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A Heterogeneous Multi-Agent Modelling for Distributed Simulation of Supply Chains

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Abstract. This paper presents a heterogeneous (cognitive/reactive) agent based approach to model supply chains. The proposed model based on an actors' representation introduce the behavioural studies of active entities constituting the logistics organization. Supply chains members behaviours are split up in two categories: deliberative and operational. The design and exploitation of distributed simulation model by multi-agents systems permits to supports the representation of entities realizing decision-making and operational activities. To facilitate the design of such models, a particular agent model is proposed for each category of behaviour: the Decision Agent and Simulation Agent.

1. Introduction

Simulation is an abstracted representation of a real system and involves elaboration of models which must reproduce the behaviour of the system following a set of hypothesis permitting the definition of different scenarios. Multi-agent simulation focuses on distributed behavioural descriptions and studies in a dynamic context. Multi-agents systems (MAS) relies upon autonomous entities simulating the complex behaviour of components whose interaction dynamics explain the real system complexity.

Multi-agent simulation models consists in identifying such entities denoted agents, their behaviours, their interactions among themselves or with the environment in which they are situated. Supply chains are composed by companies which realize activities as actors of the logistics network. Actors' behaviours are split into two categories: deliberative and operational. Deliberative behaviours refer to decision-making achieved by actors in the system. Operational behaviours take into account how such decisions are realized. Our multi-agent modelling approach allows dissociating representation between decision-making level and operational activities level. This approach facilitates the behavioural specification and the *agentifying* phase.

Our work proposes a design phase for simulation models by heterogeneous MAS. The second paragraph presents general principles underlying supply chains and related works on agent based supply chain management. The third paragraph introduces the model of the Actor Agent enabling the representation of supply chain entities. The fourth paragraph illustrates this modelling approach in the field of supply chains. Next section deals with the specifications concerning behaviours specification and interactions description between deliberative and reactive agents. Finally we conclude and give some perspectives of our research work.

1. Supply Chain : from network of actors to agent society

In the present economic context industrial companies join collaborative logistics network: supply chains. Supply chains architecture constitutes an economical advantage for companies and represents economic and social systems. This policy allows apprehending the whole product transformation process from the first supplier to the final consumer. This new organization, is then composed of a set of companies, where each member is attributed a role and responsibility in the global manufacturing process. Such roles encompass raw material supply, transformation of the items (into parts or finished products), and delivery to the final customers.

Supply chains are composed of a set of sub-systems organized to reach their own purposes and/or objectives made possible by information exchange. The information processing and analysis allows the organization to adapt its behaviour to the environment dynamic. Information induces then a process of permanent adaptation of the organization to modifications of environment characteristics.

Through concepts such as autonomy and cooperation, multi-agent systems have demonstrated their ability to provide a modelling and simulation framework for industrial systems and in particular supply chain [9]. However, most works such as DASCh [10], MASCOT [12] and the Supply Chain Demonstrator [13] deal mainly with homogenous agent societies composed of either deliberative (decision-making ability) or reactive (simplified predefined behaviours) agents.

Our work focuses on supply chain control based on performance measurement. This aim leads us to consider how decisions are made locally and executed as well as their impact on the local and global performances. Thus our modelling approach identifies a set of interacting constituents (micro analytical approach) with different coordination, cooperation and negotiation abilities [3]. We define such abilities according to three decisional levels (strategic, tactic and operational). This is done in order to fulfil own actors' strategies as well as the emergent global strategies of the chain, which are ruled by the environment. These different action-able and social constituents are denoted actors: the supply chain is therefore modelled as a network of actors prior to its operationalization into a heterogeneous agent society.

1. Modelling approach by multi-agent paradigm

This section introduces the concept of Actor Agent enabling the study and the analysis of complex systems according an agent-based modelling approach. The micro analytical approach considers a system as a set of interacting entities is called Individual Based Modelling in ecosystems modelling field. This approach of modelling allows the representation of the dynamic characteristics of a system and thus the specification of the actions, events, behaviours and interactions between the different individual entities composing the population system. The term of individual is not restricted to an anthropomorphic sense but rather in a more general meaning (an individual = an atomic unit).

