

A Coordination Framework for Intelligent Agents in the Distributed Enterprise

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Abstract

This research constitutes a contribution to the modelization of the distributed enterprise (DE) more particularly centered on the coordination strategies between autonomous units composing it. We develop a conceptual framework to apprehend mechanisms of coordination in the DE largely inspired from works in economic sciences and more particularly relative to the theory of contracts. We present in detail a coordination model (CAT) based on the previous conceptual framework and researches in the area of Multi-Agent Systems from Distributed Artificial Intelligence and which is defined through the convention, agreement and transaction concepts. Finally, we conclude on our ongoing and future researches.

Keywords

networked enterprise, coordination, multi-agent systems, convention, agreement, transaction, protocols.

1 INTRODUCTION

Manufacturing enterprises are currently confronted with a market which is very different from the one characterized by its stability and a low diversity of products proposed which prevailed in the 1980s. The manufacturing enterprise is now plunged in a global market which is strongly competitive and customer oriented. This market is characterized by a demand of products of greater quality, available in minimal periods, less expensive and personalized (Vernadat, 1994; Browne et al., 1995).

In order to act efficiently in this new environment and to confront these new trends, the manufacturing enterprise must transform its physical, decisional and information systems. Several new organizational structures have been recently proposed with the concepts of extended enterprise, virtual enterprise and networked enterprise. The paradigm of extended enterprise proposes to consider all the enterprise components intervening in the life cycle of a product being part of the global enterprise (Browne et al, 1995). The virtual enterprise proposes a geographically distributed enterprise structure whose duration of life can be limited and predefined (Goldman et al, 1995; Ettighoffer, 1992). Finally, the networked enterprise proposes an enterprise structure mainly based on the collaboration and the decentralization of responsibilities (Poulin et al, 1994).

These different organizational structures present many common points. The most significant common characteristic they recommend is the distribution of the enterprise on units with a certain degree of autonomy. The distinctions between these different organizational structures (extended, virtual or network enterprise) are not significant for our research. Consequently, in the continuation of this paper and in a generic manner, we will discuss the "distributed enterprise" (D.E.). To support this distribution, all these structures emphasize on three fundamental points : (i) the usage of the new information technologies, (ii) the responsibilities and decisional distribution of the enterprise on autonomous units and finally (iii) the development of cooperation strategies between these units composing the enterprise (Spinosa et al., 1997; Bernus et al., 1997).

The usage of information technologies is vital for the enterprise in its positioning and the cost of its products and services. Consequently, information technologies govern the competitive power of the enterprise, its identity and even its surviving (Butera, 1991). Snow et al. (Snow et al., 1992) stipulate that the global enterprise cannot operate efficiently if the units it is composed of do not have the capacity to communicate precisely, rapidly and over long distances. The potential of electronic data exchange between enterprises (electronic mail, ftp, http, EDI, EDF, etc) has not to be proved.

Concerning the two other points, i.e. the responsibilities and decisional capacity distribution leading to the characterization of autonomous units on the one hand and the development of cooperation strategies between units composing the enterprise on

the other hand, to our knowledge, few things have yet been proposed. To approach these points necessitates an effort of modelization of the DE, of its structure and its behavior.

The present work constitutes a contribution to this modelization, more particularly centered on the modelization of the coordination strategies between units composing the DE. In this modelization, recent works relative to multi-agents systems (MAS) in distributed artificial intelligence (DAI) constitute a very relevant tool. These modeling tools have already been used in the area of the industrial engineering (Parunak, 1990; Kouiss and Pierreval, 1995; Barbuceanu and Fox, 1994; Tranvouez et al 1998). This research is part of the NetMan project that consists of developing an operative system for the distributed manufacturing enterprise.

