An Overview of Agent Coordination and Cooperation

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Abstract. By their very nature, intelligent agents possess four important social abilities. These include the ability to communicate, cooperate, collaborate and the need to be coordinated. This paper presents an overview of two of these social abilities, that of being coordination and cooperation. The discussion develops the theory of each and derives the current definitions. The definitions will then be linked into a single multi-agent system (MAS) model, Agent Coordination and Cooperation Cycle Model. This shows a cognitive loop that replicates the link between coordination and cooperation in systems such as organizations, management and biological systems. This paper will also present the advantages, consequences and challenges associated with the implementation of Agent Coordination and Cooperation Cognitive Model (AC^3M) within intelligent multi-agent systems.

1 Introduction

There are many applications where agents are designed or based on human behavior. Most have some form of HCI that communicate in a human-like fashion. The personification of agents is possible using a single agent [1] and is proving more successful in MASs [2].

Bratman (1990) introduces Practical Reasoning and discusses how personification can lead to an agent's ability to possess desires, values, cares and beliefs [6]. Rao and Georgeff (1995) further explain this definition based on an agent's actions [7] in order to achieve its objectives. The essential characteristic of the state of the environment is representative of the informative component and is seen as the *beliefs* of an agent, while priorities and rewards associated with the completion of tasks are seen as an agent's *desires* to complete a specific goal.

Finally, the current chosen course of action provides an agent with a deliberate component and can be seen as the *intentions*. Wooldridge (2002) illustrates how these characteristics combine into the Beliefs, Desires and Intensions (BDI) framework [8] called the Practical Reasoning System Architecture.

The introduction of the personification into agents has set the stage for the research in agent interaction [1, 2], and has been heavily focused in the social abilities of coordination and cooperation. The decentralised nature of personification enables the development and implementation of organisational structures and behavioural strategies using coordination and cooperation within MASs [2].

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2 Multi-agent Interaction

Broadly speaking, interaction can be defined as the formation of a dynamic relationship of two or more agents through their influential actions [3]. Interaction between agents occurs either through direct or indirect contact in a mutual environment. Communication is an integral part of interaction but does not have to be direct. It can be indirect by means of a resulting action. Communication in MAS can be implemented either as message passing or data transactions to the agent or its environment [4]. Weiß (1999) also include competition and negotiation as important attributes of interaction [5]. This paper concentrates on cooperation and coordination in MAS.

3 Coordination and Cooperation Theory

3.1 Introduction to Coordination Theory

Ehlert and Rothkrantz (2001) discuss a simple way of managing coordination via task allocation methods [4]. They classify task allocations as: centralized, distributed or emergent in nature. Using centralized allocation, one central 'leader' conducts task distribution either by imposing tasks upon agents (hierarchical downwards through coordination or delegation) or by trading/brokering tasks (hierarchical upwards through cooperation or liaison). Using distributed task allocation, each agent attempts to obtain the services it requires from other agents either by sending requests to agents whom it knows have the required services or by sending requests to all agents and accepting the best offer. Alternatively emergent cooperation, is the characteristic of reactive systems, where each agent is designed to perform a specific task, therefore no negotiation is necessary. It is important to note that task allocation may not always be adequate in attaining a goal as some tasks may require additional coordination methods such as planning, synchronization and learning.

Prior to this Malone and Crowston (1990) focused on the notion of coordination theory by describing how the actors or objects work together harmoniously [9]. These key arguments include the need to subdivide goals and deciding how these actions can be assigned to one or more agent. They also identified resources usage as a critical factor for success [9] and defines coordination as: "… *the act of working together harmoniously* …" By refining the definition of each keyword a simple, but powerful definition of coordination is established as:

> *"The act of managing interdependencies between activities performed to achieve a goal"* [8].

Based on this definition, four distinct components of coordination must be examined. They include actors, activities, goals and management of interdependencies [9]. More importantly, three interaction processes need to be clarified: group-decisions, communication and the perception of common objects [9]. Malone and Crowston (1990) provide the taxonomy of these components in Table 1.