1.1. The Actor Agent model

The social characteristics of each individual, i.e. the roles it plays as well as its responsibilities, affect the decision-making processes carried out in a system. Such decisions results in actions executed by the actors of the organization. The simulation of theses two point of view involves the exploitation of the events, actions and interactions between entities of the complex system. To address this issue we propose to model complex dynamic systems as a set of actors. An actor is defined as a social entity, an individual or a group of individuals [1]. An actor of the system represents either a decision-making capable entity (deliberative activity) or an operational entity (operational activity). In the real system each type of activity is associated to a particular level of granularity and represented in the Actor Model {Decision Center, Physical Resource}. The Actor Agent relies upon a simplified model of the reality allowing a behavioural study through the couple {decision, action}. The elaboration of the simulation model requires identifying the entities in the real system and activities associated. Same Activities are gathered into one or several Decision or Simulation Agent. The Actor Agent is composed by agents (deliberative or reactive) modelling different activities of an actor.

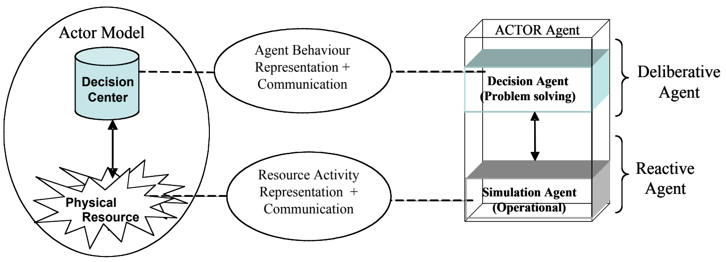

Figure 1. From Actor Model to Actor Agent

Decision Agent represents the Decision Center decision-making activities of an actor of the system and transmits decisions to the Simulation Agent. Simulation Agent reproduces the behaviour of an operational activity and transmits signals the Decision Center to report activities results. Figure 1 illustrates this duality in the Actor Model and shows which behaviour each agent adopts. Activities of the Decision Agent and the Simulation Agent differ on the internal architecture and capabilities of the agent. The Decision agent is based on a deliberative agent architecture allowing the representation of knowledge as well as rules using this knowledge and plans specifying complex behaviours [14]. The Simulation Agent relies upon a reactive architecture and more precisely “reflexes with states” [11]. The Actor Agent structure can represent an actor with a single agent either deliberative or reactive depending on its characteristics.

1.1. The Actor Agent model applied to Supply Chains

The logistic network is composed of a set of actors which have roles and additional responsibilities defined from the competences and activities they are able to realize. When the network responsibility is set up by the pooling of local strategies the structure of the collaborative actors' network emerges. The responsibilities which belong to the actors according to the supply chain level decomposition define new responsibilities for the actors of companies’ level (decision centres). They can coordinate theirs decision-making activities that lead to the fulfilment of local strategic objectives. This method of responsibility decomposition and distribution is in a similar way applicable to intra company level (activity cells). Actors of these cells have the responsibility for realizing the operational activities by use resources. Figure 2 shows the modelling of supply chain actors.

