Intelligent Awareness in Support of Collaborative Virtual Work Groups

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Abstract. Collaborative Virtual Work Groups (CVWG) are small groups of people that perform tasks, share responsibilities, goals and decisions but are distanced in terms of space, time and cultures, and maintain their connections through technology. Collaborative Systems support them enabling a *shared environment* and informing of its state and changes through a mechanism called Awareness. In this paper we argue that these changes and their consequences can be understood in an ontological work context (we call it “semantic awareness”). This approach allows us to infer the *relevance* of the awareness information and control its delivery. To do so, we determine a user context (location, device, preferences), which allows us to infer the user willingness to be exposed to this information. The mechanism is enabled through a Multi-Agent System (MAS), where an agency represents each user’s perception and actual context. We also present a case study and discuss the obtained results.

1 Introduction

Current computer network improvement and the possibility of remaining networked, has encouraged the organizations to assign tasks to Collaborative Virtual Work Groups (CVWG). They are small groups of people that perform specific tasks, share decisions, goals and responsibilities, but are distanced in terms of space, time and cultures, and maintain their connections through communication technologies [1], [2]. The main advantage of these groups resides in their flexibility, fast conformation, reorganization and breakup, besides the use of work expertise without incurring in reallocation costs.

They need to react rapidly to changes in their environment and face the uncertainty and distrust imposed by their fragmented environment [3], [4], so they must overcome their infrastructure and time differences in order to coordinate actions, maintain formal and spontaneous interactions and keep informed of the project’s daily activities [5], [6].

Collaborative systems allow them to share software artifacts, objects and self-representations enabling a virtual *shared environment*. The state of this environment

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and its changes are rendered to the user through a mechanism called Awareness, that due to the nature of CVWG, needs to be highly proactive (called *passive awareness*).

The actual approach consists of manifesting the user's interest in being notified automatically of changes in predetermined objects in the environment [7], [8]. But, when the environment is dynamically constructed, those objects are created on the fly, so the notification can even be nonexistent. Also, if there is a temporal distance between the team members, it can fail to reach the user in the appropriate time or can overload him or her if the number of events is too high.

In this paper we propose a semantic approach, in the sense that every object in the shared environment corresponds to a *work context* ontology¹, so that when an action attempts to change the object's state, we infer the *relevance* of the resulting event and its *consequences* from this ontological context. In addition, we define a *user context* that comprises a series of *electronic places* (logical and physical devices) or contact points as well as a preferences profile.

Both contexts allow us to infer the user willingness to be exposed to awareness information given the actual device interaction capabilities, the user preferences and the relevance of the event.

The awareness mechanism is conceptualized as a Multi-Agent System (MAS). An agent is a software process that controls its own actions (autonomy), perceives its environment (react) and can take the initiative to perform an action (proactively) in order to accomplish tasks on behalf of its user [9], [10], [11]. A MAS system can be seen as a collection of possibly heterogeneous agents.

The proposed MAS constitutes an awareness server composed of heterogeneous agents, organized as agencies responsible for delivering user awareness information (one agency per user).

Every agency comprises a pair of intelligent agents. One of them is responsible for estimating the relevance of events perceived in the shared environment, according to the proposed work context ontology. The other one is responsible for scheduling the information delivery according to the designed user context.

Each agent's knowledge is maintained in its own separate knowledge base, so they keep a partial view of the shared environment. Each agent within the agency behaves cooperatively as their actions complement each other.

Agents' communicative interaction follows the conventions described by FIPA² ACL (Agent Communication Language) standard. FIPA ACL describes a language in which communicative acts can be expressed; those acts are based on Searle's speech act theory [12] grounded in a logical framework. Agents interchange logical propositions, actions and objects referencing elements of work and user ontologies.

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¹ An ontology is an explicit formal specification of the terms in the domain and the relations among them [13].

² FIPA (Foundation for Intelligent Physical Agents) is a non-profit organization aimed at producing standards for the interoperation of heterogeneous software agents. See <http://www.fipa.org/> for further details.

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Our aim is to build ubiquitous collaborative applications, in the sense that the awareness mechanism can encounter the user, rendering the shared environment to him or her proactively.

Based on the proposed MAS we implemented an awareness server (AwServer) and developed a case study application: a collaborative web Scheduler (CScheduler).

The ontologies and their main inference criteria are presented in section 2. In section 3, we present the proposed MAS architecture. The MAS implementation and the case study are presented in section 4. Finally, in section 5 we discuss the results.

