Context Aware Agents for Personal Information Services

Enric Plaza and Josep-Lluís Arcos

IIIA - Artificial Intelligence Research Institute
CSIC - Spanish Council for Scientific Research
Campus UAB, 08193 Bellaterra, Catalonia (Spain)
Vox: +34-93-5809570, Fax: +34-93-5809661
Email: {enric,arcos}@iiia.csic.es
WWW: http://www.iiia.csic.es

Abstract. We present a society of personal information agents that work for a community of users and that are aware of the physical and social context of their users. We show how context-awareness is a feature that allows the agents to improve their performance when they work with limited resources in information spaces with a large amount of information. The use of context information allows the agents to focus their information search and, as a result of this, increase the quantity and quality of information delivered to the user. Moreover, we propose an implemented agent architecture with context-aware capabilities. We discuss this architecture in detail, focusing on the capability of exploiting the windows of opportunity provided by the awareness of the users' activity. The agents use these windows of opportunity to furnish the user with information and advice in the situation where it can be most useful. In particular, we show how context-aware information agents can assist a community of attendees to big conferences and fairs. In this application, an information agent gathers relevant information based on a model of specific interests of a user. Given the multiplicity of interesting events, and their distribution in time and space, an information agent has to deliver the gathered information in a few hours and comply to the schedule constraints. Finally we report some experimentation results to illustrate how context-awareness improve the service a society of information agents provides to a community of users in the conference application.

1 Introduction

The goal of personal information agents (PIAs) is to gather relevant information based on a model of the specific interests of a user. The current research in information agents covers several approaches such as cooperative and non-cooperative information agents, information agents with adaptation capabilities, mobile agents, or information agents for e-commerce [4]. Our research is focused in a society of personal information agents that interact among them for pursuing user interests. That is, we are using a dialogical approach for modeling the information gathering process. Moreover, we are interested in personal information agents that work in environments with a large amount of information and

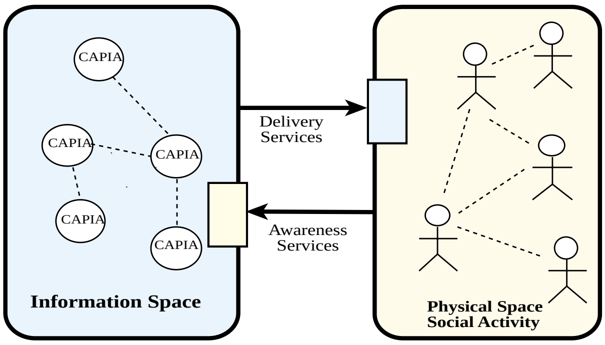

Fig. 1. A schema of the dual space of information agents and human users with the mediation services between them.

limited resources for dealing with this information. Specifically, in those environments the PIAs are not able to cover all the search space and the design of search strategies are required.

Our proposal is that personal information agents should be able not only of searching relevant information and of making contact with other interesting agents on behalf of the user; PIAs should be aware, as far as possible, of the physical and social context of the user in order to focus their information search and provide to the users information in the place where and at the time when that information is more relevant and useful. In this paper we present context-aware information agents that function in a particular physical and social setting, that of persons attending to conferences and fairs. Limiting our research effort to this specific context allows us 1) to design concrete PIAs that help users in some tasks they typically perform in conferences and fairs, and 2) develop context-awareness mechanisms that support those tasks.

In the next section we present the issues that have to be addressed in order to develop a society of interacting information agents aware of the physical and social context of their users. In Section 3 we introduce a specific application where users participate in a conference and a collection of PIAs, with a (partial) awareness of the users' physical and social context, provide information to the users. In Section 4 we present an implemented agent architecture with context-aware capabilities. In Section 5 we report the experiments performed with our agent architecture in the conference application. Finally, in Section 6 we compare our work with existing literature and summarize our proposal.