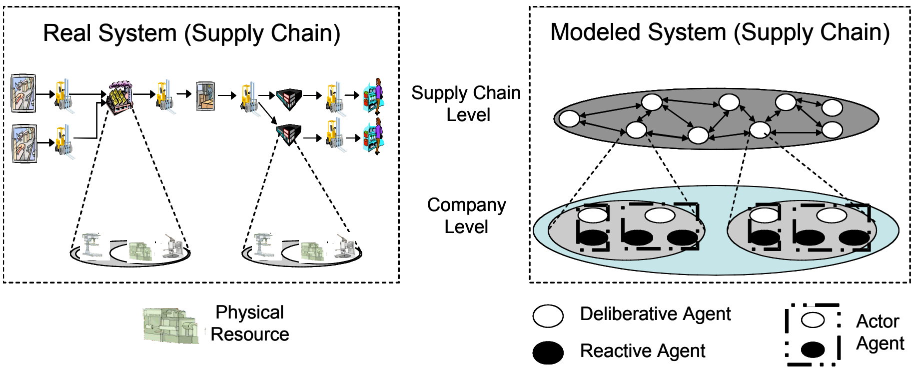

Figure 2. Decomposition of the Supply Chain

This mode of representation according to an organisational point of view makes it possible to exhibit relationships and interactions between actors of the supply chain according to the responsibilities decomposition and distribution levels. However this mode of representation is not satisfying from a completed operational point of view. In the model the following processes do not appear: the items movements, the registering and the state of available resources, the operational activities realized by the actors and the data need at each decision levels affecting the flow traffic.

1. A heterogeneous multi-agent system

MAS consists of a set of autonomous entities called the agents. Every agent possesses one or more roles defining the expertise and behaviour enabling him to act in an autonomous way. The general behaviour of the system emerges from the realization of the individual agents' actions. Our modelling approach is based on heterogeneous MAS as it is composed of two different architecture agents. Agents of a same kind form a society with uniform interactions mode (message or signals). Both societies interact through the actor link between decisional and operational agents. Actions realized by reactive agents influence decisions emitted by deliberative agents, and conversely. This section describes how these agents societies manage to form a MAS.

1.1. Architecture of heterogeneous multi-agent system

Within the framework of modelling a real system, an entity will be represented by an Actor Agent called Decision Agent to realize deliberative processes for problem solving and one or several reactive agents called Simulation Agent to perform operational activities. The conception of multi-agent simulation models should be flexible [6] and adapted according to the types of behavioural studies for the representation of decision-making and/or operational activities. These models represent individual actions of actors' interactions as well as consequences of these interactions on the environment. This approach allows dissociating the conception of MAS from the application domain.

The model of the physical system represented by a MAS can be decomposed into sub systems. Every system or physical sub-system consists of a set of Actor Agent. The MAS architecture proposed consists of two societies of heterogeneous agent: deliberative and reactive agents. The Actor Agent allows establishing linkages between both agents' societies. Agents which are presents in the deliberative agent society can act in an autonomous way to attempt their own objectives. They have an explicit representation of the environment and possess capacities of reasoning and knowledge treatment. The agents can play several roles within the MAS. Agents which are presents in the reactive agent society act in answer to stimuli issue from environment. They don't have an explicit representation of the environment and their behaviours are predefined by rules. They are not able to reason about their intentions. It's the general behaviour of the reactive agent society which can be intelligent.

Every agent is situated according to a level of abstraction which does not manipulating the same concepts and does not consider the same elements of the environment. Structure of the MAS concerns the description of entities possessing properties and relations among them according to agents' societies which they belong. The MAS is constituted by agent who allows representing the entities' behaviour of the real system. The approach by heterogeneous agent society proposes an architecture dissociating decision-making, operational and informative processes within the MAS. This decomposition allows differentiating the behaviour, the roles and competence adopted by entities.

1.1. Multi-Agent System applied to Supply Chain Modelling

The model of supply chain presented is formalized from the model of the Actor Agent. It allows obtaining a heterogeneous MAS constituted of deliberative and reactive agents. The principle of heterogeneousness is to enable the separation of the representation of decision activities from the operation activities. In the supply chain model, deliberative agent societies assume the behaviour of the supply chain actors which implement decision processes at strategic, tactic and operation level. Reactive agent societies assume the behaviour of the physical resources employed by deliberative agent societies, to realize transformation activities. Next figure presents the organisational model coupled with the supply chain operational model for the behavioural modelling of operation and decision activities of the logistic network.

