
Cooperative ambient intelligence: towards autonomous and adaptive cooperative ubiquitous environments

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Abstract: Cooperative ambient intelligence provides users and groups of users with seamless and flexible support for communication and work in groups at one location and among groups at distributed locations. Autonomous and adaptive cooperative ubiquitous environments that are conceptually elegant, technologically sound and user-centred provide vital contributions for their success. This article characterises the evolution of interactive systems based on five foci, identifies the respective strengths of autonomous and adaptive behaviour from a users' perspective, and derives research issues for future cooperative ambient intelligence environments.

Keywords: adaptive and autonomous behaviour; cooperative ambient intelligence; ubiquitous computing.

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1 Introduction

The *International Journal of Autonomous and Adaptive Communication Systems* is looking for contributions concerning

"foundational, engineering and technological aspects of communications systems exhibiting emergent and adaptive behaviour." (Vasilakos, 2008)

Human-centred computing can be characterised by a perspective aiming to develop technological concepts and systems based on an understanding of how people interact with and communicate through computing technology (Bannon, 2005). From this perspective elegant and sophisticated technical concepts for autonomous and adaptive system behaviour are important, yet should be mostly hidden from users in order to facilitate their task-oriented interaction with the system.

In this article, we discuss autonomous and adaptive behaviour of systems from the perspective of human-centred computing addressing the central issue of the requirements for the system behaviour from a users' perspective. Subsequently, we describe the evolution of interactive systems from early interactive systems for single-users to environments for cooperative ambient intelligence in five foci with their respective characteristics and adaptive behaviour. We then identify research challenges and present some examples of concepts, systems and platforms that tackle these challenges.

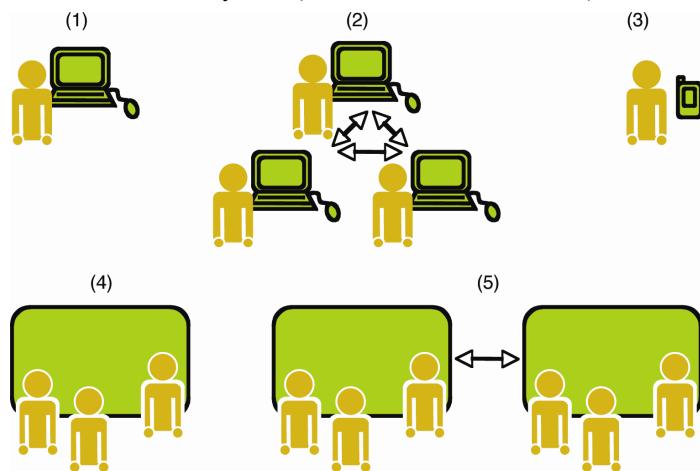
2 Five foci on interactive systems

The evolution of interactive systems with respect to their autonomous and adaptive behaviour from a human-centred perspective over the last decades had five distinct foci. These foci are (cf. Figure 1):

- single-user WIMP-based interactive systems
- cooperative systems for CSCW
- single-user ubiquitous computing
- single-user ambient intelligence
- cooperative ambient intelligence.

Before we characterise these foci below, it should be said that these foci are not mutually exclusive – rather, they can have partly overlapping concepts and they can sometimes coexist.

Figure 1 Five foci of interactive systems (see online version for colours)



2.1 Single-user WIMP-based interactive systems

Interactive Systems have been based on Windows, Icons, Menus and Pointing devices (WIMP) have been around since the 1960s when Ivan Sutherland presented the SketchPad, the first interactive graphics application (van Dam, 1997; Sutherland, 2003). They allow users to directly manipulate digital objects with computer keyboard and mouse and present the results interactively and incrementally in a Graphical User Interface (GUI) on the computer screen (Preece, Rogers and Sharp, 2007). Single-user WIMP-based interactive systems have been developed and published since the 1970s.

Since the early 1990s, concepts and systems for autonomous and adaptive behaviour of these interactive systems were developed. Two basic approaches can be distinguished: adaptability allows users to explicitly adapt and configure the systems according to their needs, whereas adaptivity facilitates the monitoring of the users' interaction with the system and automatically adapts the system's configuration and services (Oppermann, 1994).