2 A Framework for Context-Aware Agents

Our framework is composed by a collection of context-aware personal information agents (CAPIAs) working in an information space and a collection of human users interacting in a same physical space. A useful way to visualize this distinction is the *dual space* schema depicted in Figure 1. Human users, on the right hand of Figure 1, are in a location, interacting with other persons (that might be users or not) in the context of social activities. Information agents, on the left hand of Figure 1, inhabit an information space where they interact with other agents and gather information in the interest of the users.

Moreover, we have *mediation services* connecting the information space of agents and the physical space of human users. Specifically, we are currently using two mediation services, namely an *awareness service* and a *delivery service* (see Figure 1).

2.1 Awareness and Delivery Services

The *awareness service* takes charge of pushing information from the physical space to the information space. Specifically, the awareness service provides to CAPIAs a real-time information about the physical location movements of users. The specific data provided depends on the particular sensors available in the awareness service for a particular application. For instance, in the conference center application the awareness service provides a real-time tracking of attendees location as well as the group of other attendees nearby a given attendee—see in Section 3 the features of the awareness service in the COMRIS Conference Center application.

Concerning the *delivery service*, it offers mediation and brokerage capabilities (subscribed by the human users) for delivering information from the information space to the physical space. Specifically, the delivery service provides the channels for delivering the information gathered by the CAPIAs to their corresponding users. For instance, in the conference center application the delivery service allows to send information as audio output by means of a wearable computer and HTML pages by means of screen terminals scattered through the conference building.

2.2 Agents Requirements

The society of agents has to be able to communicate using a common ontology for a specific application, and they have to share a collection of interaction protocols appropriate for that application. Our approach is to use the notion of *agent-mediated institution* [6] to specify the ontology and interaction protocols to be used by a society of agents for a particular application.

In addition to support the ontology and interaction protocols of an agent-mediated institution the agents should be able to manage with context awareness information. That is to say, a context-aware agent should be able to react dynamically when a new physical context information is received from the awareness service. Moreover, since the future physical and social context of the user is not known, a desired feature of CAPIAs is the capability of gathering information that may become relevant in a future context. For instance, in the conference center application, when an attendee is at a specific exhibition zone the CAPIAs use the knowledge provided by the conference about the physical distribution of booths for trying to anticipate the next movement of the attendee.

In our framework, context-aware personal information agents (CAPIA) are based on the distinction between two kinds of information valuation, namely *interestingness* and *relevance*. Information *interestingness* measures the intersection of a given information with the user model a CAPIA has for the tasks it is charged with. That is, $interestingness : Info \times U_M \mapsto e_I$ where $Info$ is a given information; U_M is the user model; and e_I is the estimation of the interest that the user has in $Info$.

However, depending on the physical and social context of the user and on the time some information may be more or less *relevant* for the user on each particular point of time. Information *relevance* measures this intersection of a given information with the time and the context of the user. That is, $relevance : Info \times time \times UC \mapsto e_R$ where $Info$ is a given information; U_C is the user context; and e_R is the estimation of the relevance of $Info$ in U_C. For instance, in the conference application when an attendee is nearby to an exhibition booth, the information related to the booth is estimated as more relevant. Another example of increase of relevance is when a conference event is close to start: a CAPIA has a time constraint for deciding if that event is useful for the user interests.

3 The Comris Conference Center

This section introduces the framework of context-aware information agents in a particular application, that is to say in the physical location and the social activity context of a Conference Center in the COMRIS[1] project [8]. We view the Conference Center (CC) as an agent-mediated institution where a society of information agents work for, and are aware of, the attendees of a conference [1, 7]. The ontology of the CC institution defines the conference activities that take place in the CC. Examples of conference activities are exhibition booths and demo events, plenary and panel sessions, etc. The ontology also defines the roles that a person takes in different locations while performing different activities, e.g. speaker, session chair, attendee, organization staff, etc. Other important elements defined by the CC ontology are the different locations of the conference such as the exhibition areas, the conference rooms, and the public areas—i.e. halls, cafeterias, and restaurants. This information is used by the agents for reasoning about the movements of users in the conference. The schedule of conference events is also defined in the CC ontology.

