. CSCW **11** (2002) 411–446

[7] Dourish, P., Bellotti, V.: Awareness and coordination in shared workspaces. In: Proceedings CSCW, Toronto, Ontario, Canada, ACM (1992) 107–114

[8] Halverson, C.A.: Activity theory and distributed cognition: Or what does cscw need to do with theories? Computer Supported Cooperative Work (CSCW) **11** (2002) 243–267

[9] Kaptelinin, V., Nardi, B.A.: Acting with Technology: Activity Theory and Interaction Design. The MIT Press (2006)

[10] Kuutti, K.: The concept of activity as a basic unit of analysis for CSCW research. In: Proceeding ECSCW, Amsterdam, The Netherlands, Springer (1991)

[11] Fitzpatrick, G., Tolone, W.J., Kaplan, S.M.: Work, locales and distributed social worlds. In: Proceedings ECSCW, Stockholm, Sweden, Springer (1995)

[12] Fitzpatrick, G.: The Locales Framework: Understanding and designing for Wicked Problems. Kluwer Academic Publishers (2003)

[13] Hutchins, E.: Cognition in the Wild. The MIT Press, Cambridge, MA (1995)

[14] Nardi, B.A.: Studying context: A comparison of activity theory, situated action models, and distributed cognition. In Nardi, B.A., ed.: Context and Consciousness. The MIT Press, Cambridge, Massachusetts (1995) 69–102

[15] Suchman, L.A.: Plans and Situated Actions: The Problem of Human-machine Communication. Cambridge University Press, Cambridge (1987)
[16] Satyanarayanan, M.: Pervasive computing: Vision and challenges. IEEE Personal Communications **8** (2001) 10–17
[17] Greenberg, S.: Context as a dynamic construct. Human-Computer Interaction **16** (2001) 257–268
[18] Dey, A.K.: Understanding and using context. Personal and Ubiquitous Computing **5** (2001) 4–7
[19] Edwards, W.K.: Putting computing in context: An infrastructure to support extensible context-enhanced collaborative applications. ACM Transactions on Computer-Human Interaction **12** (2005) 446–474
[20] Harrison, S., Dourish, P.: Re-place-ing space: The roles of place and space in collaborative systems. In: Proceedings of CSCW, Boston, Massachusetts, USA, ACM Press (1996) 67–76
[21] Weiser, M.: The computer for the twenty-first century. Scientific American **265** (1991) 94–104
[22] Ishii, H., Ullmer, B.: Tangible bits: Towards seamless interfaces between people, bits and atoms. In: Proceedings of the SIGCHI conference on Human factors in computing systems, ACM Press (1997) 234–241
[23] Schmidt, K., Simone, C.: Coordination mechanisms: Towards a conceptual foundation for CSCW systems design. Computer Supported Cooperative Work (CSCW). An International Journal **5** (1996) 155–200
[24] Robinson, M.: Design for unanticipated use... In: Proceedings ECSCW, Amsterdam, The Netherlands, Springer (1991) 195
[25] Nomura, S., Edwin, H., Barbara, E.H.: The uses of paper in commercial airline flight operations (2006)
[26] Bellotti, V., Bly, S.: Walking away from the desktop computer: Distributed collaboration and mobility in a product design team. In: Proceedings CSCW, Boston, Massachusetts, United States, ACM (1996) 209–218
[27] Kraut, R.E.e.a.: Informal communication in organizations: Form, function, and technology. In Oskamp, S., Spacapan, S., eds.: People's reactions to technology in factories, offices, and aerospace. Sage Publications (1990) 145–199
[28] ISTAG: Scenarios for ambient intelligence in 2010. Technical report, EU (2001)
[29] Covi, L.M., Olson, J.S., Rocco, E., Miller, W.J., Allie, P.: A room of your own: What do we learn about support of teamwork from assessing teams in dedicated project rooms. In: Proceedings CoBuild. (1998)
[30] Brush, A., Inkpen, K.: Yours, mine and ours? Sharing and use of technology in domestic environments. In: Proceedings UbiComp. Springer (2007) 109–126
[31] Neustaedter, C., Brush, A.J.B., Greenberg, S.: 'The calendar is crucial': Coordination and awareness through the family calendar. ACM Transactions on Computer Human Interactions **In press** (2009)
[32] Mackay, W.: Media spaces: Environments for informal multimedia interaction. In Beaudouin-Lafon, M., ed.: Computer Supported Co-operative Work. John Wiley & Sons, Chichester, UK (1999) 55–82