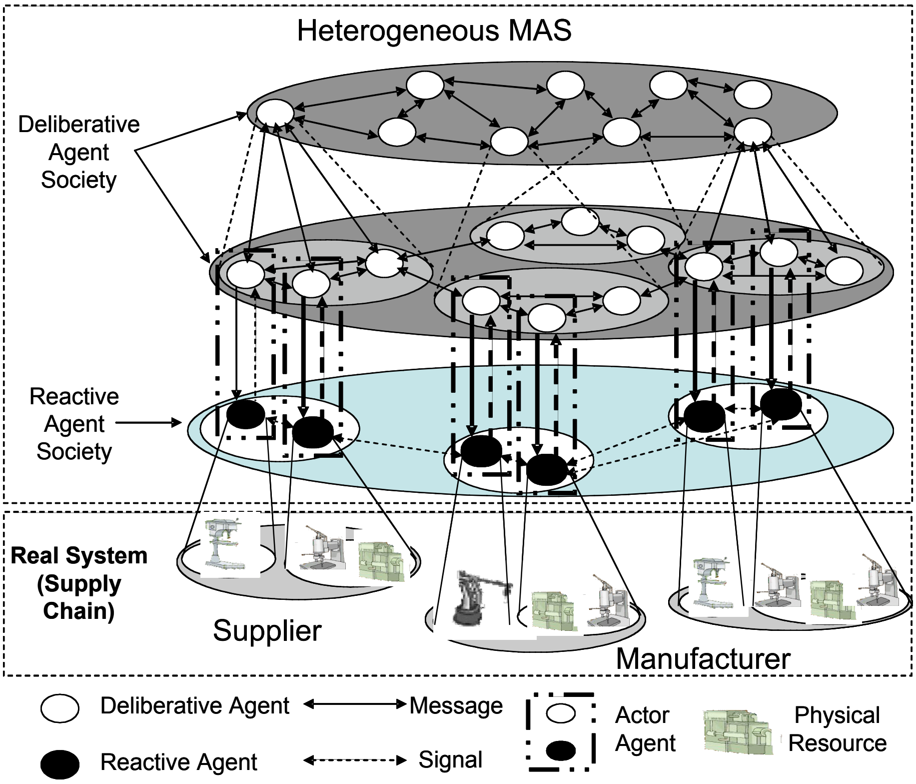

Figure 3. Heterogeneous MAS Supply Chain modelling

This approach is based on a representation of individuals and behaviour associated. It allows representing according to several levels: the individual, groups and the whole system. Modification of the structure system during time should appear according to interactions established among individuals of the population. This approach of modelling is adapted to simulate organized complex systems of which global functioning emerge from individuals' actions.

1. Agents specifications and interactions

1.1. Specification of Decision Agents behaviours

As expected from a deliberative agent, the Decision Agents have an explicit representation of the environment in which it evolves, take into account its modifications during their deliberative processes and communicate through exchanges of messages. The part of the simulation based on such agents result from the cooperation of a relatively small number of agents, allowing for example, the sharing of tasks to solve a complex problem [7].