Table 1. Components of Coordination

Process Level	*Components*	*Examples of Generic Processes*
Coordination	Goals, activities, actors, resources, interdependencies.	Identifying goals, ordering activities to actors, allocating resources, synchronizing activities.
Group decision making	Goals, actors, alternatives, evaluations, choices.	Proposing alternatives, evaluating alternatives, making choices.
Communication	Senders, receivers, messages, languages.	Establishing common languages, selecting receiver, transporting message.
Perception of common objects	Actors, objects.	Seeing same physical objects, accessing shared database.

3.2 Coordination of Agents

Based on the working definition of coordination, agent coordination within a MAS is the act of managing interdependencies between agents' activities, which are performed to achieve a system goal[1].

The advantages of coordination allow agents to specify and achieve a set of goals. It also provides a group of agents the ability to aspire to desired properties, such as coherency, and completion of plans and actions to achieve these goals [8, 10].

However, there have been problems. Nwana, Lee and Jennings (1996) provide some drawbacks relating to the lack of flexibility of coordination models in current applications due to erroneous assumptions about an agent's behaviour [11]. Furthermore, they state that current models do not take into consideration an agent's ability to conduct complex reasoning and have difficulty in validating the strategies used.

3.3 Introduction to Cooperative Theory

As with coordination, the term cooperation has multiple definitions. A universally accepted definition of cooperation is *acting together with a common purpose* [13]. In simple terms, cooperation is achieved when a number of persons enter a relationship with others for a common benefit or collective action in the pursuit of the common well-being. Cooperation requires an actor or an object belonging to a community to willingly share their knowledge. However, cooperation requires a group of actors or objects to make a voluntary association for a mutual benefit.

[1] Agent coordination is an important aspect of a MAS because, as with human society, agents need to be coordinated so they will act desirably. With the generic processes which Malone and Crowston (1990) have identified in their Coordination Theory, the three main reasons for agent coordination are completion of goals, plans and actions, coherency and distribution of resources [11, 12].

Tulken (2001) uses game-theory cooperation to describe cooperation in economics and describes it in terms of explicit influence from either a leader or referee and implicit influence of norms and values. This influence is from the norms and values that are common to the actors [14].

3.4 Cooperation of Agents

The advantage of autonomous agents is their ability to generate their own goals and to also decide when they wish to adopt the goals of others. When an autonomous agent enters a relationship with another agent voluntarily, they are said to be cooperating. Therefore the definition of agent cooperation is when an agent enters a relationship voluntarily and adopts the goals of an agent. There are two important aspects to this definition. First, the agent is autonomous, and by the nature of intelligent agents, this is assumed. Secondly is the goal acquisition that occurs during cooperation. An intelligent agent will acquire a goal of another if there is some positive motivational effect that will eventuate [15, 16]. Wooldridge and Jennings (1999) provide four important characteristics of agent cooperation. These include recognition, team formation, plan formation and team action [15].

Agent cooperation also relies on seven assumptions asserted by Wooldridge and Jennings (1999). A closer examination of their fifth assumption (agents initiate the social processes) shows that for an agent to effectively cooperate with interaction components, cooperation must take on either an external or internal perspective. An external perspective determines how an agent is to cooperate and the effectiveness of the cooperation. The internal perspective uses an agent's internal state to form the basis of cooperation [15].

Cooperation is said to take on an internal perspective. As with an external perspective, there may be difficulties in distinguishing between the coordination and collaboration of actions. However, cooperation should include both an external and internal perspective. Just relying on the agents internal states may not provide for effective cooperation. By allowing external perspective in cooperation, agents can perform cooperative actions, but also form a team and manage these actions [15].