[33] Abbott, K.R., Sarin, S.K.: Experiences with workflow management: Issues for the next generation. In Neuwirth, R.F., Christine, eds.: Proceedings CSCW, Chapel Hill, October 22-26, NC, USA, ACM Press (1994) 113–120
[34] Russell, D.M., Streitz, N.A., Winograd, T.: Building disappearing computers. Communications of the ACM **48** (2005) 42–48
[35] Malone, T.W., Lai, K.Y., Fry, C.: Experiments with OVAL: A radically tailorable tool for cooperative work. ACM Transactions on Information Systems **13** (1995) 177–205
[36] Lieberman, H., Paterno, F., Wulf, V., eds.: End-user Development. Springer (2006)
[37] Newman, M.W., Sedivy, J.Z., Neuwirth, C.M., Edwards, W.K., Hong, J.I., Izadi, S., Marcelo, K., Smith, T.F., Sedivy, J., Newman, M.: Designing for serendipity: Supporting end-user configuration of ubiquitous computing environments. In: Proceedings DIS, London, England, ACM Press (2002)
[38] Ruyter, B.d., Sluis, R.V.D.: Challenges for end-user development in intelligent environments. In Lieberman, H., Paterno, F., Wulf, V., eds.: End User Development. Springer (2006) 243–250
[39] Greenberg, S., Roseman, M.: Using a room metaphor to ease transitions in groupware. In Ackerman, M., Pipek, V., Wulf, V., eds.: Sharing Expertise: Beyond Knowledge Management. MIT Press, Cambridge, MA (2003) 203–256
[40] Churchill, E.F., Snowdon, D.N., Munro, A.J.: Collaborative Virtual Environments. Springer (2001)
[41] Bly, S.A., Harrison, S.R., Irwin, S.: Media spaces: Bringing people together in a video, audio, and computing environment. Communications of the ACM **36** (1993) 28–46
[42] Farshchian, B.A.: Presence technologies for informal collaboration. In: Being there: Concepts, effects and measurement of user presence in synthetic environments. Volume 5 of Emerging Communication: Studies on New Technologies and Practices in Communication. IOS Press, Amsterdam (2002) 209–222
[43] Mansfield, T., Kaplan, S., Fitzpatrick, G., Phelps, T., Fitzpatrick, M., Taylor, R.: Evolving Orbit: A process report on building locales. In: Proceedings Group, Phoenix, Arizona, USA, ACM Press (1997) 241–250
[44] Schmidt, K., Simone, C.: Mind the gap! towards a unified view of cscw. In: COOP, Sophia Antipolis, France (2000)
[45] Roseman, M., Greenberg, S.: Teamrooms: Network places for collaboration. In: Proceedings CSCW, Boston, Massachusetts, USA, ACM Press (1996) 325–333
[46] Bardram, J.E.: Activity-based computing: Support for mobility and collaboration in ubiquitous computing. Personal and Ubiquitous Computing **9** (2005) 312–322
[47] Edwards, W.K., Newman, M.W., Sedivy, J.Z., Smith, T.F., Balfanz, D., Smetters, D.K., Wong, H.C., Izadi, S.: Using speakeasy for ad hoc peer-to-peer collaboration. In: Proceedings CSCW, New Orleans, Louisiana, USA, ACM Press (2002) 256–265

[48] Johanson, B., Fox, A., Winograd, T.: The interactive workspaces project: Experiences with ubiquitous computing rooms. IEEE Pervasive Computing **1** (2002) 67–74
[49] Tandler, P.: The BEACH application model and software framework for synchronous collaboration in ubiquitous computing environments. Journal of Systems & Software **69** (2003) 267–296
[50] Goldie, B.T., McCrickard, D.S.: Enlightening a co-located community with a semi-public notification system (2006)
[51] Divitini, M., Farshchian, B.A.: Shared displays for promoting informal cooperation: An exploratory study. In Darses, F., Dieng, R., Simone, C., Zacklad, M., eds.: Proceetings COOP, HyÃÍres Les Palmiers, France, IOS Press (2004) 211–226
[52] Greenberg, S.: Collaborative physical user interfaces. In Okada, K., Hoshi, T., Inoue, T., eds.: Communication and Collaboration Support Systems. IOS Press, Amsterdam (2005) 24–42
[53] Cheverst, K., Smith, G., Mitchell, K., Friday, A., Davies, N.: The role of shared context in supporting cooperation between city visitors. Computers & Graphics **25** (2001) 555–562
[54] Farshchian, B.A., Divitini, M.: Ubicollab architecture whitepaper. Technical report, Norwegian University of Science and Technology (2007)
[55] Bannon, L., Bødker, S.: Constructing common information spaces. In: Proceedings ECSCW, Kluwer Academic Publishers (1997) 81–96
[56] Olsen, K.A.G.: Distributed Session Management, Session Mobility and Transfer in UbiCollab. PhD thesis, Norwegian University of Science and Technology (NTNU) (2008)