2.2 Cooperative systems for CSCW

Cooperative systems for CSCW are

“largely based on extensions of the GUI to a distributed multi-user context, providing distant users with shared access to online digital environments”

and

“when direct communication between distributed users is desired, these systems are traditionally augmented with voice/video conferencing technologies.” (Brave, Ishii and Dahley, 1998, p.169).

These groupware systems are

“computer-based systems that support groups of people engaged in a common task (or goal) and that provide an interface to a shared environment.” (Ellis, Gibbs and Rein, 1991, p.39).

Collaboration-aware synchronous cooperative system that have been implemented from scratch and support real-time cooperation among online users often provide special GUI components to facilitate cooperative interaction like tele-pointers showing the respective user's own cursor position and the cursor positions of the other users on the screen (Edwards, 1995). Cooperative systems for CSCW have been developed and published since the 1980s.

In CSCW and groupware, the two basic concepts of adaptivity and adaptability are also present in concepts and systems – yet, adaptability refers to articulation and adaptivity is mostly system-specific.

Articulation work in cooperative settings means that team members in order to cooperate efficiently – besides their teamwork *per se* – continually need to organise their group process by discussing and arranging their team setting. This team setting comprises task allocations to team members, performing tasks and particularly aligning task outcomes. Adaptable cooperative systems for CSCW should allow users to perform this articulation work as well as to adapt the systems accordingly (Bannon and Schmidt, 1989). Examples of such adaptable cooperative systems for CSCW are group editors that let users plan and implement their preferences concerning the group process of distributing writing tasks, allowing or disallowing parallel editing, free or locked editing and so forth.

Adaptivity in cooperative systems for CSCW is supported in some specific applications. Here, adaptivity refers to the fact that the cooperative system captures information about the team and the interaction among the team members and provides automatic adaptations. Examples of such systems are communication systems that allow users to exchange messages, but also adapt resources according to the communication (e.g. semi-structured messaging systems analyse meeting arrangement emails and automatically make room reservations for the respective meeting).

2.3 Single-user mobile and ubiquitous computing

Ubiquitous computing according to Mark Weiser – the very prominent inventor of the term

“enhances computer use by making many computers available throughout the physical environment, while making them effectively invisible to the user”

and

“the goal is to achieve the most effective kind of technology, that which is essentially invisible to the user.” (Weiser, 1993, p.75).

So, the issues that are central to ubiquitous computing are computing devices of small size, but in big numbers, with novel forms of user interaction. Single-user mobile and ubiquitous computing came up at the end of the 1980s and the first publications of Mark Weiser, with other authors following, appeared at the beginning of the 1990s.

Lyytinen and Yoo (2002) discuss the notion of ubiquitous computing in relation to other related areas. They introduce two dimensions of distinction: embeddedness with low meaning a loose integration of technology into the environment and high meaning strong integration, and mobility with low referring to technology that cannot be moved around and high corresponding to technology that is movable. They define ubiquitous computing as being high on embeddedness and mobility, pervasive computing as high on embeddedness and low on mobility, mobile computing as low on embeddedness and high on mobility and traditional business computing as low on both. In all these areas three interaction themes are dominant: natural interfaces via speech and gesture and beyond keyboard and mouse, context-aware applications that react to their surrounding, and automated capture of and access to information (Abowd and Mynatt, 2000). Although some authors also mention social aspects of ubiquitous computing – for instance, Lyytinen and Yoo (2002) write that ubiquitous computing should embed technology into users’ physical but also social environments, most concepts and systems in the recent literature on ubiquitous computing has focused on single-users.

