Human-human Collaboration Formalism for Groupware Tailorability in Collaborative Augmented Environments

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Abstract: In this paper, human-human collaboration formalism has been proposed to support groupware tailorability for Collaborative Augmented Environments (CAE). Our work is based on the 3C functional model proposed by Ellis. This model decomposes the collaboration into communication, coordination and production. This decomposition has been adapted to design tailorable groupware for CAE. A new concept called "distribution" has been introduced to consider the properties of collaborative and distributed 3D environment. A new formalism integrating this concept is proposed in order to adapt a groupware system to the real need of users evolving in 3D shared scene. Multi-agent technology is, therefore, used to determine the collaboration protocol between humans, through machines, over the network for implementing the desired tailorability.

1 INTRODUCTION

Computer-based collaborative tools support the transition from simple human-computer interfacing to more human-to-human interfacing mediated by computers. This emphasis on the mediation role of computers adds new technical challenges to the development of IT tools. Augmented Reality (AR) technologies are suited for mediating human-to-human interactions over the engineered facility life cycle because the combination of images and information from the real (field conditions) and virtual (plans and other engineering information) sources and the attendant interaction metaphors can be tailored to enhance group decision-making processes. AR technology benefits can be maximized for various situations if the concepts of Computer-Supported Collaborative Work (CSCW) and groupware tailorability are incorporated into the design of AR systems envisaged to mediate human-human collaborations for shared production tasks. This paper presents an investigation into how groupware principles and concepts should be applied in designing collaborative AR systems in order to support human-human collaboration.

Recently, researchers have explored how Collaborative Augmented Environments (CAE) can provide spatial cues to support group interactions. Works on this field often adopt approaches based on desktop computers, HMDs, backpack laptops and handhled devices. In this sense, several projects have been realized to develop AR for CSCW applications such as Shared Space (Billinghurst, 1998), TransVision (Rekimoto, 1996) and AR pad (Mogilev, 2002). The drawback of the developed applications is that often use AR libraries in their development and not based on a software architecture design. Other applications are based on components-based architecture design but could not support adding or modifying functionalities and services within the application. Computer Supported Collaborative Work in CAE requires the construction of tailorable groupware that supports interaction by multiple users. Tailorable groupware concepts could, then, be applied in a study for AR mediated human-to-human collaboration. The research results presented in this paper could be useful to assist in designing tailorable groupware for CAE. In this paper, principles and formalism have been proposed to design tailorable groupware for AR collaborative applications. Agents-based approach is proposed to support the human-human collaboration formalism over Internet.

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2 GROUPWARE TAILORABILITY

Several researches in CSCW domain show that tailorability is a fundamental property that should be taken into consideration when developing collaborative systems. The authors in (Stiemerling, 1999) define a tailorable application as a system that can be properly adapted to the changes and diversity of needs. The authors in (Biemans, 1999) argue that tailorability is the capacity of an information system to enable a user to adjust the application to his/her personal needs, or the task that is being done. The authors in (Bourguin, 2004) emphasizes that a tailorable application is both usable and modifiable by its users. One of the reasons that software should be tailorable is the complexity of establishing users' needs before using the application or having a task at hand. The authors in (Kahler, 2001) provide three essential reasons for software to be tailorable (1) Multidimensional diversities that tailorability must take into consideration in order to implement a software able to support different uses, (2) the dynamism of individual and organizational work that matches the changing nature of work, forces the software itself to change over time, (3) the uncertainty and ambiguity due to work practices require the use of alternative methods to achieve tasks.

For Collaborative Augmented Environment (CAE) other reasons make that the tailorability is necessary such as (4) the evolution of AR interfaces (changing states of 3D visualization data and 3D interactions, distribution of 3D data and tasks, etc.) and (5) the constraints due to the AR environment (tracking, scene recognition, occlusion, brightness, etc.).

In our work, multi-agent systems will be used to build tailorable groupware for CAE. In fact, software agents have been successfully used for implementing collaborative architectures. They increase the capacity of systems to become autonomous and intelligent while exchanging and distributing 3D data and tasks within Internet. An important benefit of software agents is their ability to provide flexibility in human-human collaboration.