In the part two we develop a conceptual framework to apprehend mechanisms of coordination in the DE. We specify the context of coordination that we adopt as well as the preliminary hypotheses that we make for our research. This conceptual framework is largely inspired from works in economic sciences and more particularly relative to the theory of contracts. In the part three we develop in detail our model of coordination for the DE (CAT), which is based on the conceptual framework previously introduced, and works already developed in the area of SMA and which is defined through the concepts of Convention, Agreement and Transaction. Finally, we conclude on our ongoing and future researches.

2 A CONCEPTUAL FRAMEWORK FOR THE STUDY OF THE COORDINATION IN THE DISTRIBUTED ENTERPRISE

Generally, the creation of DE is associated with the realization of a global process leading to produce one or several products or services. The global process primarily defines the sequence of all primary activities to be executed as well as precedence relationships between these activities. Each of the activities produces outputs which will be used as inputs by another activity. In this work, we will focus essentially on the coordination of resources to be assigned to each of these activities. Before a conceptual framework to apprehend the coordination in the enterprise network can be developed, it is necessary to specify our modelization of the DE and to situate the problematic of its coordination.

2.1. A multi-agents modelization of the distributed enterprise

In the life cycle of the DE (cf. Figure 1) one can distinguish several main steps. The first is associated to the specification of needs. These needs being defined, the two next steps consist of, on the one hand elaborating activity diagrams associated to the realization of these needs and, on the other hand, identifying available resources. Activity diagrams and available resources defined, the last step consists of defining the

DE, in particular specifying its resources, allocating these resources to activities to be executed, and also defining coordination mechanisms that will allow these implied resources to coordinate themselves. Once its mission fulfilled, the DE might then even be dissolved.

In this research we focus only on the last step, the step of the DE constitution and, more particularly, on the definition and the study of the mechanisms allowing its coordination. To that purpose, we model the enterprise network by a graph composed of nodes that we associate to autonomous units (partners) composing it, links representing relationships kept between these units and flows exchanged between them.

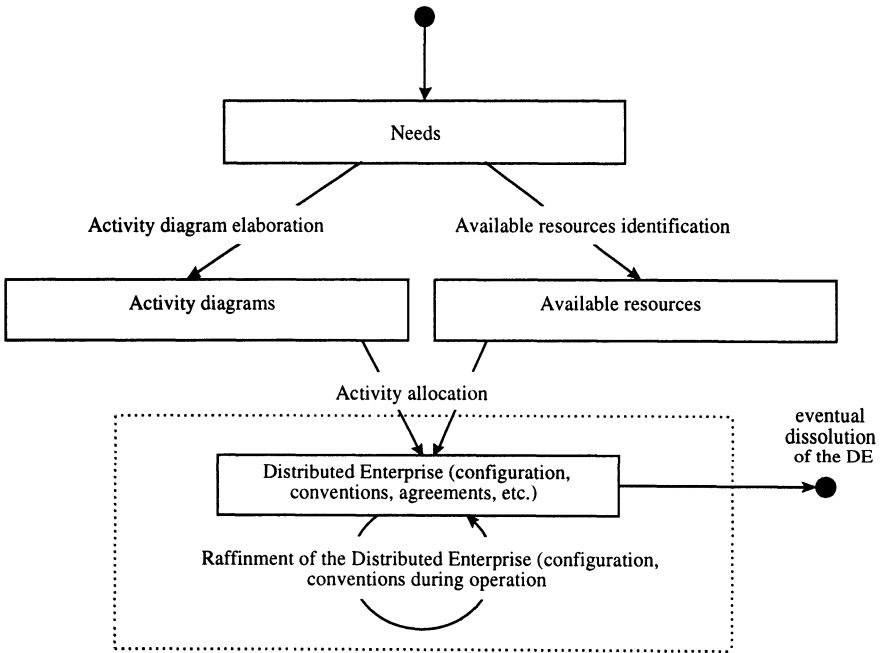


Figure 1 Life cycle of the distributed enterprise

When a DE is constituted, agreements established between the nodes constitute structural and organizational relationships of the DE. Physically, the nodes of the DE are connected by links. The nodes are considered as agents having a certain degree of autonomy and the movement of matter or information between these agents is transported by flows. As we will see in the following paragraph, the coordination of these agents, object of our research, is based on a definite set of relationships leading to the definition of interaction rules, partnership types, common objectives, etc.

