INTERVAL BASED INTEGRATED REAL-TIME COORDINATION FOR MULTI-AGENT SYSTEMS

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Abstract: Real-time computations in agent based simulations and (serious) games possess an inherent element of temporal relationships as well as time constraints for their performance and utility measures. Such time relationships and temporal constraints can be observed in individual agent behaviors as well as coordination process involving multiple agent. The temporal relationships and time constraints in multi-agent coordination come in terms of message passing, resource management and negotiations. The idea behind such temporal relationships and time constraints is to efficiently handle complex interactions as different patterns of coordination emerge as per the updated situations under certain time durations. Here we propose our position about integrating both dimensions of individual and collective coordination in a unified manner where the coordination patterns are expressed through Allen's interval paradigm. We also introduce concept of "timers" to ensure real-time with explicit expressiveness of the interval paradigm.

1 INTRODUCTION

One of important issues in multi-agent systems (MASs) based games and simulation is to deal with the interaction of the user(s)'s actions at one end while keeping track of internal coordination of the game/simulation objects. In most of the situations, users need to interact with an application with little care of number, time or resource availability of participating game/simulation characters. However, if these aspects of interaction are taken for granted, the results may appear in either irrelevance to the real situation or very poor user interaction.

The problem becomes more clear when we visualize evolution of user actions and games objects' internal interactions. Different scenarios emerge as the system progresses as a result bringing complex patterns of coordination. The games need to introduce increasing complexity, maintain user interaction with the game and progressively difficult scenarios to keep up the user's attention. Although all these aspects need to be carried on throughout the game but defining every user, game interaction brings a quite cumbersome and bulky task for the game designers. Here we are particularly interested in addressing coordination in agent-based simulations and (serious) games in a way that complex patterns of temporal coordination are expressed through very minimal primitive time relationships between two events. We suggest Interval script paradigm (Pinhanez et al., 1997) based on Allen's Algebra (Allen, 1984) to express temporal relationships in real-time coordination for agent-based (serious) games and simulations. Here we argue that it is not only possible to express all temporal aspects of coordination through a limited set of time relationships but it may bring the "real-time" phenomenon for these application domains by introducing "timer" mechanisms.

The rest of article is structured as follows: the first section discusses some motivations from earlier works and real world scenarios for investigating coordination issues; then the following section is about characterizing some key aspects of coordination and influence of "real-time" on them. We then describe integrated approach of real-time coordination; then a basic discussion on interval paradigm's possible usage in the integrated real-time coordination is presented and finally, we conclude the article by a conclusion and future works of this study.

2 MOTIVATIONS

Real-time systems and multi-agents systems have individually contributed to many complex, heteroge-

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neous and diverse real-world applications even before joining hands to be applied in domains particularly known for distributed, time-critical and autonomous features. A transfusion of both disciplines has shown quite interesting results in diverse domains ranging from sensor networks (Sierra and Sonenberg, 2005) and (Soh and Tsatsoulis, 2005) to virtual class rooms (Liu et al., 2003) and from e-commerce applications (DiPippo et al., 2001) to soccer robots (Kim et al., 1997). Apart from these applicative studies of multi-agent and real-time systems, many works have tried to define, develop and implement efficient agent models presenting features of both disciplines (like (Julian and Botti, 2004) and (Julian et al., 2004)) Some others have focused on frameworks simulating such real-time agents (Micacchi and Cohen, 2008); even others align to developing joint architectures for such type of agents (Soler et al., 2002) and (Carrascosa et al., 2008)

However a fundamental issue of coordinating MASs under real-time constraints has remained largely unaddressed, even if some of works which have tried to address the agent coordination are limited to focus on only one aspect of coordination instead of addressing the issue in an integrated manner. Our motivations to address the problem has theoretical as well applicative inspirations. From the perspective of applications, most of the real-time MASs are functioning in resource-constrained environments.