2.1 The 3C Model

Our approach is based on the 3C model proposed by Ellis, shown in Figure 1 (Ellis, 1994). According to this functional model, a groupware is described by three specific functions: communication, coordination and production.

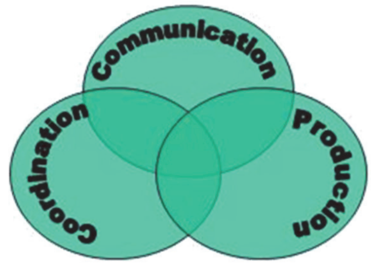


Figure 1: 3C's Ellis model.

The communication space allows actors exchanging a set of information. The coordination space defines the tasks to be achieved in order to produce objects in the production space. The latter represents the objects resulting from the activity of the group.

There exists several works that adopt the 3C model for constructing collaborative applications (Laurillau, 2002), (Fuks, 2007), (Oliveira, 2007). One of the advantages of this decomposition is to help evaluators focus their attention on the communication, coordination and productions aspects of the application for identifying usability problems (Fuks, 2007). In this paper, the decomposition of Ellis (Ellis, 1994) is adopted in order to design tailorable groupware for CAE, this, based on the advantages of software agents concepts. With this model the three main aspects of the collaborative work will be preserved.

2.2 Multi-Agent Systems

The authors in (Khezami, 2005) have identified an agent as a computing object (in the sense of object-oriented languages) whose behaviour can be described by a script with its own means of calculation, and can move from a place to another in order to communicate with other agents. According to (Maamar, 2003), an agent is a piece of software that acts on an autonomous basis. The agent shows a number of features that differentiate it from other traditional components, including self-direction, collaboration, continuity, character, communication, adaptation, mobility and temporal continuity.

3 HUMAN-MACHINE-HUMAN COLLABORATION

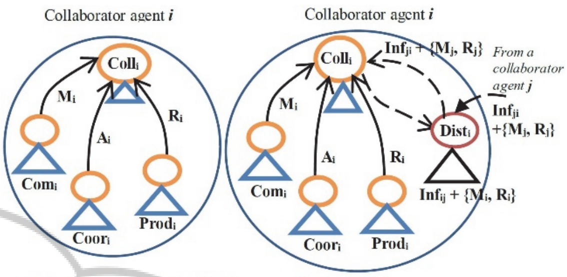
Software engineering methods give way to new development paradigms, including component based and agent-based approaches. These approaches gain a lot of attention, where passive software components are remedied by the dynamics and social character of software agents. Indeed, agents-based technologies provide new mechanisms for components in order to engage in tasks as well as cooperate and process the requirements of dynamic and heterogeneous environments.

One of the multi-agent systems developed for groupware we can cite the C4 model (Khezami, 2005) dedicated to the collaborative teleoperation through Internet. This model is based on the PAC* model (Khezami, 2005) that proposes three agents dedicated to the three spaces of the 3C model, this, to ensure the modularity of the system. In addition, the C4 model proposes a fourth agent: Collaboration agent. The combination of these four agents constitutes the "Collaborator Agent". Despite the advantages of this approach, this model does not consider the distribution of information, data and tasks, especially, in AR collaborative environment. It focuses only on collaboration aspects between communication and coordination agents. Thus, we propose to enrich this model by adding “Distributor agent” responsible for integrating distributed aspects of AR collaborative environment. We obtain in our configuration the C5 model (Figure 2).

In the other hand, the collaboration using C4 model is limited to communication and coordination of tasks; the result produced by a collaborator agent is not communicated to its counterpart, whereas it’s necessary in VR & AR applications. Indeed, collaboration in VR/AR concerns usually the visualization and manipulation of virtual objects (translation, rotation, zoom, etc). In most of VR/AR applications, it is necessary for each collaborator to see the result performed by its counterpart. For some applications, it is necessary for each collaborator to have the viewpoint of its counterpart.