The DE concept necessitates a specific terminology. We propose some definitions of terms essential to our modelization of the enterprise network. The first two definitions are those relative to the terms of "process" and "activity":

Definition 1 **Process:** *a process is a network of required activities for the realization of a product or a service which are connected by flows specifying the inputs and the outputs of each of activities.*

Definition 2 **Activity:** *the activity is the principal component of the process and is generally in charge of undertaking the transformation of inputs into outputs. An activity is assumed by an agent who will realize it by executing a specific process. The initial process does not specify sub-processes but activities in the form of black boxes of which one knows only the inputs and outputs.*

The definition of the DE brings us to define a correspondence between the activities of a global process and the agents which are affected to each of these activities for their realization. The DE associated to a given global process is then composed of a set of affected agents to activities of this process. As figure 2 illustrates, we distinguish in our modelization of the DE two essential levels.

At the upper level, associated to the global process, activities are represented in boxes. The flow connecting two boxes expresses a dependence between the two activities. The upstream activity produces elements that are necessary for the downstream activity. These elements are transported by the flows.

At the lower level which is associated to the agents composing the network enterprise, the agents are assigned to the activities defined on the previous level. An agent can be assigned to several activities (for example here the agent s is assigned to activities a and b). The flows connecting agents are agreements (Aw to Az) that stipulate modes of exchange of elements circulating on the flows. This second level constitutes the DE for this given global process. It is important to note that agreements mainly concern informational flows even if the flow of matter is explicitly concerned.

We propose for this notion of "flow" the following definition :

Definition 3 **Flow:** *in a process, a flow represents the circulation of required elements for the realization of activities. This flow will be present in the DE and represents the movement of matter, information or knowledge between agents.*

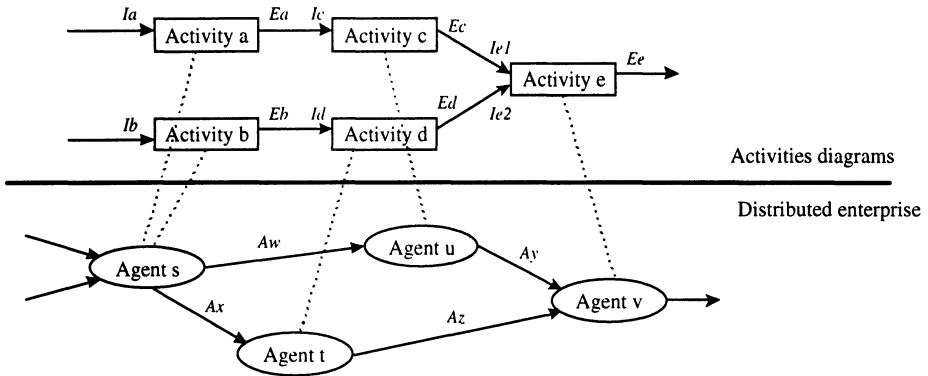


Figure 2 From global process to agents of the network enterprise

Hence, agents are resources affected to activities to be realized within the process. When an agent is assigned to an activity, it may be the only one to know the way in which it will realize this activity. In fact, the agent can subdivide an activity to which it has been affected into a new activity diagram. To insure the realization of this new activity diagram, a new DE constituted of new resource agents can be defined. Each agent has responsibilities and commitments towards the DE, towards activities and towards the other agents with which it has interactions. We introduce the following definition of the concept of "agent":

Definition 4 *Agent*: an agent is an autonomous entity with the necessary competence for the realization of activities and a sufficient intelligence allowing it to consider the consequences of its actions as well as its responsibilities towards its commitments.