Finally, the CC ontology supports the definition by each user of the "instruction set" that her CAPIA should follow. The instruction set is entered by the conference attendee using a WWW browser while registering and basically includes i) an interest profile (specifying the topics with weights the attendee is interested in), ii) those tasks the user commissions the PIA to do in her behalf

[1] COMRIS stands for Co-Habited Mixed-Reality Information Spaces. More information is available at URL `<http://arti.vub.ac.be/~comris/>`.

(e.g. if she is interested or not in making appointments); and iii) the delivery modes that the CAPIA will use to communicate with her.

We implemented two types of CAPIAs in the conference center application: CAPIAs representing interests of attendees and CAPIA advertisers. There is a CAPIA for each attendee, a CAPIA advertiser for each exhibition booth, and a CAPIA advertiser for each paper session. The goal of CAPIA advertisers is convince people for attending to the conference event they are representing.

3.1 Delivery Service

The delivery service in COMRIS allows the users to receive information in two ways: by means of a wearable computer with text and audio output and by screen terminals scattered through the Conference Center. The wearable computer is used to convey short messages that are relevant for the user with respect to her current physical and social surroundings. The user can walk to a terminal if she wishes to have more information about this message or other recent messages she has received. When the user approaches a screen the wearable computer detects this terminal's identifier, and then it sends this identifier to the user's CAPIA. Once the CAPIA is aware of this situation, the agent sends to that screen the report of the performed tasks and the report of ongoing tasks.

The delivery service comprises several components. The first component is the natural language generation (NLG) component. The NLG component receives the message sent by a CAPIA and generates an english sentence explaining the message content and taking into account the current attendee context and the sentences previously generated. Then, when the message has to be delivered as audio, the sentence structure is sent to a speech synthesis component that produces the actual audio heard by the user. Similarly, there are components that transform CAPIA's messages into HTML or VRML in order to be delivered to the screen terminals.

3.2 Awareness Service

The awareness service keeps track of the whereabouts of the attendees in the Conference Center. In the COMRIS CC the detection devices are a network of infrared beacons (marking the different rooms, places and locations in the CC) and the wearable computers the attendees carry. The COMRIS wearable computer detects the infrared beacons and thus informs the awareness service of the location of its user. Moreover, the wearable device possesses an infrared beacon, allowing the detection of other persons, wearing a parrot, located nearby. In order to have access to this information, each CAPIA in the information space "subscribes" its user to the awareness service. As a result, the CAPIA receives messages about the changes in location of that person and a list of other people close to that person. When the CAPIA interacts with other CAPIAs (representing other conference attendees), and decides that those CAPIAs are interesting persons, subscribes those persons to the awareness service. Consequently, the CAPIA is aware of the location of the most interesting persons for its user, and detects for instance when one of these persons is in the same location as the user—a most relevant situation to push to its user the information concerning that person that is interesting *and* nearby.

Tasks The tasks that the COMRIS Conference Center supports are the core of the activity in the CAPIAs. It is important to remark here that, in order to perform these tasks, the information agents use *both* the CC ontology and the awareness service to infer the situation of the user. That is to say, knowing that the user is in a particular place, the current time, and the activity scheduled by the Conference for that place at that time, the information agent can infer the social activity in which the user is involved.

We will briefly summarize the tasks performed by COMRIS CAPIAs and the scenes they are involved in.

• *Information Gathering*: is responsible of establishing initial conversations with other CAPIAs for estimating the interestingness of the attendees or conference events they represent. We say that the information gathering task constructs the *interest landscape* of a given attendee. The interest landscape holds all the information considered as useful for the interest of the attendee and is used and refined in the other tasks. In CAPIA advertisers, this task has been specialized for attracting persons that might be interested in the conference events (exhibition booths or conference sessions) they represent.