In agent-based (serious) games and simulations often situations presume a real-time behavior in game and simulation objects' behavior as well their interaction, communication and resource sharing. Taking a simple example of a war jet in a game, it assumes that when it is launched it has real-time perception of enemy attacks, devising updated strategy of further plan (reasoning), receiving and delivering message instantaneously(message passing), sharing air space with other fellow pilots (resource sharing) and ability for collected decision making (reaching an agreement as a result of negotiations) all at once. Hereby, addressing only one aspect of temporal constraints may not address the overall issue but probably bringing serious challenges to the performance and utility for the users. Although the problem seems quite challenging one and addressing all aspects of individual agent performance and interaction with other agents at each instant of time even unrealizable but here we suggest a mechanism which introduces constraints on particular time relations. The time interval relationships phenomenon introduced by James Allen in (Allen, 1984) suggests introducing temporal relationships based on 13 primitive relations. These time relations like a description based on what to do after/before/meet another interval. We find this line of research quite interesting for agent based games and simulations due to simplicity, explicit expressiveness and generalization of the interval algebra. As the formalism is based on Allen Algebra's 13 primitive time relationships so almost all temporal aspects of coordination are expressed through primitive relationships; similarly time relationships' explicit characterization brings a clear picture of the coordination at any particular instant; finally, as we per our fundamental thesis that all aspects of temporal constraints need to be addressed under one roof, here this model fulfills the condition in a very general manner. This "position" nature of our work examines agent coordination studies at different levels and suggests an integrated as well comprehensive framework for efficient "real-time coordination".

Having a brief idea about the implications of "time factor" in agent coordination, now we individually describe the factors involved in amelioration of "time factor" in agent computations as argued by Mahdi et al. in (Mahdi et al., 2010). By description of these "performance contributors", we argue that these processes may be viewed as constituting aspects in global agent coordination process for an integrated view of "real-time coordination" in MASs. Here we describe different studies on these "performance contributors" and their role in integrated and comprehensive understanding of "real-time coordination" of MASs.

3 TIME NOTION UNDER DIFFERENT ASPECTS OF AGENT COORDINATION

3.1 Time in Message Passing

Assuming agents process incoming messages atomically as soon as they receive them (or buffered in the message inbox), we need to take care of how much time it takes to deliver a message. Having timing constraints on the delivery of messages may play a substantial role in managing temporal behavior of the overall system. Embracing monitors that ensure timely dispatch of the messages do not have to come in conflict with the timing constraints in message processing in a way that message delivery is not to breach the agent encapsulation of how and when the message is processed, rather it's sole concern would be about timely delivery of the incoming messages.Jamali et al. (Jamali and Ren, 2005) suggest similar approach for MASs in resource allocation. Although the approach works quite nicely, but its performance improvement is limited to resource management, in other words, it covers only one aspect of real-time performance in MASs.

3.2 Time in Agent Reasoning

Once a message is passed to the concerned agent, it may take time some time to read the message, evaluate the contract content and subsequently reply in denial or follow the message contents. If time factor is not involved in such message processing or agent reasoning it would unnecessarily affect the agent performance resulting in delay of overall coordination process. Many works of Julien et al. (like (Julian and Botti, 2004), (Julian et al., 2004) and (Soler et al., 2002)) are addressed on development, design and implementation of real-time agents without considering coordination as the main subject of studies. Here we need to make such models enough flexible with other real-time computations like the above mentioned ones. In absence of timing constraints the system processes the messages may take too much time and leading to affect the overall progress of the system.

3.3 Time in Resource Management

Agents being part of open systems compete for resources due to sharing of independent computations. Such competition to acquire resources leads to functional and non-functional dependencies. Functional dependencies are about whether sufficient resources are available or not, how to acquire and release certain resources and how to deal with multiple requests of the same resource at the same time. By non-functional dependencies, we mean that availability (or at least information of unavailability) of the required resources in certain time bounds. Such availability or unavailability information would be seen as an important factor in overall agent coordination. Here we need to manage autonomy of agents in a way that agents are not to be let to accumulate all the resources so here some type of resource management behavior is also recommended. Jamali et al. (Jamali and Ren, 2005)'s work on real-time resource allocations is seminal on the subject that it not only ensures real-time in resource allocations but also handles excessive resource acquisitions problem common to agents based on actor model.

3.4 Time in Negotiations

Although agent coordination doesn't imply cooperation but many times coordination is seen as a cooperative process to maintain heterogeneous body of agents in an environment. Agent negotiations are used as a means to reach an accord through communications. Agent negotiations are usually seen as a compromising tool to mutual benefits of efficient resource usage and task distribution. Despite benefits of reaching an agreement, agent negotiations process is presumed as a costly and time consuming practice. When agent negotiations are left to work on their momentum it would not only delay the coordination process but also consume unnecessary resources. A model for real-time agent negotiations for sensor networks is presented in (Soh and Tsatsoulis, 2005), other important works on the subject include Kraus et. al(Kraus et al., 1995) and Fatima et al. (Fatima et al., 2002) but both of these works address negotiations to be constrained by time rather than directly treating it as real-time issue.