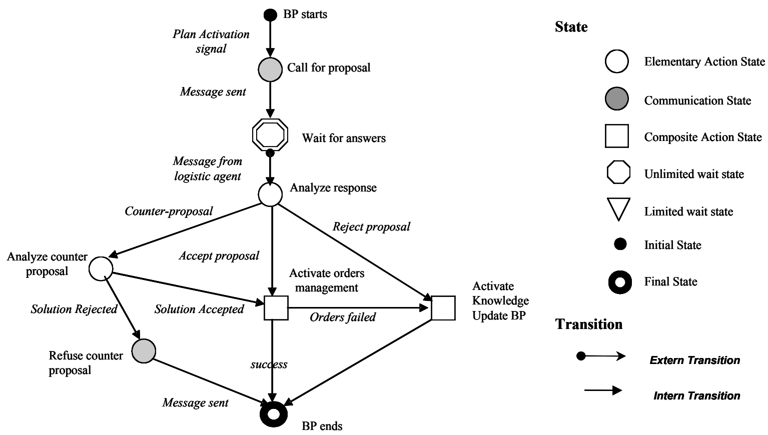

Figure 4. Notation of ABR formalism and example of Decision Agent behaviour

The deliberative agent model can be related to a Belief Desire Intention [4] as its behaviours are explained and designed with plans. These plans, denoted Behaviour Plans, are used to specify and execute (after a phase translation in a target rule-based language) the behaviour of the agents according to two models: individual and social [14]. Within the individual model is represented the autarkic behaviour of the agent (Local Plans), i.e. interactions with the other agents are not required to reach its goals. The social model involves the social behaviour of an agent (Role Protocols) and thus specifies how an agent interacts with others (message passing) as well as the actions leading and resulting from these interactions. The set of Behaviour plans of an agent describe its ability to react and solve problems whether communicating with other agent or not.

These plans are specified with the ABR Formalism (Agent Behaviour Representation) [14] which consists in a state graph formalism with strongly specialized states and transitions. A state represents what the agent is doing i.e. computing or sending a message for example in an action state or waiting for a message in a wait state. A transition is then activated depending on the outcome of an action (internal event) or a message arrival (external event) and in turn activates another state. Thus the different states composing behaviour plans describe the sequence of actions an agent has to perform in a particular context. The description can be recursive as a state can itself be a behaviour plan. As indicated before, such plans can be rather easily translated in a rule-based language, and thus can be reused to guide the implementation phase of Decision Agents. When alive, the agent will monitor its environment and react accordingly to its modification by instantiating the corresponding plan. Theses plans are also used to state how an agent can reach its goals. The deliberative agent architecture is already define and operational.

1.1. Specification of Simulation Agents behaviours

As reactive agents Simulation Agents' behaviours are restricted to simple sequences of actions consisting in reacting to signals and emitting in turn new actions. They do not represent themselves the environment in which they evolve and have a simplified communication device. They do not possess an intelligent individual behaviour even if their global behaviour through their interactions satisfies a purpose [15]. Activities of a Simulation Agent are specified with the UML statechart diagrams formalism [2]. The statechart diagrams describe the operational activities in the Actor Model. Each state represents an action which can be carried out in answer to stimuli from the environment. Stimuli represent interactions with other agents (reactive or deliberative) or objects of the environment. A state is characterized by a duration time for the action to be realised. A transition represents the immediate passage from a state to another one. A transition is activated by a particular event (e.g. a stimulus). Figure 5 propose give an example on how a production activity can be specified.

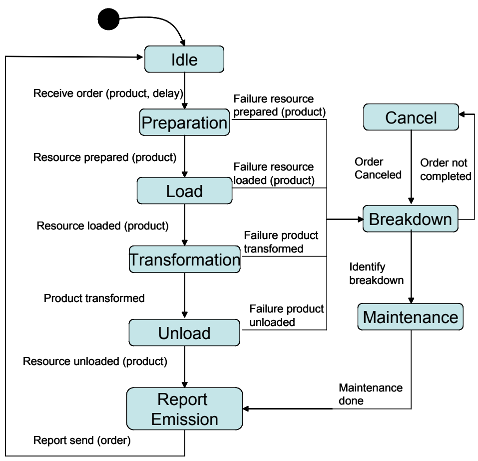

Figure 5. Example of Simulation Agent behaviour (UML)

1.1. Hybrid architecture of Actor Agent

The Actor Agent model is composed of two different agent' types of the different granularities. This difference of granularity implied to use two different formalisms for the representation of their specific behaviours. The Actor Agent represents the actor of the real system as a whole i.e. encompassing both aspects of its behaviour.

This modelling approach helps to easily pass from an Individual Based Modelling to an executable multi-agent modelling. Decision and Simulation Agents reproducing an actor complex behaviour are thus linked by their real world identity. Figure 6 illustrates how the Decision Agents are linked together: the Decision Agent(s) make decisions communicated to the Simulation Agents where they are carried out.