In single-user mobile and ubiquitous computing adaptivity concerns the contents and the user interface, and adaptability is not prominent. Adaptivity of the contents in terms of the information and functionality offered to the user often relies on capturing the context of the user and reacting to it. Yet, the context is frequently reduced to the current location (Schmidt, Beigl and Gellersen, 1999). Examples where this is sufficient are navigation systems that analyse the current position and automatically calculate the route to specific remote locations or points of interest. Adaptivity of the user interfaces refers to cross-platform applications where the layout and interaction of GUI-based systems is automatically adapted to respective mobile device such as mobile phone, smartphone or personal digital assistant.

2.4 Single-user ambient intelligence

Ambient intelligence

“is often based on ubiquitous computing technology and goes beyond the traditional WIMP”. (Fetter and Gross, 2007, p.44)

Weber, Rabaey and Aarts (2005) mention additional characteristics of ambient intelligence such as that it can be

“enabled by simple and effortless interactions, attuned to all our senses, adaptive to users and context-sensitive and autonomous.”

Ambient intelligence requires that the environment is embedded, adapts to the presence of people and objects and assists users smartly while preserving security and privacy. And ambient intelligence supports human contacts (Weber, Rabaey and Aarts, 2005). So, there is already a focus on humans in the surrounding. Yet, the approach is often a departure from single-users with special consideration of multi-user scenarios. Single-user ambient intelligence as a term came up at the end of the 1990s to describe visions and ideas of future development, mainly in the European Union.

Ambient intelligence entails autonomous and adaptive behaviour, which is mostly based on capturing the status and the changes of the environment, processing the captured data and inferring on their semantic meaning and finally actuating the environment accordingly.

2.5 Cooperative ambient intelligence

Cooperative ambient intelligence is based on ambient intelligence that

“aims to improve users’ work and private life by analysing and adapting to the current situation with a special focus on the presence and activities of users.”
(Fetter and Gross, 2007, p.44)

It is similar to single-user ambient intelligence and is based on the same concepts and base technology. The difference is that cooperative ambient intelligence departs from social settings assuming that the presence of a single person is possible, but that the presence of a group of persons is more likely and is the primary focus (Markopoulos et al., 2005). In fact, it picks up a paradigm shift that was also part of the emergence of CSCW, where Marca and Bock (1992, p.60) write:

“groupware is a conceptual shift; a shift in our understanding. The traditional computing paradigm sees the computer as a tool for manipulating and exchanging data. The groupware paradigm, on the other hand, views the computer as a shared space in which people collaborate; a clear shift in the relationship between people and information.”

Cooperative ambient intelligence is currently emerging. This emergence can be seen similar to Social Software and Web 2.0 – that is, whereas there has research been going on in this field for some years in some universities, research laboratories, and companies the term is not fashionable yet.

Cooperative ambient intelligence is highly autonomous and adaptive from a perspective of the social settings in which groups can form, evolve and dissolve; groups can be present at the same location, either sequentially or parallel; and groups can

cooperate with other groups at remote sites. This requires – besides the capturing and inferring information on single-users – also capturing and inferring on the states and changes to the groups and the social interaction within them. Subsequently, we will discuss the implications of this cooperative ambient intelligence perspective on research issues.

3 Research issues for cooperative ambient intelligence

There are number of research issues for cooperative ambient intelligence that result from the above five foci. In order to elaborate on these research issues, we first summarise the five foci in Table 1 below, and we then identify research issues.

The following research issues are partly being addressed in current research and will be highly relevant for the success of cooperative ambient intelligence environments. They are based on a thorough literature study and our own experience of 10 years of designing, implementing and evaluating sensor-based infrastructures at Fraunhofer FIT and at the Bauhaus-University Weimar.

Some key messages of other authors are the following. In order to provide flexible support for both structured and informal and unstructured tasks, it is important to note that many human activities do not have a clear beginning and end, are interrupted frequently, and are performed concurrently with other activities (Abowd and Mynatt, 2000). Amongst others, environments should address issues of social implications, privacy and trust, and support implicit actions (Tscheligi, 2005). And, finally, besides concepts when designing the environments also concepts when evaluating them are important (Markopoulos et al., 2005).