After a brief introduction of different real-time mechanisms in MASs, we return to our earlier proposition that coordination should be viewed as a meta-collection of different aspects based on an integrated approach covering all aspects of coordination. Here we briefly discuss our proposition of an integrated real-time coordination mechanism suggested for fully realizing real-time through all aspects of temporal behavior.

4 INTEGRATED REAL-TIME COORDINATION FOR MULTI-AGENT SYSTEMS

Coordination in MASs has been studied from different perspectives of "real-time", namely reasoning, message passing , resource management and negotiations. All these perspectives of real-time coordination can be seen as "aspects" or "dimensions" in overall agent computation and coordination process. Real-time distributed computing processes can be viewed as a composition of aspects (instead of a single coordination process) where each process coordinates with its comprising components along with other subsystems at its stage while being part of the global coordination process. There are two approaches to see the real-time coordination in MASs:

- Incorporating time constraints on individual processes and coordination of any of the individual process would of course bring amelioration in the performance of that system but not at the optimum level.
- Setting up a meta approach of real-time as well as coordination in a way that the coordination is in-

volved at all aspects' level which improves overall real-time performance of the system at global level.

Our vision to see real-time agent coordination distinct from other coordination mechanisms may prove useful in understanding both coordination as well as real-time performance of MASs. Due to the differences in the architectures and performance measures of different systems we suggest an integrated treatment of "real-time" problem at the level of each aspect. Human societies also adopt coordination mechanisms which may involve myriad aspects, at some extent seem even irrelevant but after all serve a global purpose. Like an office working procedure may adopt different procedures and aspects for their coordination and time constraints but after all it serves timely performance of the main objective. Real-time MASs have special architectural foundations and design aspects current approaches in real-time agent systems were not set forth with those considerations therefore there is a performance as well as efficiency gap in effective agent coordination. Earlier studies on the subject have either dealt scalable agent coordination (Durfee, 2001) and (Durfee, 2004) or particularizing coordination for different application domains (like (Liu et al., 2003) and (DiPippo et al., 2001)). As per our knowledge we haven't seen studies on real-time agent coordination which involves real-time in all aspects, although similar studies are carried out in robotics and communication domain from the perspective of coordination (Bouroche et al., 2006) and communication(Mock and Nett, 1999).

5 ALLEN'S ALGEBRA FOR INTERVAL-BASED INTEGRATED COORDINATION

Given any situation of integrated coordination different agents' possible temporal interactions can always be expressed through disjunctions of Allen's primitive time relationships between two intervals. A major bottleneck in integrated coordination has been the expressiveness of the interactions at each instant of time and the severity of the situation increases with any attempt of describing all possible time points with all four dimensions. The result of such situation emerges in such a complexity that it becomes almost impossible to track interactions even if temporal constraints are not there. Some of the primary motivations include unavailability of some strict timers to handle the constraints (i.e. It is more inclined to timely completion of agent intervals than interrupting them unnecessarily); then there is relatively smooth and convenient job at the programmers' end that they have to handle only the relevant relationship for any time instead of managing all time instants; also the notion of disjunction of intervals can be incorporated to define multiple paths and interactions in a coordination mechanism, which makes it the best candidate mechanism for any integrated approach; and finally a programmer can integrate quantitative aspects of temporal behavior through introducing timers to the qualitative notion of time interval as per our requirements.

Interval script paradigm (Pinhanez et al., 1997) based on Allen's Algebra (Allen, 1984) to express temporal relationships between two interval. The paradigm uses basic thirteen relationships(summarized in Fig. 1) to express all type of possible temporal relationships among agents. The temporal relationships provide an explicit declaration of time intervals between agents at one hand through limited number of time relationships; on the other hand it is enough flexible to determine implicit relationships between different agent (like if agent A is BEFORE interval agent B and B is BEFORE agent C, it can infer that interval agent A is BEFORE C). Based on our proposed integrated approach of coordination we suggest that almost all of coordination patterns can always be expressed through disjunction of these these primitive time relationships. Taking a game object's coordinating with other game objects can occur when the object either STARTS or FINISHES or happens DURING or is EQUAL to the interval when the game object is in movement. In other words, the time relationships between a game object's movement and interaction can be described by the disjunction of START,FINISH,DURING,EQUAL. Similarly an agent's behavior, negotiations and resource