The implementation of the coordination in the DE physically translates into the exchange of flows of different nature between the agents. This leads to the problem of, (i) the modelization of coordination mechanisms between the agents of the DE and (ii) the investigation of the adaptation of these mechanisms during the realization of the activities, replying to various anticipated or unforeseen situations the network enterprise has to face. This adaptation of the coordination is mainly supposed to dynamically modify the relations and the links between the agents of the DE. For the modelization and the study of the coordination within the DE, we make the following preliminary hypotheses :

1. A global process elaborated by a so-called "supreme" authority exists already. This process specifies a set of activities linked between them by flows indicating the inputs necessary for an activity and the outputs of an activity;
2. For each flow of the global process, initial specifications indicate the nature of the circulating elements;

3. The activities of the global process have already been assigned to the agents who will execute them (assignment by the supreme or any other instance);
4. For each flow between two activities, there is an initial agreement (relationship) between the agents assigned with the activities upstream and downstream to the flow.

This set of preliminary hypotheses circumscribes the problematic of our work. The activities are thus already assigned to the agents and agreements between these agents are already existing. We propose to study the problem of the dynamical management of the structure of the commitment of the agents.

2.2 Coordination in the distributed enterprise : a contractual approach

The coordination of the relationships between contractual partners of a DE can be apprehended at two different levels (Paché and Paraponaris, 1993): (i) the level of the space of physical circulation of the materials and (ii) the level of the techniques of transmission, treatment and stocking of information permitting the releasing of operations. Regarding the usage of information technologies and particularly telecommunications technologies, we will essentially focus on the second level given the fact that it actually supports the first level.

The dynamic management of exchanges and agreements between the partners of the DE is mainly done via the refinement of the structure of commitment of the agents, by learning and adaptation. The agents have the capacity to make their agreements evolve in order to improve their coordination and react better to unexpected situations. We call this dynamic of commitments the contractual dynamic. To better approach this contractual dynamic, it appears necessary to investigate how economic sciences apprehend the study of the mechanisms of coordination between economic agents.

In economy, the study of coordination mechanisms between economic agents is apprehended through the notion of contract. More precisely, in contract theory, a contract is an agreement by which economic agents commit themselves to give away or appropriate, to do or not to do certain things (Brousseau, 1993b). In general, one studies contract theory in a bilateral relationship context. However, specialists are also interested in contracts between more than two parties.

In contract theory, Brousseau (Brousseau, 1993b) identifies three essential theoretical contributions : (i) the agency theory, (ii) the transaction cost theory and (iii) the analysis of conventions. We will not present here these different contributions but they have substantially contributed to the construction of our coordination model. Depending on the type of relationship prevailing between the intervening parties, one can develop different types of complex contracts containing several clauses. The contract theory proposes concepts going beyond simple bilateral commitment contracts. Other concepts like contingency plans or assignment of authority propose

so-called "complete" or "incomplete" contracts, a very interesting coordination mechanism.

It is a fact that the contract is the universal frame used for the coordination between enterprises. Regardless of the degree of collaboration between the enterprises, a contract is the base of established agreements, apart from informal collaborations which we will not consider here. Contracts can take different forms depending on the degree of collaboration. In the DE, the coordination is realized through the intelligent management of contracts and agreements defined between its nodes. Due to the number of nodes that may be important and the intensity of exchanges required for the coordination, this management can be extremely complex. The more intense the coordination, the more it requires the sharing of information to be efficient (D'Amours et al., 1995).

The concept of contract has been introduced in DAI through "Contract nets" as coordination mechanism by Smith et Davis (Smith and Davis, 1981; Smith, 1988). These mechanisms are mainly based on the principle of calls for offers and are principally used to solve tasks attribution problems. The contracts used in these mechanisms are very rudimentary : one of the agents, the contractor, commits itself to execute a task or to reach a goal towards a contracting agent. Even if this approach has also been used in other works (Sandholm, 1993; Sandholm and Lesser, 1995a; Sandholm and Lesser, 1995b), the concept of contract has not been deeply developed.