• *Appointment Proposal*: in this task, using the interest landscape, the CAPIAs try to arrange an appointment between two attendees. First, CAPIAs negotiate a set of common topics for discussion (the meeting content). When they reach an agreement, CAPIAs negotiate on the appropriate meeting schedule.

• *Proximity Alert*: in this task an attendee is informed that she is physically near to another person with similar interests —or near an exhibition booth or a thematic session with similar topics.

• *Commitment Reminder*: this task is responsible of checking if attendees are aware of their commitments. The CAPIA uses context to determine that the user may be unaware of a commitment, e.g. if she is not near the location of an appointment (or a bus scheduled to leave) a few minutes before.

For each task several *activities* are launched in the CAPIA. For instance, when an agent in COMRIS is discussing about appointments with several CAPIAs, each thread of interaction is managed by a distinct activity.

4 Personal Information Agents

The architecture of CAPIAs has to fulfill adequately the requirements posed by context awareness. Essentially, the fact that an agent is aware of the context implies that i) the changes in the context cause immediate changes in the internal inference, and ii) some activities the CAPIA is pursuing cannot be completed until a satisfactory context is reached. On the other hand, it's not possible for an agent to wait until a context is reached and then start the relevant activity. Since the CAPIA needs to perform some interaction with other agents, and those agents may delay too much their answers, the agent could have to wait too long and see the context change again, losing its window of opportunity. Because of that, the CAPIAs has to anticipate the work on activities that can arise as future candidates. Thus, the architecture of CAPIAs has been designed for dealing with a high number of concurrently competing activities focusing on the most promising activities at any point in time. The architecture of CAPIAs consists on five components, as shown in Figure 2, and are detailed below.

The *Communication Component* is responsible of communicating the agent with the society of agents. Thus, the communication component registers the agent into the conference application and manages the incoming and outgoing messages. Messages incoming from the awareness service will be consumed by the awareness component. Messages incoming from the delivery service will be consumed by the delivery component. Messages incoming from other CAPIAs or from the conference will be consumed by the activities in the decision component. Moreover, the communication component is the responsible of translating the internal representation structures into the communication language defined by the institution and vice versa—in COMRIS the communication component translates from/to the XML-based FIPA-compatible language defined for message content to/from the internal frame-based representation.

The *Awareness Component* is responsible of processing the messages incoming from the awareness service and provide the *context model* to the agent. The context model holds the information provided by the awareness service and information elaborated by the agent from this basic context information. For instance, in COMRIS the physical location of the attendee and the current time is used, with the schedule of the conference, for inferring the social activity of the user. Moreover, the context model stores the history of context changes. This context trace is used in COMRIS agents for changing dynamically the relevance of an information and for generating the information to be delivered to the attendee. For instance, the second time an attendee coincides in a paper presentation her relevance is increased.

The *Delivery Component* is responsible of generating the information to be presented to the attendee in the format adequate to the functionalities provided

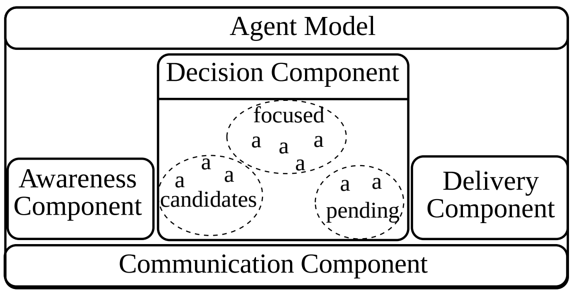

Fig. 2. The CAPIA architecture components.

by the delivery service. In COMRIS the users receive information in two ways: by means of a wearable computer and by screen terminals scattered through the Conference Center. These two complementary channels implies that the delivery component has to generate different information for each delivery channel. For the wearable output, it is important to generate short messages selecting the most relevant information. In contrast, in the screen terminals there is more room for reporting the agent activity and the main issue here is how to organize the information.