Even if (Cheaib, 2011) have proposed a collaboration protocol based on web services between machines over the network in order to exchange common services, this protocol does not allow the agents, not concerned by the collaboration, to have a copy of the exchanged services and data. Also, the exchanged services concern only communication and coordination results (the production result are not exchanged). On the contrary, in our case, the distributor agent play the role of distributing production results issued form collaboration in AR distributed system. For example, a user, in collaborative AR space, may view the tasks performed by other users and the state of virtual objects manipulated.

In our case, the C5 model integrates the relationship between production agents of different collaborator agents. Therefore, the collaboration is not restricted to communication and coordination as presented in the C4 model, but it can be extended to the production and distribution sides.



a. C4 model (Khezami, 2005) b. C5 model

Figure 2: Internal interaction in a collaborator agent *i*.

3.1 Collaboration Formalism

We propose to enrich the C4 model by integrating “Distributor agent” in the collaboration agent proposed in (Khezami, 2005) and enriched by (Cheaib, 2011). Also, we integrate a relationship between production agents. We, therefore, obtain, new formal model of collaboration (C5 model) which is based on multi-agent systems. This model integrates the properties of software agents and the characteristics of the production and distribution in addition to communication and coordination considered in the C4 model. Moreover, we make the C5 model more dynamic and proactive.

In the C5 model, a software agent can be described by a pair of dynamic system $< i, w >$ where the agent has only one global state in relation to the collaboration task. A world w of an agent i is dynamic and changing at every action or reaction of the collaborator agent. This world w is modelled by:

- E represents the environment in which a collaborator agent evolves. It’s represented by other collaborator agents of the environment that collaborates with this agent.

- Γ is the set of actions produced by an agent that modifies the world’s evolution. In our configuration, Γ is composed of four subsets $\{Inf_{ij}\}$, $\{Action_i\}$, $\{Result_i\}$, $\{Dist_i\}$ (equation 1).

$$\Gamma = \{\{Inf_{ij}\}, \{Action_i\}, \{Result_i\}, \{Dist_i\}\} \quad (1)$$

Inf_{ij}: a set of information sent by the agent i to other agents j of the environment that collaborates.

$Action_i$: a set of actions executed by the agent i.

$Result_i$: a set of results issued from the execution of actions of the agent i.

$Dist_i$: a set of information, actions and results of the agent *i* distributed to other collaborator agents of the environment.

The distributor agent is designed such that its response time and latency should be reduced to a minimum when it distributes results of production space.

- Σ is a set of agent states. For us, a collaborator agent has four states: communicate, coordinate, produce and distribute (*comm*, *coor*, *prod*, *dist*). Equation 2 describes the content of Σ.

$$\Sigma = \{comm, coor, prod, dist\} \tag{2}$$

- $Percept_i$ is a set of stimuli and sensations that composed of four subsets $\{Inf_{ij}\}$, $\{Action_j\}$, $\{Result_j\}$ and $\{Dist_j\}$ (equation 3). It represents a behaviour function depending on agent data Fi.

$$\forall j,\ Percept_i = \{\{Inf_{ji}\}, \{Action_j\}, \{Result_j\}, \{Dist_j\}\} \tag{3}$$

Inf_{ji}: a set of information received by the collaborator agent *i*.

$Action_j$: a set of actions executed by the collaborator agent *j* of the environment, other than the collaborator agent *i*.

$Result_j$: a set of results produced by the collaborator agent *j*, other than the collaborator agent *i*.

$Dist_j$: a set of information, actions and results of the collaborator agent *j* distributed to other collaborator agents *k* of the environment which aren't in collaboration with the agent *j*.

- *Pi* is an agent perception function (equation 4): set of perceptions that the agent receives.

$Pi: \Sigma \rightarrow Percept_i$

$$\forall j,\ \{comm_i, coor_i, prod_i, dist_i\} \rightarrow \{\{Inf_{ji}\}, \{Action_j\}, \{Result_j\}, \{Dist_j\}\} \tag{4}$$

- *Fi* is an agent behaviour function that determines the agent's state from its perceptions and its previous state (equation 5).