2 Semantic Awareness

Dourish and Bellotti [14] define awareness as “an understanding of the activities of others, which provides a context for your own activity”. As pointed out by [15]: *“awareness is a state of mind of a user .... that it involves the activities of others and that it provides a backdrop (‘context’) for own activities ... while awareness mechanisms are techniques employed by a system to achieve this state of mind”*

Despite there is not a precise definition, we can imply that the objective of the awareness mechanism is to support the maintenance of a shared context by the group members, so they can understand how his or her actions fit into the team’s overall goals in order to coordinate their actions [16].

But we can distinguish, at least, two kind of context related to the awareness mechanism: a work context in which the group members’ actions are interpreted and is to some extent common to group members; and a user context that involves the actual state of the user when he or she perceives the awareness information (that is, interacts with the awareness mechanism).

Passive awareness is a strategy to build awareness mechanisms, whose objective is to maintain the user informed of events without requiring him or her to make a conscious effort to do so (i.e. sending notifications through a messaging system, a mail system or something alike) [14], [17].

Due to the physical and temporal distance, the interactions that occur within a CVWG are mainly asynchronous. In this scenario, passive awareness is best suited to keep the team up-to-date to the shared environment’s actual state.

The drawback of this approach is that it requires the user to explicit his or her interest in a predetermined object (subscription), a task that the users are not always willing to perform [18]. If a designer predetermines those objects, the mechanism could be too rigid or unable to adapt to the team development.

A naive approach consists of observing every object in the shared environment, notifying any change occurred. The evident inconvenience is an information overload that neither guarantees the awareness information reception (the user can be out of reach) nor its coherent perception (if the mechanism employs different channels).

Additionally, the user context is neither static nor homogeneous. So that shared environment’s unexpected situations of use (i.e. delays in document reading due to

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time or technological infrastructure differences) are potential sources of misunderstandings, information loss and casual interaction opportunities lost [19].

The underlying problem consists of determining the *relevance* of events occurred in the shared environment, and recognizing the context in where they are perceived.

We face the problem by defining a *work context ontology* and a *user context*. Work ontology allows us to interpret the events and to define a set of rules in order to derive their relevance and consequences. User context allows us to schedule the delivering of awareness information, concerning the events taken place, in terms of user's *electronic location* and time where the user is willing to perceive the information.

To infer the user willingness we consider the relevance of the information, the user's preferences and the interaction capabilities of his or her actual *electronic location*. The next sections present the ontological contexts in detail.

2.1 Work Context

Ontology. The Workflow community characterizes work context through an explicit model of business processes. This model comprises tasks, schedules, actors, software tools and information sources and allows to determine the current activities, as well as activities' state, history and related events [20], [21], [22], [23].

This approach has a main drawback because it requires a detailed and anticipated model of the underlying process that is impossible to obtain from CVGW teams, because they conform a heterogeneous environment and do not follow strictly a standard procedure but act according to their needs and team evolution [24].

Although their contexts are built dynamically, their main components remain the same. According to Haake [25], these components define 3 categories: *Content* (software tools and shared objects), *Processes* (activities and their schedules) and *People* (people and teams). So that, work context would emerge from the dynamic articulation of these components, that is, the dynamic creation of relationships between them.

Those relationships define the semantics associated with work practice: roles, authority and responsibility, available resources, task precedence, etc. [26], [27], [28]. That is, the components and their relationships define a work ontology (Fig. 1).

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Fig. 1. Content or *SoftwareArtifacts* component comprises a set of *Applications* and a generic *Repository* of shared objects; *Process* component consists of a *ProjectPlan* composed of *Activities* and *Subactivities*. *Person* component is implemented via an *Organization* that includes *Teams* assigned to accomplish an *Activity* and *Person* instances as *Team* members. The generic operations are also presented (*AddElement*, *UpdElement* and *DelElement*)

Fig. 1 presents the ontology components and their relationships. We also present there the generic operations Add, Update and Delete, and an additional operation called RegisterLocalVocabulary.

This last one represents the operation of extending the ontology vocabulary in order to specialize it according to a specific collaborative application.

For example, in the study application (CScheduler), defining a specific activity like *fix_appointment* requires defining the domain specific concepts “appointment”, “Free”, “answer” (appointment confirmation), etc., in order to define activity preconditions and effects or goals (i.e. “Free (me, invitee)”). This is important because a precondition fail must be of interest of the Activity responsible (the team as a whole or a Boss) as well as an Activity goal achieved. Those are considered logical consequences of an Activity element (*fix_appointment*) addition.