The *Agent Model* is the component that holds i) the attendee's interests and instructions and, ii) the interest landscape—i.e. the models about the other attendees. The interest landscape stores the profiles and interests of other attendees and a record summarizing the history of the interactions with their CAPIAs. In COMRIS the attendee's interests and instructions is a static information that can be partially tuned using the screen terminals. An attendee can inspect her interest landscape in the screen terminals and change the valuation performed by the CAPIA influencing the future behavior of the CAPIA. The models about the other attendees are built from the interaction with the other CAPIAs and are influenced by the decisions taken by the attendee when the attendee accepts or declines the suggestions received from the CAPIA.

The *Decision Component* is responsible of performing the tasks on behalf of attendee's interests. The Decision Component manages the collection of ongoing activities by dividing them in three groups (see Figure 2):

- *Focused* activities are those pursued in an interleaved mode. When a focused activity in order to proceed needs an answer from another CAPIA or requires a specific context, the activity is demoted to the *pending* group.
- *Pending* activities are those waiting for the answer of another CAPIA or waiting for a specific attendee's context. When the communication component receives a message for a given pending activity or the attendee's context satisfies the pending conditions of an activity, that activity is promoted to the *candidate* group.
- *Candidate* activities are those competing for promotion to the focused group. This group is composed by new activities (generated either internally or by foreign requests) and activities previously members of focused or pending groups.

Given a set of activities, the goal of the decision component is to decide which candidate activities have to be promoted to the focused group and which focused activities are demoted to candidates. The decision component uses the context model provided by the awareness component to make those changes. For instance, in COMRIS we have associated to each activity an activation record ρ with five values $\rho = \langle T, S, e_I, e_R, e_C, a_V \rangle$ where T is the type of the activity (information gathering, appointment proposal, proximity alert, or commitment reminder); S is the starting time (the time when the activity started); e_I is the estimated interestingness of the information the activity is elaborating; e_R is the estimated context relevance of the information; e_C is the estimated confidence that the activity will succeed; and a_V is the activation value.

Table 1. Comparison of experimentation results with different interest intersection ratios.

	100 %		50 %		25 %		10 %	
	Tot.	%	Tot.	%	Tot.	%	Tot.	%
Without Context	1080	43.2	540.32	43.22	270.59	43.3	108.8	43.23
Context Awareness	1080	43.2	609.87	48.79	441.37	70.62	236.95	94.78

The estimated confidence e_C is a number assessing the likelihood of success in an activity (for instance, for an appointment proposal activity the confidence that an agreement can be reached). e_C is calculated using features such as the time delay in receiving answers or the flexibility in accepting counter-proposals. The activation value a_V of a given activity is a number that aggregates 1) the interestingness of the information e_I with 2) the relevance of the information e_R (given the current context and the activity type T) and 3) the estimated confidence e_C that the activity will succeed. The activation values of all ongoing activities are used by the decision component, with a threshold mechanism, for determining which activities are promoted to focused and which other are demoted to candidates.

5 Experimentation Results

We have performed several experiments for evaluating how context awareness improve the information provided by the CAPIAs. For our experimentation purpose we have used a context simulator that provides context information about attendees movements without requiring the existence of attendees physically walking around a conference building. The context simulator allows us to generate different sets of context traces varying several testing conditions.