4 AC^{3}M – Agent Coordination and Cooperation Cognitive Model

The purpose of this model is to show the link between coordination and cooperation. Furthermore, it can show that coordination and cooperation do not simply co-exist, but is a cognitive loop that will lead into one another. There are two components in AC^{3}M. They include the Cooperative Coordination and Coordinative Cooperation models, where each component combines the definitions of cooperation and coordination.

Both models are cyclic and viewed from a coordinative or cooperative perspective. They are designed to show that when a coordinative or cooperative event occurs, it will result in either cooperation or coordination respectively. Cooperative Coordination occurs when the agent has entered a voluntary relationship. However, once cooperation is achieved, the managing of the interdependencies between agents must occur. Hence, this gives rise to *Cooperative Coordination*. A draft of this

concept is shown in figure 1 and demonstrated during the invited session on Intelligent Agents and their applications at KES 2006. Further detail will be provided in future articles [17].

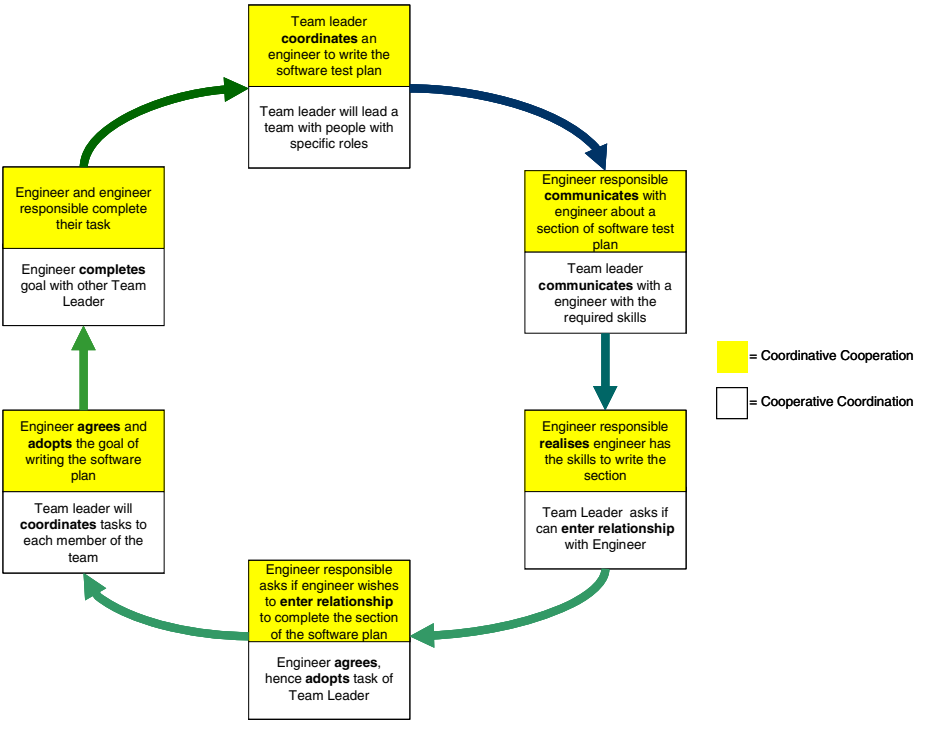

Fig. 1. Cooperative Coordination and Coordinative Cooperation Example

5 Conclusion

This paper provides an overview of the current research in relation to coordination and cooperation in a MAS. Agent coordination and cooperation are essential as it ensures agents behave desirably, do not waste efforts and squander resources in a system. It is also important to realize that if cooperation and coordination within a MAS are not achieved, contingency plans must be in place so the objectives are still met.

Another important assumption within an MAS is that agents must be the first to initiate the social processes within the system. This can be achieved with the proposed model by the use of Coordinative and Cooperative Events. This model can also provide some solutions to the current drawbacks in current models of coordination and cooperation. One solution is the possibility of reducing inflexibility. This can be achieved by simply using coordination and cooperation theories as well as the concepts of the personification of agents to emulate more realistic and human-like MAS.

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