Relevance. Events taken place in the shared environment are seen as the result of performing any of the generic operations (Add, Delete, Update) over some ontology component instance.

The semantics associated with each operation depends on the component itself (a Delete operation performed over a Person involves a notification sent to the Person itself, but also to the user that makes the call, to the team where the Person belongs, to his or her Boss, etc.). Those operations are seen as *transformation operations* [29], executed explicitly or as a logical consequence (implicit) derived from the semantic relationships of the ontology elements.

In relation to human awareness, artifacts have associated transformation operations that are performed when the artifact is used. If an artifact works well (success), it allows us to focus our attention on the main activity objective, thus the artifact is

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transparent to us (its salience is low) until it fails (failure), then it renders itself to us gaining our attention (its salience is high) [29], [30].

According to this theory, we determined some salience or relevance rules considering the result (success or failure) of performing any of the envisioned generic operations over some instance of an ontology element (Table 1). We take into account the event originator, which is the user that originates the operation (me or a partner); because the transformed artifact exists in the shared environment from which the operation is requested, but also, in each partner's environment.

Table 1. Relevance criteria of events generated when a transforming operation is executed considering its result and the perspective from which it is perceived: the event relevance to me (if I request the operation) and the relevance that it has to my partners (if I request the operation). The scale from minor relevance to a higher one is: none, low, medium, high, sure

Operation	Result	Relevance to me	Relevance to a partner
AddElement	Success	Low	Medium
	Failure	High	None
UpdElement	Success	Medium	High
	Failure	High	Low
DelElement	Success	Low	Sure
	Failure	Medium	None

For example, if a user calls an operation, which is executed successfully, the event's salience is low. That is to say, the shared environment worked well for the user, it fulfilled his or her expectations. But the salience of the event is higher for his or her partners, because for them the event is unexpected.

2.2 User context

E_Place. User context is currently a hot topic of research in the area of context-aware computing [31], [32]. In this community, user context is described in terms of the user's current location taking into account the social - at home, at office, etc. - (Office Assistant [33], GeoNotes [34]), physical - light, noise, etc. - (Tangible Bits [35]) and informational - guided tours, tourist maps, etc. - (CoolTown [36], Tourist Guide [37]) characteristics of the user's current physical environment.

In relation to user location, our focus is on defining electronic places (e_Places), which, resembling abstract *contact points*, describes the user's location in terms of its interaction capabilities and allow us to *reach* or *contact* the user.

Those represent the collection of physical and logical devices available to the user, considered as a whole the awareness mechanism interface [38], [39] (i.e. an e-mail via cellular phone, a collaborative application running in a desktop computer, a private messaging system, a WAP system, an SMS system, a beeper, etc.). Fig. 2.A presents some properties that characterizes the class (or concept) e_Place. The fea-

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tures describe the electronic place in terms of *content*, *location* and *interaction capabilities*.

Fig. 2. An *e_Place* (A) is an electronic place that resides in a physical *device* (a desktop computer, a cellular, a PDA, etc.), has an electronic address (*e_address*) and a *content* delivery method. Additionally an *e_Place* is described in terms of its interaction capabilities, those are: *portability*, degree of *synchrony* provided and *delivery* methods (pull, push or both). We present some *e_Places* as examples (B), these are: *eMailPlace*, *WebPlace*, *collabAppPlace*, *privMessagingPlace*, *cellular_MailPlace* and *cellular_SMSPlace*

Each *e_Place* is related to an electronic address (*e_Address*). Fig. 2 presents three examples: an email address (*eMailAddress*), an URL (*URLAddress*) and a network address described in terms of socket's host and port (*SocketAddress*). These types are arbitrary and could easily be replaced by an URI (Uniform Resource Locator).

For example, the *collabAppPlace* represents a socket where the collaborative application could listen the awareness mechanism in order to allow the collaborative application's developer to integrate the awareness information in the application interface. The *WebPlace* represents a Web based collaborative application (a Web site). The *cellular_MailPlace* and *cellular_SMSPlace* are associated with web services delivery so they have *URLAddresses*.

An *e_Place's content* includes its format (string or byte), length and content body (the content itself). An *e_Place's location* comprises the device where it resides (a desktop computer, a cellular, a PDA, etc.), its *e_Address*, in order to be contacted; and a method that implements the content delivery through the *e_Place*.