We performed experiments with populations of 2.000 attendees participating in a conference. The conference was designed with 420 different locations: 400 exhibition booths distributed along 8 exhibition areas; 10 seminar rooms with 10 parallel presentations in each of them; and 10 public areas such as halls, cafeterias, and restaurants. The duration of the conference was 6 hours and the attendees remained in the same physical place from 5 to 15 minutes (with an average of 10 minutes). Notice that attendees visit about 40 different locations as average. Each attendee participating in the conference was represented by one CAPIA—i.e. 2.000 CAPIAs representing attendees. Moreover, a CAPIA advertiser was assigned to each exhibition booth and each paper session for trying to attract people to the event the agent is representing—i.e. 410 CAPIAs more. Finally, we also restricted the amount of information that each CAPIA is able to manage: 3 different information sources (conference events or interactions with other CAPIAs) per minute. This constraint limited the amount of different information an agent handled during the 6 hours of the conference experiments to 1080, i.e. around the 40 % of the total amount.

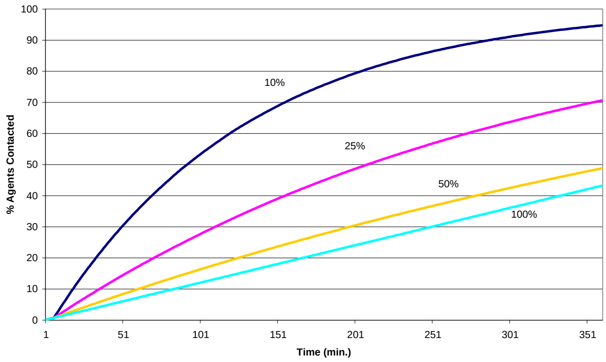

Fig. 3. Experimentation Results.

Given the previous conference scenario we performed experiments using four experimentation settings with different interests intersection between attendees. A first setting with 100 % of interest intersection (everybody interested in the whole conference), a second setting with 50 % of interest intersection, a third setting with 25 % of interest intersection, and the last setting with 10 % of interest intersection (attendees only interested in the 10 % of the conference).

The experiments were performed following two modes: with and without context information for guiding the CAPIAs decisions.

The results of the experiments shown that without the context information the CAPIAs are able to identify and deliver to the attendees only the 43 %, in average, of the whole conference information interesting by users (see first row of Table 1). Notice that the absolute number of final messages delivered to users depends on the experimentation setting but the ratio with respect to the potential interesting information is the same.

The results of the experiments performed using the awareness service shown that the CAPIAs improved their results (see second row of Table 1). When the interest intersection between attendees is 100 % there is no difference with respect to not using context information. The explanation is trivial because when everybody is interested in the whole conference, the context information is not relevant. Nevertheless, when the interest intersection of attendees decreases the use of context information arises as a crucial capability of the agents for focusing the information search (see comparison in Table 1).

A detailed analysis of the performance of the CAPIAs along the conference time (see Figure 3) shows that as soon an attendee went to a place interesting for her, the CAPIAs started to exploit the context information allowing a fast identification of interesting information. When the number of delivered information increases the rate of new information decreases (see in Figure 3 how the slope of the curves decreases). This phenomenon can be explained by the fact that the value of context information decreases because many of the attendees detected by the awareness service have already been reported in previous occasions by the CAPIA.

Another important experimentation result was the analysis of when the information was delivered to the users. It is clear that using the awareness service the CAPIAs deliver more messages to their users —but an important issue is how these delivered messages are distributed along the conference period. An analysis of the first mode (without using context information) shows that the distribution of messages is uniform along the conference period. An analysis of the second mode shows that when CAPIAs use the awareness information for focusing on the most promising activities, they can take advantage of the opportunities generated by the attendee's context. Then, the messages delivered to attendees are better distributed along the conference period. This is because in the second mode CAPIAs use awareness information to guide its evaluation of the most promising activities. For instance, if a CAPIA is aware that a certain attendee is nearby its user, the agent increases the activation value aV of the activities related to that attendee. Therefore the CAPIA has more chances to exploit windows of opportunity offered by its user's activities than an agent working on the first mode.

Summarizing, the experiments shown that the use of context awareness allows CAPIAs to deal with high amount of potential information without degrading significantly their competence. When an agent fully uses the awareness service to guide its work, as it does in the second mode, it's less affected by size problems since it can dynamically adapt its focus to those CAPIAs that are relevant given the concrete surroundings of its user's activity.