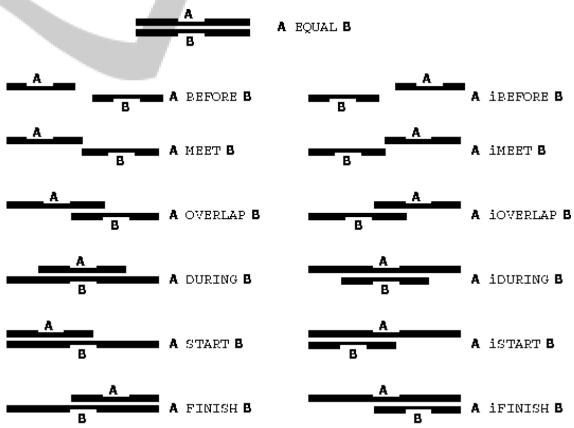

Figure 1: The possible 13 primitive relationships between two agents (Allen, 1984).

management can be expressed through these primitive time relationships as in real occurrence any one of the relationships can happen at a time. The main task for the designer to do is determine the relationships between the agent intervals along with defining corresponding sensing and actuating routines for the game objects.

5.1 Introducing Timers

Although one of the defining characteristic of the interval paradigm is that it does not require any explicit specification of the interval duration but as in our case we address real-time issue we need some specific time references. Hence, we suggest some timer mechanism for an interval agent in a way that we have a desired and actual constraints on the intervals as suggested by (Pinhanez et al., 1997). The desired interval can be used for turning the timer on and off under specific time constraints; while actual interval is used for triggering other actions as the timer expires. The usage of desired constraints ensures time constraints on the interval agents while actual timers are about the solution enough generic to handle normal routines where there is not any involvement of time constraints.

5.2 Integrated Real-time Coordination for Agent-based Games and Simulations

Again taking the earlier mentioned example of a war jet in a game, we can describe possible time relationships and temporal constraints in a scenario. Considering space limitations and position nature of the paper here we provide only few situation where the interval phenomenon shows its applicability and simplicity to apply:

- When a jet flies, wait for a message from the base station BEFORE launching any attack.
- When in the air, in case of attack iBEFORE (after) change the position to x units.
- When an enemy jet MEET your targeted range do not wait for the message.

similarly all other temporal relationships of agent reasoning, communication, negotiations and resource management can be explicitly expressed through a limited set of 13 primitive time relations; in addition to that the "timers" can be implemented that in a way that how many time units to wait BEFORE launching an attack or any other situation in the game.

One of most difficult aspect of agent behavior and coordination comes in keeping track of different activities of game/simulation objects in the case of integrated coordination. It is often the case that in an attempt to address all aspects of coordination the user is unable to track even a single aspect and in our case of real-time coordination it becomes even more difficult. The problem can be handled through the interval approach in a way that there are conditions on the time relationships rather than time instants however to maintain the real-time spirit timers ensure all temporal constraints.

6 RELATED WORKS

Allen's interval algebra has been used in different application domains as a means to provide a delicate balance between explicit expressiveness and efficiency of its deductive engine. PNF calculus based on Allen's interval algebra developed by Pinhanez and Bobick(Pinhanez and Bobick, 1996) for defining a method to propagate occurrence information through a network of intervals. The PNF calculus based scripts were used by Pinhanez et al. in (Pinhanez et al., 1997) for testing a story-based, interactive system named SingSong. The system provides reactive and interval script following computer-generated partners to the human performers. Another important work using interval script paradigm is handling visitors' musem intelligent visits intelligently(Pinhanez and Bobick, 2003). The work handles time intervals for visitors' information, but once it discovers that the visitor has changed its visiting course, modifies its intervals as per the visitors' latest location.

7 CONCLUSIONS AND PERSPECTIVES

Here in this position paper, we have tried to understand the peculiarities of integrated real-time coordination for MASs. We suggest that current approaches on the subject present some serious concerns for understanding and applying coordination models in MASs. Here in this paper, we have argued that real-time coordination has some different implications when viewed from a global perspective of "real-time" at different levels of multi-agent computation and coordination. We are of the view that, in order to support efficient coordination mechanisms for real-time MASs, we need to understand the key differentiating factors that make real-time coordination different in MASs. We have discussed different aspects of "real-time coordination" in MAS and suggested an interval based paradigm to address the particular related issues. Finally, we suggest "timers" to introduce real-time in interval-based integrated real-time coordination.

The approach discussed here would let both MAS and real-time communities to see each other's requirements and prospectus in their domains. More precisely, the agent community to see coordination in MASs deal differently than it has been and the real-time community to take a more realistic picture about the agents' functionality and effectiveness in MASs. Clearly there is much left to be done. As a future work, we plan to work on a formalism based on Allen's interval algebra for our suggested approach for integrated real-time agent coordination.

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