The *e_Place's interaction capabilities* correspond to the interaction modes that an *e_Place* affords, and is described by its portability, its delivery method (push, pull or both) and its degree of synchrony.

The degree of synchrony is an index that establishes a measure of potential synchrony that could be achieved when an interaction between the awareness mechanism and a user through that *e_Place* occurs. That is, the greater the index, the shorter the delay between communicative actions.

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Fig. 3. Examples of E_Places ordered by their *synchrony index*. E_Places resides in a *portable* device or in a *fixed* one. The example devices are a *desktop computer* and a *cellular phone*

Fig. 3 presents an e_Places' example ordered according to their synchrony capability. A negative index represents an *asynchronous* characteristic and a positive index a *synchronous* one. E_Places residing in portable devices are considered to have a higher synchrony capability than those residing in fixed devices. The presented e_Places resides in a desktop computer and a cellular phone as the figure shows, although the user could have more than one fixed device or portable device at a time.

Fig. 2.B presents some e_Places as examples. The e_Places in order of synchrony capability are: *eMailPlace*, *WebPlace*, *collabAppPlace*, *privMessagingPlace*, *cellular_MailPlace* and *cellular_SMSPlace*.

Perceptual schedule. E_Places approach, allows us to build ubiquitous collaborative applications, in the sense that the awareness mechanism can encounter the user in some of those e_Places rendering the shared environment to he or she proactively.

The e_Place's inherent interaction capabilities (synchrony) allow us to prescribe an appropriate time and interaction mode to deliver the awareness information taking into account the relevance of that information in the work context.

We do so via a schedule that relates the information with an *appropriate* e_Place (location selection) and an *appropriate* time (time selection) where the information will be perceived (it could be delayed).

Location selection. The appropriate e_Place is inferred considering the relevance of the information in the work context, but also, the e_Place from where the user requested the operation (*event source*) and his or her *current* e_Place.

The event's relevance indicates the degree of required synchrony (i.e. associating "urgent" events with e_Places with higher synchrony index).

The event source and the current e_Place describe the coupling level of the interaction (coupled or uncoupled) [24].

That is, if event source and current user location correspond to the same e_Place, then the ongoing interaction is likely to be a coupled one. The selection criterion, in this case, is to direct the awareness information to the event source (Table 2).

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Table 2. E_Place selection criterion for delivering the awareness information assuming that the user has the following e_Places options: “eMail”, “Web”, “collabApp”, “privMessaging”, “cellular_Mail” and “cellular_SMS”, in increasing disturbance degree order. The criterion takes into account the coupling level of the interaction, the current user location (one of his or her e_Places), the disturbance associated with the e_Place, and the work relevance (Table 1) to choose an e_Place

Relevance	Coupling	Required interaction	Current Location	Delivery
low	coupled	synchronous	collabAppPlace	collabAppPlace
medium	coupled	synchronous	collabAppPlace	collabAppPlace
high	coupled	synchronous	collabAppPlace	collabAppPlace
sure	coupled	synchronous	collabAppPlace	privMessagingPlace
low	uncoupled	asynchronous	WebPlace	eMailPlace
medium	uncoupled	asynchronous	Cellular	eMailPlace
high	uncoupled	synchronous	Cellular	cellular_MailPlace
sure	uncoupled	asynchronous	Cellular	cellular_SMSPlace

An exception is considered for the case related to events with the highest relevance level (sure). In this case, the criterion is to consider the next e_Place in the synchrony order that resides in the same device, in order to favor coupling interactions (*privMessagingPlace* in the example).

When the current interaction is uncoupled, the criterion is to direct the awareness information to an asynchronous e_Place. Obviously, selected e_Places must have the capability of supporting push technology. *WebPlace* is the first asynchronous e_Place, but as is a regular Web site, lacks the push capability. For this reason, it is not eligible and the selected e_Place must be the *eMailPlace*. The exceptions are those events with higher relevance (high and sure). In these cases, the criterion is to favor synchronous interaction (because they are urgent) so the selected e_Places have the higher synchrony index (*cellular_MailPlace* and *cellular_SMSPlace* respectively).

For example, when the user is outside the collaborative application, the e_Place is chosen according to the event relevance (*uncoupled* interaction), but when he or she is in the application, the mechanism will prefer the e_Place associated with the collaborative application allowing coupled interactions.

When events are the result of inference processes (implicit operations) we assume that the event source is the current user location, in order to favor coupling interaction.