A contract oriented coordination based on one hand the works in economics, more specially on the contracts theory and on the other hand on the MAS paradigm seems relevant for the DE. This contractual approach of the coordination has to permit the definition and the study of the coordination mechanisms according to their structural, cinematic (constant structure) and dynamic aspects (changing structure) associated with an adaptation by learning in front of foreseen or unexpected situations.

3 CAT: A COORDINATION MODEL FOR THE DISTRIBUTED ENTERPRISE

The MAS paradigm refers to the collaboration between autonomous entities, called agents. Each agent owns specific decisional capacities and action capacities. It is thanks to their interactions and their cooperation that the agents will be able to reach individual or common goals.

Each autonomous unit of the DE, or node, can be seen as an agent which has to take decisions and coordinate itself with other agents associated to other units or nodes, according to its individual objectives and the common objectives which can be shared by the other agents. MAS platform are already used to supply information systems or to integrate different competence centers of an enterprise or also to support multi-site enterprises physically distributed (Parunak, 1990; Kouiss and Pierreval, 1995; Barbuceanu and Fox, 1994).

The coordination model we propose is called CAT because it is based on the principal concepts of Convention, Agreement and Transaction. Conventions, Agreements and Transactions are developed between the DE resources considered as agents. These agents are allocated to the activities of a process and have responsibilities. In the following paragraphs we detail these three base concepts of our model.

3.1 The convention in the CAT model

A convention, as in our human society, is associated to a specific context. Politeness rules or the highway code are good examples of conventions. These conventions are specific to a group of individuals and they can be different from one group to another. In the DE context, these conventions allow the agents to take relevant decisions without having previously expressed some decision rules in any contract. The conventions could be generic negotiation protocols, information exchange formats, automatic decision, etc. It is important to distinguish conventions from an agents knowledge about other agents and its environment. The knowledge of an agent can be similar to the knowledge of other agents but they are individual, not a convention.

The conventionalist approach of the contract theory defines the convention as a generalization of the contract notion. Conventions are considered as explicit or implicit criteria for the individuals to make decisions (Gomez, 1996). We will use this concept of convention in our model to give beliefs and general behaviors to the agents. These beliefs and behaviors are specific of the enterprise culture, sincerity, confidence and the basic rules which manage commitments, etc.

The convention notion adopted in CAT is directly inspired by the philosophical works of Lewis (Lewis, 1969) who uses this notion in a coordination means perspective. Lewis defines three main conditions to satisfy for a knowledge R to be a convention in a population P . In a recurrent situation S, a regularity R in the knowledge of the members of a population P is called "convention" if it is established that all members of P :

- conform to R;
- consider that all members of P are conforming to R;
- choose to conform to R under the condition that all members are conforming to R, because the S situation requires a coordination and a uniform conformity to R permits to reach a coordination equilibrium for S.

These considerations related to the convention notion are not limited to the action protocols specification. The conventions can also establish facts, data representation formats, ontology languages, etc. For CAT, we propose the following definition for the convention concept :

Definition 5 **Convention:** *A convention is a set of implicit or explicit criteria an agent refers to at the moment it makes a decision. Conventions are common knowledge owned by several agents permitting to act socially in a consistent manner.*

3.2 The agreements : exchange forms between agents

The agreement concept is largely inspired by evolutive contracts based on the transaction costs economics (Williamson, 1989; Williamson, 1993; Orléan, 1989). An evolutive contract (Gomez, 1996) is used when the uncertainty is important for the agents and it is impossible for them to elaborate a definite and precise contract. Often, the agents agree together on a general agreement which defines the general rules of the agreement. This type of contract is particularly used in an uncertain environment where all the clauses of the agreement cannot be fixed a priori. In our model, this agreement will constitute a framework to the transactions.