Table 1 Summative overview of five foci with respect to time, key concepts awareness well as autonomous and adaptive behaviour

	<i>Single-user WIMP</i>	<i>Cooperative systems</i>	<i>Single-user Unicom</i>	<i>Single-user ambient</i>	<i>Cooperative ambient</i>
Time	1970s	1980s	1990s	1990s	2000s
Key concepts	Graphical user interfaces; icons, menus and pointing devices	Graphical user interfaces; computer-based communication, screen sharing and telepointers	Vast availability of embedded and mobile technology; periphery of user attention	Attuned to users' senses; adaptivity part of any environment	Adaptivity to groups of users part of any environment
Autonomous and adaptive behaviour	Adaptability through user customisation; adaptivity of user interface	Adaptability through articulation works support; adaptivity of resource allocation	Adaptivity of information and functionality	Highly adaptive to (mostly single-users') presence and activities	Highly adaptive to presence and activities of local and remote groups, and to their needs for local group interaction and remote group-group interaction

Some examples of our own research towards cooperative ambient intelligence environments that gave us experience and insight into conceptual and technical issues of developing and using are the following. We developed the generic platform Sens-ation allowing developers of sensor-based infrastructures to easily build environments (e.g. Gross, Egla and Marquardt, 2006b; Gross, Paul-Stueve and Palakarska, 2007). We developed concepts for context modelling (e.g. Gross, Braun and Krause, 2006a). We realised editors for the easy configuration and programming of environments through end-users and software developers without thorough knowledge of base technology of sensor and actuator hardware (e.g. Gross and Marquardt, 2007; Gross and Marquardt accepted). And, finally, we envisioned and realised scenarios of future use of cooperative ambient intelligence environments (Fetter and Gross, 2008; Gross, Fetter and Liebsch, 2008).

The following descriptions of research issues only addresses some important examples resulting from the thorough literature study and our own experience:

- *Dynamic user and group authorisation and authentication:* concepts and technical solutions for dynamically registering single users and detect group constellations need to support the evolution of co-located groups and remote groups. This includes traditional session management known from distributed systems and computer-supported cooperative work, since groups structures and starting, resuming or terminating processes need to be detected automatically.
- *Dynamic access rights:* concepts and technical solutions for dynamically granting, adapting and revoking access rights to co-located groups and remote groups are needed. They should also allow to include policies to deal with privacy, trust and shared ownership of the artefacts that are created and manipulated by the group in the cooperative ambient intelligence environment.
- *Advanced context models and meta-models:* concepts and technical solutions for modelling the situations in the environment including the human and computer actors, their actions, their locations, their mood, the group process as it should be and as it is evolving.

Here both models for each location with cooperative ambient intelligence and meta-models for comparison and exchange among different locations are needed.

- *Machine learning:* solid concepts for analysing and inferencing on the data captured on the users, their presence and movements, their actions, their artefacts and so forth are vital for correct autonomous and adaptive behaviour of the cooperative ambient intelligence environment. They are also the basis for facilitating mobility of users, groups, artefacts, applications as well as places in terms of changing lieu where a team meets to do their work.
- *Advanced hardware and network technology:* on top of the existing hardware novel technology for mobile devices of various sizes and natural ways of interaction, sensors for precisely capturing data, actuators for adapting the environment is needed. On top of existing networks novel network technology for fast and secure communication among the stationary and mobile hardware is required.

4 Conclusions

In this article, we have motivated the need for novel concepts and advanced technology for autonomous and adaptive behaviour of systems in order to better support human-centred computing and users' needs. We have described the evolution of five foci on human-centred computing from single-user WIMP-based interactive systems, to cooperative systems for CSCW, to single-user ubiquitous computing, to single-user ambient intelligence and finally to cooperative ambient intelligence and identified the respective key concepts from a users' as well as from a autonomous and adaptive behaviour systems' perspective. We have finally outlined key research issues for future cooperative ambient intelligence environments. Although these issues are based on a thorough literature study and a long experience in conceptualising and developing such environments, it is clear that much of the research will need to be pragmatic where concepts are developed, environments are built, and users really work with them and where quantitative and qualitative user studies are the ultimate proof of their success.

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