Time selection. On the other hand, the delivery schedule of awareness information must take into account the *appropriate* time where the information will be perceived.

For synchronous interaction, the chosen time is the closest to the actual (now), while for asynchronous interaction, the time is chosen according to user preferences.

User preferences have been studied in the area of interface agents, indicating that they can be established from the semantics that user actions have in a specific application [9], [10], [39].

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Fig. 4. The *WEventNotification* is scheduled (*NotificationSchedule*), and render through an *e_Place*, considering its origin, the user *currentLocation*, his or her *Availability* patterns, *PerceptualHistory* (coherence) and *UserReaction*. The *e_Place* modeling is also presented

The user preferences are recorded in an *availability profile* based on relevance and time intervals (i.e. “Available (high, 8, 21)”). When an asynchronous interaction is required, notifications are scheduled to the closest *available* time for the notification’s relevance (i.e. 8am if currently is 7 am). Work events are scheduled for being perceived through *e_Places* according to availability preferences (Fig.4).

An acknowledgement must be sent indicating that the notifications have reached the user. Otherwise, the notification will increase its urgency level and another *e_Place* with a higher degree of disruption will be chosen.

When more than one event are scheduled to an *e_Place*, their precedence order is determined by their arrival order. As the user acknowledges the notification receipt, the event becomes part of the *Perceptual History* log, and the *User Reaction* is recorded in order to correct or reinforce agents’ assumptions.

3 Architecture

An *agent* can be seen as a software process that controls its actions (autonomy), perceives its environment (react) and can take the initiative to perform a behavior (proactive) in order to accomplish tasks on behalf of its user.

A MAS can roughly be considered as a system composed of multiple and possibly heterogeneous agents. MAS’ control can be distributed, so the agents that compose it must communicate among them (social abilities) in order to cooperate and accomplish their goals [9], [10], [11].

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Finally, agents require an execution environment that put at their reach, the necessary sensorial information to perceive their environment (sensor) and act upon it (effector).

In this section we describe the architecture of the proposed awareness mechanism.

Environment. Both work and user context ontologies represent the knowledge of two types of agents, a work and a user context agent, WCA and UCA respectively (See grayed boxes in Fig. 5). A pair of these agents works in a cooperative fashion, conforming an Agency, which is associated to a single user.

The agency is responsible for rendering the awareness information to the user according to the relevance of the information (inferred for WCA) and the user's current location and preferences (inferred for UCA).

A third agent, called Proxy Agent (PA) has the responsibility to put at the reach of every agency the capability of perceiving the shared environment events (sensor) and act upon it (effector).

The collection of agencies conform an Awareness Server (Fig. 5).

In Fig. 5, we present the interactions between the main components of the proposed architecture. WCA and UCA agents are represented by small heads labeled *WCA* and *UCA* respectively, which has above a gray box representing each agent's knowledge.

WCA's knowledge is structured according the work context proposed in this paper (Fig. 1); which comprises the general work ontology (labeled as "project knowledge") as well as a particular instance (labeled "domain specific knowledge") related to a specific collaborative application (the CScheduler in this case).

UCA's knowledge is structured according to the user context proposed which is detailed in Fig. 4.

In both cases we remark the kind of inference rules that apply; for WCA *relevance rules* are concerned as well as inference rules related to the collaborative application's specific domain. For UCA, the inference rules are related to the determination of the user availability, user location and notification (preferred *e_Place* and time).

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Fig. 5. Every user has an associated agency comprising a WCA agent (Work Context Agent), that infers the *relevance* of events occurred in the *shared environment*, and a UCA agent (User Context Agent), that determines the *e_Place* and time where the *notification* will be delivered. Events are propagated (perceived) to the agency through messages received by a PA agent (Proxy Agent) that broadcasts them to the entire agents' society

When an event occurs in the shared environment, it is propagated to the Agency through the PA agent (an ACL message is sent to the PA agent). If the event is related to work ontology (work context operation), PA broadcasts the message to every WCA agent. If the event is related to user ontology (user context operation), then PA sends the message to the UCA agent that conforms the user's Agency (unicast).

The communication between WCA and UCA (work event) occurs inside the Agency (unicast). User's responses to Agency notifications are also directed to the respective agent (unicast).

The awareness server can be centralized, containing all the agencies that represent each user. It can also be distributed in local servers containing the user agency, as every agent acts based on its own knowledge base (a partial view of the situation). In both cases, a single PA agent or a collection of them can be instantiated, but only one agency must be assigned to every user.