$Fi: \Sigma \times Percept_i \rightarrow \Sigma$

$$\{comm_i, coor_i, prod_i, dist_i\} \times \{\{Inf_{ji}\}, \{Action_j\}, \{Result_j\}, \{Dist_j\}\} \rightarrow \{comm_i, coor_i, prod_i, dist_i\} \tag{5}$$

- $Infl_i$ is the agent action function, which modifies the evolution of the world by producing influences (equation 6). A collaborator agent, being in a given state, and following this state, could produce information that changes its evolution and the evolution of other collaborator agents in the system. In the other hand, this parameter represents a production function of the influences depending on the agent's behavior.

$Infl_i: \Sigma \rightarrow \Gamma$

$$\{comm_i, coor_i, prod_i, dist_i\} \rightarrow \{\{Inf_{ij}\}, \{Action_i\}, \{Result_i\}, \{Dist_i\}\} \tag{6}$$

- *R* represents a law of evolution of the collaboration (equation 7).

$R: \Sigma \times \Gamma \rightarrow \Sigma$

$$\{comm_i, coor_i, prod_i, dist_i\} \times \{\{Inf_{ij}\}, \{Action_i\}, \{Result_i\}, \{Dist_i\}\} \rightarrow \{comm_i, coor_i, prod_i, dist_i\} \tag{7}$$

3.2 Collaboration Process

Figure 3 shows the collaboration process of three collaborator agents (collaborator agent *i*, collaborator agent *j* and collaborator agent *k*.) The collaborator agent *i* is the agent that starts collaboration process with the collaborator agent *j*. All information between two agents are represented by "*$Mission_i(M_i)$*" that represents the mission chosen by the communication agent *i* and the communication agent *j*. "*$Actions_i\ (A_i)$*" and "*$Actions_j(A_j)$*" are actions defined by coordination agent *i* and coordination agent *j*. "*$Resluts_i(R_i)$*" and "*$Results_j(R_j)$*" are the results of execution of tasks of production agents *i* and *j*.

A collaborator agent *i* has four states: communicate, coordinate, produce and distribute ($comm_i$, $coor_i$, $prod_i$, $dist_i$). The transition from a state to another depends on the perceptions that the agent receives. When receiving a request for collaboration $\{Inf_{ji}\}$ from an agent *j*, or the perception of a need to collaborate that the collaboration agent triggers, the collaborator agent switches to the communicate state, where he communicate with its counterpart executing the communication function ($f_{icom} \in Fi$) through the communication agent, this function returns the new state of the collaborator agent which is either $comm_i$ (communicate state) if the communication process is not completed or $coor_i$ if it is. On the coordinate state, the collaborator agent execute the f_{icoor} function $\in$ Fi that allows the collaborator *i* to coordinate the operations with its counterpart by the coordinate agent. Once the coordination ended, the collaborator agent switches to the produce state ($prod_i$) where the production agent executes the $actions_i$ arising from the previous state and produces a set of results that are communicated to the collaboration agent that instructs the distribution agent, to share the relevant data and tasks with the "team work"; during this procedure the collaborator agent passes to the distribute state ($dist_i$).

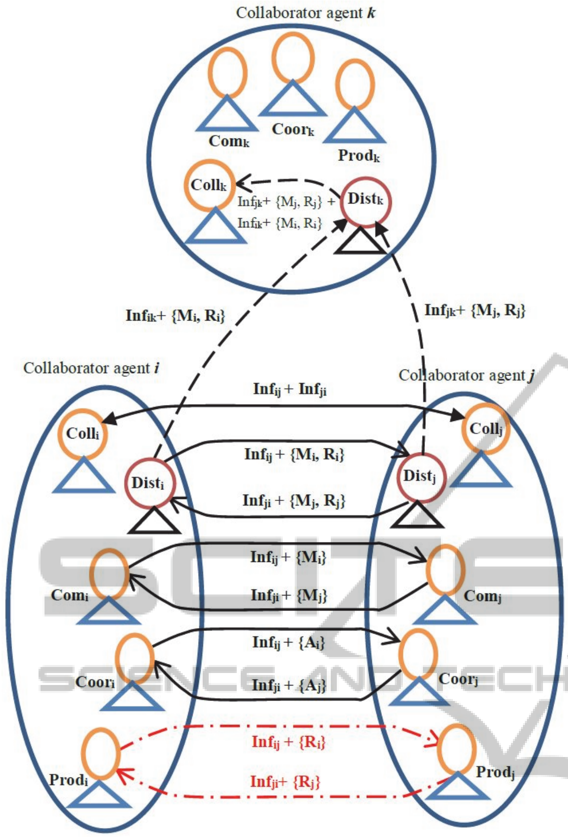


Figure 3: External interaction between multiple agents in C5 model. The agent *k* is not involved in the collaboration process between agents *i* and *j* but it belong to the same working group of these two agents.