An agreement between two agents concerning the flow between two activities is elaborated by a supreme authority which can be responsible of the global process. We do not treat here the complete process of activities allocation to the agents and of general contract elaboration. This process implies legal notions, negotiations, etc. In fact, when an agreement is established between two agents, these agents commit themselves towards the supreme authority to respect the agreement. In CAT the definition of this agreement concept is the following :

Definition 6 **Agreement:** *an agreement is an evolutive general contract which implies two or more agents and which stipulates the behaviors and the responsibilities of each of these agents regarding their interactions in a specific context. The agreement corresponds to the relationships between the nodes of the DE.*

Note that the agreement can be established between on one hand an agent using inputs to perform an activity and on the other hand the agent producing these inputs (outputs for him). In this case, the agents play the roles of customer and supplier. The agreement stipulates the behaviors and the responsibilities of each agent according to the roles they play. Finally, the agreement specifies the intervening parties and a set of interactions or transactions (transaction patterns) which can be realized between the agents within the limits of this agreement.

3.3 Transactions and transaction patterns

A transaction is defined as a specific interaction between two agents of the DE As we have seen before, the agreement defines a set of transactions which can be realized

between the agents concerned by a given agreement. This set of possible transactions is defined through a transaction pattern.

The transaction pattern describes the possible interaction protocols assuming the coordination between two or more agents through exchanges. For each transaction pattern, the following elements must be detailed :

- the language used to communicate ;
- the ontologies (set of knowledge) on which these communications are based;
- a set of roles that the intervening parties of the agreement can play in the limits of this transaction pattern (customer, supplier, tenderer, manager, etc.);
- a set of aims for which this transaction pattern can be used (for instance to sell X, to buy Y, to obtain Z, etc.) ;
- a formal protocol which consists of a set of role protocols defining how each role must act in the limits of this transaction pattern ;
- an assignment rule (or function) of roles to the agents (sometimes roles can be predefined in a standard contract, or sometimes they can change from one execution pattern to another);
- an association rule (or function) of aims and roles (the aims accessible with a transactions pattern are not the same for all roles, for instance the seller role will permit to reach an aim as sell X and the purchaser role will permit to reach the buy Y aim);
- an allocation rule (or function) permitting to allocate the different role protocols of a transaction pattern to each role played by the agents.

4 CONCLUSION AND PERSPECTIVES

In the current context of competitiveness, the manufacturing enterprises adopt new distributed enterprise structures (virtual enterprise, extended enterprise, network enterprise) which all recommend their distribution on units with a certain degree of autonomy. The coordination of the interactions between these autonomous units allowing in particular the development of cooperation strategies is essential and has to benefit from the new information technologies.

The work presented in this paper constitutes a contribution to the modelization of the distributed enterprise, more particularly centered on the modelization of the strategies of coordination between the units composing the enterprise. To this purpose, our inspiration has been the works developed on one hand in economic sciences via the contract theory, and on the other hand in distributed artificial intelligence (multi-agent systems). We have thus approached the problem of coordination of the distributed enterprise by associating each autonomous unit to an agent in charge of insuring the coordination of the unit with the other units it is collaborating with.

The coordination model that we have proposed (CAT) is based on the concepts of Convention, Agreement and Transaction. Conventions are behaviours or knowledge shared between the individuals. Agreements are based on the concept of progressive contract and formally stipulate the agreements from the point of view of interactions between two or more agents. The transaction patterns describe the formal protocols the agents have to follow in their interactions with the other agents.

A first formalized version of our model has been developed and is currently being tested with simple examples inspired by manufacturing enterprises and an agent architecture has been developed to support it. The next steps of our work will consist of validating CAT using more complex problems, always in the manufacturing context, in order to refine it so that it will be able to support a larger variety of coordination problems.

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7 BIOGRAPHIES

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