Coordination. Agent coordination within an agency is implicit in the sense that each WCA and UCA agents' behavior is designed to complement each other, so they do not need to engage in negotiations in order to fulfill their responsibilities.

Coordination is achieved through message interchange, at knowledge level. Agents' communicative interactions follow social conventions (protocols) defined by the FIPA ACL language, which is based on Searle's speech act theory [12] grounded in a logical framework. Communication occurs as an attempt of informing the agent's

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beliefs, desires or intentions (BDI) state or as an attempt to alter the agent's interlocutors' BDI state.

Messages expressed in FIPA ACL are associated with a communicative act that is described in terms of a performative (that is the communicative act type), a specific content and an ontology that is used to interpret the message content.

Messages have precise associated semantics: the content could be logical propositions, actions or rules referencing elements of work and user ontologies.

Behavior. Communication is directed, and is established between PA and WCA agents (work context operation), PA and UCA agents (user context operation), UCA and PA agents (awareness notification) and WCA and UCA agents (work event) (see Fig. 5 and Fig. 7).

In the first and second cases, the PA agent acts in its role of agency's sensor. That is, PA observes the shared environment and propagates the transformation operations occurred to the agency, by requesting WCA and UCA to perform them over the instance ontology elements of their respective knowledge bases.

In the third case, PA acts in its role of agency's effector. That is, PA is requested by UCA to effectively notify the user of an occurred event.

Finally, in the fourth case, WCA informs to the UCA agent that the former has inferred the occurrence of an event in the shared environment as a direct or indirect consequence (inferred) of a transformation operation execution.

So the types of involved communicative acts are directive (requesting an action) and assertive (informing a mental state).

Finally, agents must politely acknowledge their requests for action or information consequences. When an action cannot be accomplished, its failure and possible causes must be informed to the requester. If an agent does not understand a message due to ontology ignorance, it must be informed to the requester.

Knowledge representation. Agents' knowledge related to the devised ontologies is maintained in a separate knowledge base (KB). That is a KB for WCA and another for UCA agent.

Facts are asserted in each KB when a transforming operation is requested through PA or as a result of each agent's inference processes.

Agents' inference process (relevance and perceptual scheduling) corresponds to a rule-based system, where an inference engine is associated to the agent and its respective KB.

Facts related to the result of performing some transforming operation (events) by the agent (WCA or UCA) are asserted into the knowledge base. The defined rules derive the consequences of asserting facts (forward chaining).

Agents record or remind their inferences in order to keep the user informed of them. Agents react to their inferences initiating a behavior that has as scope the agency (informing their mental) or the awareness mechanism (state or requesting).

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Fig. 6. Screenshot from JADE's *sniffer* agent showing the messages interchanged between the PA agent and the agencies of three users: Juan (*wjuan* and *ujuan* agents), Pablo (*wpablo* and *upablo* agents) and Maria (*wmaria* and *umaria*) when attempting to fix an appointment of CScheduler. *Top boxes*, in the right side represent agents, *arrows* represent the messages interchanged and are labeled with the message's performative

JADE provides the agents' execution platform called an agents' container, which is a JVM (Java Virtual Machine) running in a host computer. Agents developed over JADE are multitasking processes where tasks (or behaviors) are executed concurrently. Message communication is asynchronous and supports some of the FIPA ACL protocols. JADE also support ontology management and mobility.

As FIPA ACL is an abstract content language, it requires an instance language. We chose FIPA SL (semantic language) instance, which defines a syntax message and the REQUEST and INFORM performatives, all supported by JADE.

As the reasoning mechanism we used the Java based inference engine JESS⁴. JESS is an expert system that repeatedly applies a set of rules to a collection of facts and can interoperate with Java applications.

In order to fulfill their responsibilities, WCA, UCA and PA agents perform a series of behaviors defined in section 3. Below we present the agents' behavior implementation as well as an outline (Fig. 7).

⁴ Java Expert System Shell. See <http://herzberg.ca.sandia.gov/jess/>

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Fig. 7. PA agent acts in its role of sensor (*API* behavior) and effector (*Notification* behavior). WCA behavior includes performing transformation operations (*GenericOperationExecution*) registering the *LocalVocabulary* (*RegisterLocalVocabulary*), executing an Activity (*ExecutionActivity*) and informing UCA of an occurred event (*EventAlert* behavior). UCA actions also include performing transformation operations, as well as keeping the current user location updated (*SetUserLocation*) and requesting the PA's effector behavior (*EventNotification*). Both WCA and UCA, also reminds the inferred events or notifications

PA behavior implementation. PA agent propagates the changes in the shared environment through an API based on FIPA ACL syntax messages (API behavior).