To facilitate the collaboration process and avoid that the distributor agent produce an explosion of messages in the system, our collaboration network was decomposed into collaborators groups. Each collaborators group share the same augmented working environment. The corresponding collaborator agents in the same group communicate information and coordinate their actions together, and produce a set of results. Once the collaboration completed, relevant data and tasks are shared through the distribution agents of the concerned collaborators group without affecting the other groups. Thus, each agent in the group could have access to the results of the agents that collaborate.

4 GROUPWARE ARCHITECTURE

In this section we adopt the same approach as presented in (Cheaib, 2011) to design our software architecture (Figure 4) for building a tailorable groupware. The latter is based on the integration of software agents where the formalism is presented in the previous section.

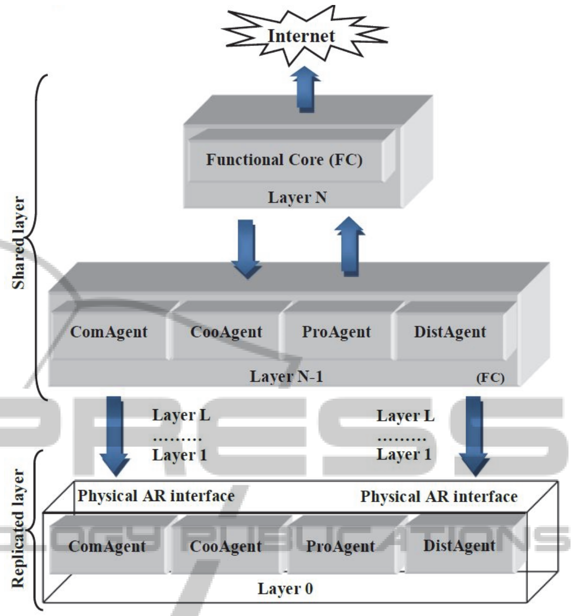


Figure 4: Groupware architecture.

We based on the Arch model (Bass, 1992) to distinct the functional core and the physical interfaces of the system. Thus, our functional core is connected to Internet to engage the collaboration protocol with other users using machines over the Network. Furthermore, we use Dewan's model (Dewan, 1999) in order to construct our groupware system in the form of shared and replicated layers. The shared layers are represented by two highest layers (Layers N and N-1) corresponding to the FC of the system. The replicated layers are the lowest layer of the system. They represent the material (physical) level that implements the interactions with users. Figure 4 shows our groupware architecture based on Dewan's model.

Our groupware architecture is composed of a root representing shared layers, meaning that it is shared among all the users in the system, and several replicated layers for every user. The layers communicate vertically using interaction events, and use collaboration events (formalism presented) for the interaction human-machines-human over the network. The FC in our model is represented by two layers that are both shared and constitute the root of the system, in contrast to the clover model (Laurillau, 2002) where the FC is split into two layers: one private and shared, while the other is replicated and public.

5 CONCLUSIONS

In this paper, we have proposed a human-machines-human collaboration formalism to implement groupware tailorability in collaborative context of augmented reality. Also, we have suggested software architecture for groupware based on the proposed formalism. The originality of our model is the use of multi-agent approach in order to generate tailorable and interoperable groupware architecture for collaborative augmented reality environments. In fact, the functional breakdown in the software architecture proposed will result in a greater modularity which reduces the complexity of groupware's implementation.

We believe that the work presented in this paper is a first step towards shifting the agent technologies' into tailoring CSCW systems. For our future work, we aim to extend the collaboration formalism discussed in this paper to the machine-machine collaboration over Internet this by using Web services technology.

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