6 Discussion

The literature on information agents is increasingly wide in number and scope. Recent books on intelligent information agents (like [5] and [4]) show a variety of research addressing societies of cooperating information agents, adaptive information agents, mobile agents, and applications to e-commerce. The focus of this paper is on context-awareness, a new feature desirable for certain applications of information agents. It is novel in the sense that the tasks that a CAPIA pursues or abandons, the information that eventually gathers, and the specific information that the user of such an agent receives, all these activities are biased and mediated by the perception that the agent has on the physical and social activity of the user. We have introduced a framework for analyzing the relationship between the information space inhabited by CAPIAs and the physical space inhabited by users. In this framework we define two mediation services between physical and information spaces, namely delivery and awareness services.

The research on context awareness is also increasing and is encouraged by the new possibilities that offers the mobile communications. The paper from Dey and Abowd [2] presents an overview about context and context-aware applications. The same authors presented a work regarding to a conference assistant [3]. Nevertheless, the focus of their research is on the relationship between context-awareness and wearable computing.

We have also presented the COMRIS application where context-awareness of a society of agents is supported to improve the information received by attendees to a conference or a fair. Concerning COMRIS we have focused on the society of information agents and we have only described other parts of the application as needed for understanding the requirements posed on CAPIAs and the tasks that those agents perform on the Conference Center application. See the COMRIS website at `http://www.iiia.csic.es/Projects/comris/` for more information. We have proposed and implemented an architecture for context-aware agents, emphasizing the need for such an architecture to be able to react to a changing surroundings, to exploit the windows of opportunity offered by the users' moving throw changing contexts, and to push the information they have gathered in situations where the users can consider that meaningful and relevant. Finally, the scenario and experiments have been used to illustrate in more detail how is the relationship between a society of agents and a community of users and why the ability of context-awareness is useful for situations as such of a Fair or a Conference Center.

Acknowledgements The research reported in this paper is partly supported by the ESPRIT LTR 25500-COMRIS *Co-Habited Mixed-Reality Information Spaces* project.

References

1. J. L. Arcos and E. Plaza. Instituting interactions among agents. In *Interaction Agents Workshop*. AAAI Press, 1998.
2. A. K. Dey and G. D. Abowd. Towards a better understanding of context and context-awareness. In *Proceedings of CHIA'00 workshop on Context-Awareness*, 2000.
3. A. K. Dey, D. Salber, G. D. Abowd, and M. Futawaka. The conference assistant: Combining context-awareness with wearable computing. In *Proceedings of the 3rd International Symposium on Wearable Computing ISWC'99*, 1999.
4. M. K. (Eds). *Intelligent Information Agents*. Springer Verlag, 1999.
5. M. Klusch, O. M. Shehory, and G. W. (Eds). *Cooperative Information Agents III*, volume 1652 of *Lecture Notes in Artificial Intelligence*. Springer Verlag, 1999.
6. P. Noriega and C. Sierra. Towards a formal specification of complex social structures in multi-agent systems. Number 1624 in Lecture Notes in Artificial Intelligence, pages 284–300. Springer-Verlag, 1999.
7. E. Plaza, J. L. Arcos, P. Noriega, and C. Sierra. Competing agents in agent-mediated institutions. *Personal Technologies*, 2:212–220, 1998.
8. W. Van de Velde. Co-habited mixed reality. In *Proceedings of IJCAI'97 workshop on Social Interaction and Communityware*, 1997.
9. W. Van de Velde, S. Geldof, and R. Schrooten. Competition for attention. In M. P. Singh, A. Rao, and M. S. Woooldridge, editors, *Intelligent Agents IV*, number 1365 in Lecture Notes in Artificial Intelligence, pages 297–311. Springer-Verlag, 1998.