As agents run in a JVM, that is the entire agents' container is executed as a Java application, the API is implemented as a socket server. PA receives the messages sent from the collaborative application and determines the appropriate receiver agent type (WCA or UCA agent *type*). Then PA broadcasts the message to every other agency in the society. The message also includes the user who makes the request (actor) and the *e_Place* from where is requested.

Since the generic operations were developed as part of the ontologies, PA has the capability of "speaking" in both ontologies. API messages performative correspond to FIPA REQUEST.

PA is also responsible for delivering the notification message (*Notification* behavior), that is to say, it executes the *delivery method* (Fig. 2) defined for the *e_Place* determined for UCA (i.e. open network connections, sending mail, etc.).

Finally, as the notifications must be acknowledged, the PA implements a *Waiting* behavior, which is an execution suspension until a responding message arrives. This is possible because ACL message has a conversation id field, which is used to reply and build a conversation thread.

WCA behavior implementation. WCA agent receives PA's operation requests and reacts to them initiating a *GenericOperationExecution* behavior. That is, the agent performs the operation (AddElement, UpdElement or DelElement an element requested) and asserts the resulting action (success/failure) in its own knowledge base.

As the shared environment constitutes a domain specific application and is built dynamically, it requires a particular vocabulary and a project instance (i.e. what kind of activities?, what kind of *e_Places*?). For this reason, the API also implements a *RegisterLocalVocabulary* behavior.

Also, WCA supports the execution of ontological *Activities* defined in the *LocalVocabulary* by describing the activities in terms of logical preconditions and consequences (*ExecutionActivity* behavior). The approach allows us to implement contingent actions in order to facilitate the collaborative process (the activity execution) as the agents can engage in a FIPA Contract Net protocol to facilitate the preconditions and effects achievement.

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JESS is a reasoning engine that runs repeatedly trying to apply the rule set every time that a new fact is asserted. When a rule applies or fires, JESS notifies the event to WCA. The agent records the event (*RemindEvent* behavior) and sends a message to UCA informing that a new work event has occurred (*WEventNotification*, see Fig. 4).

UCA behavior implementation. UCA agent also receives PA's operation requests and reacts to them initiating its own *GenericOperationExecution* behavior. That is, UCA performs the requested operation and asserting the resulting action in its own knowledge base.

As the user moves through different *e_Places* (logging in and out or interacting through them), UCA performs a location updating behavior (*SetUserLocation* behavior). That is, updates the user *current e_Place*.

In a similar fashion to WCA, the JESS engine associated with UCA fires rules requesting to perform a notification. UCA records the notification to be executed (*RemindNotification* behavior) and sends a message to PA requesting it to deliver a notification (*EventNotification* behavior).

Reasoning. As described, both agents implement their reasoning capabilities through JESS. The rules based on criteria depicted on Tables 1 and 2 are defined in the engine when agents are created. Facts are defined by templates or constructs, and rules are applied based on pattern matching techniques.

That is, we defined a series of patterns formed by facts occurrence. For example, if there is an event resulting from an *AddElement* operation, and the event result is success and I am the operation caller, then the event relevance is low.

When a pattern is matched, then the rules are applied or fired.

4.2 CScheduler

The study application is a collaborative scheduler, *CScheduler*, whose main objective is to allow their users to fix appointments between two or more of them.

In order to accomplish this objective, we developed two versions of the scheduler, and associated each of them to two different *e_Places* for coupled interactions. For asynchronous interactions, five *e_Places* were built.

On the other hand, work ontology was instanced through a *LocalVocabulary* (domain specific knowledge) which implements basic concepts, predicates and functionality related to the scheduler.

In this section we describe the *e_Places*, the work context instantiation and the linkage between *AwServer* and *CScheduler*.

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E_Places. We developed two versions of this application, a Java based and a Web based version (Java servlets) and we associated them to two different SocketPlaces. Both of them have associated a SocketAddress (Fig. 2.A) where they can be contacted. So that, when the user is in the shared environment, his or her actions are recognized as a coupled interaction and the awareness information is derived to these channels (Fig. 8.A, 8.B, 8.D).

The other five e_Places were dedicated to enable asynchronous interactions, those are: an eMailPlace (Fig. 8.C), an additional SocketPlace used as a private desktop messaging (Fig. 8.E) and three URLPlaces associated with Web services for message delivery (SMS, cellular mail and ICQ).