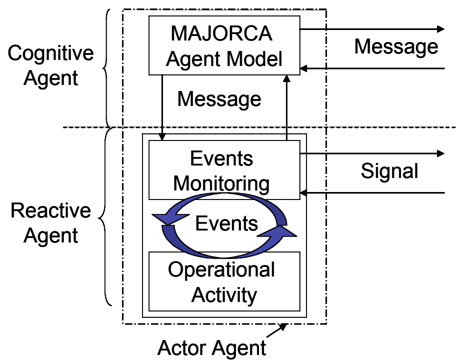

Figure 6. The Actor Agent model

The Decision Agent deliberative architecture is based on BDI architecture [14] which integrates the ABR formalism. This integration relies on tools helping the translation of ABR graphs into Jess (Java inference engine). These plans are rapidly made operational to enable an agent to react to its environment evolution. Decision Agents communicate by exchange of ACL FIPA messages. When directed to its Simulation Agents a message corresponds to an information demand or command.

Simulation Agent architecture is restricted to a module executing simple behaviours specified with UML state diagram formalism. The second module translates signals and messages received from other agents into events which activate a transition. It monitors the reactive agent activity to redirect some specific events to other agents. Simulation Agent adapts its behaviour in function of the Decision Agent orders and signals receive and can answers to signals perceived by other Simulation Agents.

1.1. Interactions representation

Simulation is constituted of a set of agents whose states changes depend on interactions with the environment. To coordinate agents' behaviour and manage their organizational structure it is necessary to define languages and protocols of communication among agents. Interactions among deliberative and reactive agents are formalized by send and receive messages following the ACL-FIPA standard. Agent UML is based on the Unified Modeling Language method used for the developments in directed objects languages [8]. With regard to objects agents realize autonomous activities to attempt their own goal. AUML replaces the notion of method by the notion of service and the notion of class by the notion of goal. This type of representation allows showing the type of exchanged messages and their contents as well as the process of activities which they activate [5].

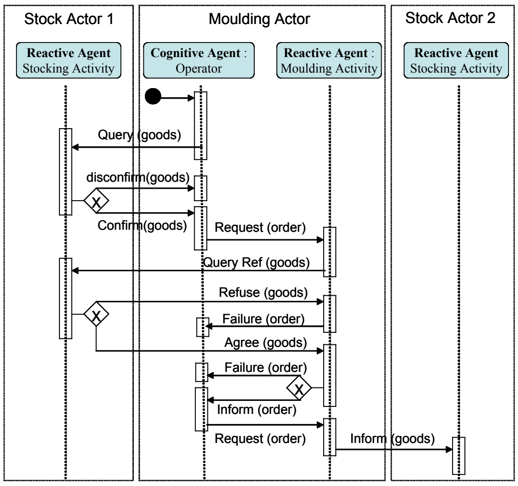

Figure 7. Sequence diagrams (AUML)

Orders are a transfer of information from deliberative agents towards reactive agents. Deliberative agents use messages to communicate among them. Reactive agents emit signals with the deliberative agents who interpret them in the form of information. Canals of transfer are bidirectional. Description in natural language help in the phase of MAS design during to represent the physical model.

1. Conclusion

This paper has presented a heterogeneous multi-agent modelling approach aiming at simplifying the transition phase from Individual Based Modelling to Distributed Simulation architecture. This objective relies upon the unifying concept: the actor. Whereas called actor in an IBM model or Actor Agent in the multi-agent model this entity takes into accounts the deliberative and operational activities. The Actor Agent model distinguishes two agent types to model their activities with specialized behaviours. The proposed approach support designers and users during the modelling phase providing different level of abstraction for the system behaviour specification. The identification of a supply chain Actor Model with an Actor Agent makes possible the study of the global and local behaviour of the supply chain actors.

The work presented here constitutes the first stage leading us towards a multi-agents based simulation platform dedicated to the behavioural study of supply chains. Our experience in former agent development projects will support this phase. Agents controlling the simulation process already identified but not presented for lack of space will be integrated in this heterogeneous architecture.

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