For each e_Place, we also implemented the methods associated with the content delivery (Java Mail, Java URL and Java socket invocation).

Domain specific knowledge. As well as user ontology needs to be instantiated through the specification and construction (content delivery methods) of e_Places, work ontology needs to be instantiated through the specification of concepts, predicates and functionality (activities) related to a particular domain, CScheduler in this case.

Work ontology was instanced through a LocalVocabulary, a class that contains the definitions of basic concepts (“appointment”, “answer”, etc.) and predicates (“Free”, “Busy”) related to the scheduler domain (Fig. 1.). A special remark needs to be done in relation to activity definition (i.e. “fix_appointment”).

As we argue in section 2.1 an activity definition involves the definition of its pre-conditions (“Free (me, invitee)”) and effects or goals (“Busy (me, invitee)”), as well as a start and duration time. So that, if an activity doesn’t fulfill its preconditions when startup and hence fails to start, the consequences will be notified automatically to the responsible, in our case the user who “creates” the “fix_appointment” activity (the inviter).

Nevertheless the activities are characterized in a particular domain, its conceptual definition allow us to infer logical consequences.

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Fig. 8. Screenshots from *CScheduler*. A) The Java based application version, B) The Web based version, C) A notification received through the user eMailPlace, D) The notification through the SocketPlace associated with B) and E) The notification through the Monitor (an independent SocketPlace)

Awareness mechanism. Once the ontologies were instanced, we launched an agency for each user (“juan”, “pablo” and “maria”). Actions taken place in the applications (Fig. 8.A, 8.B, 8D, 8E) are propagated to the PA agent by sending ACL messages referred to the ontologies and the generic operations (Add, Delete, Update).

For example, we request to add a “fix_appointment” activity in order to fix an appointment. As a result, the agency schedules the activity to start “now”, then WCA validates the predicates representing preconditions (i.e. “Free (me, time_interval)” AND “Free (invitee, time_interval)”), if preconditions are satisfied, it executes the activities’ *ExecutionBody* method and verifies if the effects or goals are achieved (i.e. “Busy (me, time_interval)” AND “Busy (invitee, time_interval)”).

As the relationships among an activity, its preconditions, effects and execution (validation, execution and verification) are defined at an abstract level (work ontology), the JESS engine fires logical consequences, rate its urgency and determine the e_Place whereto send the event notification.

Fig.8 presents notifications received when attempting to fix an appointment, through the Monitor (E), an e-mail (C) and the SocketPlace associated with the Web version (an Http response). Fig. 6 presents the exchanged messages in the background between the three agencies representing users “juan”, “pablo” and “maria” and the PA agent when attempting to fix an appointment.

5 Discussion and future work

The devised architecture enabled us to build a collaborative application with a proactive awareness behavior, where the environment can reach the user, taking into account his or her preferences as well as the relevance of the event in the work context.

We believe that the approach would permit the collaborative application developer to implement complex policies from the relevance and availability criteria, as well as permitting the user to tune those criteria according to his or her actual preferences (they change in time).

However, the chosen knowledge representation does not allow us to define stronger restrictions to the relationships between ontology elements (i.e. transitive relationships, numeric quantifiers, etc.), so the logical expressions are not complex enough to allow a latter dynamic context construction.

In addition, the approach demands a large effort from the user to explicit his or her availability preferences and is not able to adapt to changes in work and user context; that is the rules are not inferred or learned.

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Finally, the user context's elements *User Reaction* and *Perceptual History* are not currently implemented. These elements are very important because they will allow the agency to adapt to user preferences dynamically.

In order to accomplish these objectives, our next step consists of employ OIL (Ontology Inference Layer) [41] for a richer ontology representation, as well as to experiment with FACT (Fast Classification of Terminologies) [42] for deriving rules.

FACT is a server that provides inference services based on concepts (ontology elements) classification. Concepts must be expressed in OIL, which is based on description logics (DL). DL allows the expression of logical propositions in modal and temporal logics.

Based on those changes we plan to include machine learning techniques to infer relationships between work context elements, and to recognize availability preferences in order to allow the agency to adapt to the teams' changes.

Finally we plan to include another agent to the agency in order to create an agency-user interface. This will allow the user and the developer to perform queries and tune the criteria, and the agency to explain its reasoning, but also to receive negative feedback from the user in order to adjust the agency's inference processes.

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