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GRAPH-BASED EVALUATION OF ORGANIZATION IN MULTIAGENT SYSTEMS

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ABSTRACT: *This paper deals with the evaluation of multiagent systems. The related works in this issue are most often interested in evaluation of agent design methodologies or agent tools and platforms but do not address sufficiently evaluation of multiagent applications from a general point of view, the used evaluation criteria remain either specific to a special topic or application dependent. In this work we present an evaluation approach to measure general characteristics of multiagent systems. The proposed method follows a three step process: observation, modelling and measure. The modelling technique is based on graph theory which is used to define and estimate metrics for the evaluation of structural properties of multiagent systems. In this paper, we focus especially in organization as evaluation criterion as it is a very interesting characteristic transposing the social dimension of multiagent systems. Therefore, specific metrics based on graph theory are proposed to analyse agent organizational structures. The tests and experimentations are carried out on a multiagent application for the simulation of production planning and control in supply chains.*

KEYWORDS: *MultiAgent Systems, Evaluation, Organization, Graph Theory, Measure, Modelling, Observation.*

1 INTRODUCTION

In the last decades, multiagent technology has become widely used in various fields and the number of developed multiagent applications is currently increasing considerably. Despite the great interest that the scientific community bears to this growing research area, there are still open issues particularly regarding standardization and definition of consensus on key concepts. One of the most critical issues in this domain is the question of performance evaluation which was addressed from different points of view. In this perspective, evaluating design methodologies and development platforms and tools is undeniably of great interest but remains insufficient to make a full coverage of multiagent systems evaluation. It becomes more and more necessary and urgent to provide means for evaluating and comparing multiagent applications. That is what we address through our research works which focus on agent-oriented applications evaluation based on specific characteristics especially structural ones. In previous works, we focused on one of the most important characteristics of multiagent systems which is communication. In this paper we are interested in organization and we propose several metrics to evaluate it based on graph theory. The paper is organized as follows: in section 2 a literature review of multiagent systems evaluation is presented. The proposed evaluation approach is then described in section 3. Section 4 presents an overview on organization in multiagent systems and the used metrics to evaluate it. The application

on which tests and experimentations were carried out is described in section 5 with the obtained results and their interpretations. A conclusion and a look at future work are presented in section 6.

2 EVALUATION OF MULTIAGENT SYSTEMS: STATE OF THE ART

The several studies related to multiagent systems evaluation do not address the evaluation issue from the same point of view. In the following paragraphs we classify the presented works into four categories according to the evaluation objective in order to position our contribution.

2.1 Agent technology

The early works in this domain were interested in evaluating the multiagent technology as a new software engineering technique and tried to compare it to other existing ones namely the object-oriented one, as it was considered the leading technology at that time. For instance in (Wooldridge and Ciancarini, 2000), (Tveit, 2001) and (Lind, 2001), agents and objects are compared with reference to some key criteria such as autonomy, self behaviour control, flexibility, parallelism and ability to represent mental components. All of these researches concluded that agent-oriented paradigm brought to software engineering many interesting novel concepts and that it allows dealing with complex problems and addressing dynamic environments more effectively.

2.2 Agent design methodologies

Evaluation of agent-oriented methodologies aims to provide common frameworks for comparing the wide range of existing design approaches. (Cernuzzi and Rossi, 2002) defines qualitative evaluation criteria organized as an attribute tree. Evaluation criteria are classified into three generic categories which are: internal agents' attributes, interaction attributes and process. (Sturm and Shehory, 2003) examine criteria encompassed within the methodology definition; these criteria cover four major aspects namely concepts and properties, notation and modelling techniques, process, and pragmatics. The proposed framework was used to evaluate and compare three methodologies: GAIA, Tropos and MaSE (Sturm and Shehory, 2004). In (Dam and Winikoff, 2003) almost the same decomposition of criteria is used to compare MaSE, Prometheus and Tropos. Another work (Akbari and Faraahi, 2008) attempts to identify strengths and weaknesses of agent-oriented methodologies by defining an evaluation framework that addresses six major areas: concepts, notation, process, pragmatics, support for software engineering and marketability.

2.3 Agent tools and platforms

(Sudeikat, 2004) claims that "a complete evaluation of methodologies cannot be done without considering target platforms". This type of evaluation aims to help developers choosing the agent-oriented development tool that is most suited to their expectations. In this perspective, (Boissier et al., 2002) defines criteria to evaluate and compare agent-oriented tools. The evaluation criteria were grouped into five categories that cover the whole life cycle of multiagent systems, namely: general characteristics, multiagent models, physical characteristics, development environment and execution environment. In (Nguyen et al., 2002), another set of evaluation criteria is proposed which are: standard compatibilities, communication, agent mobility, security, availability, usability, development issues. In both researches, no quantification methods were presented to estimate the proposed criteria. In (Leszczyna, 2004), the study focuses only on FIPA compliant agent platforms which were evaluated according to general criteria such as documentation, update, popularity, accessibility, etc. These criteria are not specific to agent-oriented environments; that's why the study remains too general. At the opposite, very specific criteria are proposed in (Shakshuky and Jun, 2004) to evaluate agent platforms. The work focuses especially on the Message Transport System.

2.4 Agent applications

This kind of evaluation in which we are specifically interested addresses implemented multiagent systems and deals especially with the multiagent application's performance regardless of the used design methodology and development tool.

Although there is little interest on this issue, we retrieved some related works from the literature. We classify those works into two subcategories: internal and external performance evaluation.

2.4.1 Internal performance evaluation

Internal evaluation refers to the process by which the multiagent system itself measures its performance. This is done most of the time by calculating a global utility function. A utility function expresses the functional adequacy of the multiagent system, i.e. how well it realizes the objective for which it was designed; it is defined a priori and depends on the problem to solve (Thomas et al., 2007). In (Gnanasambandam et al., 2005), the authors propose a methodology to control the performance of a distributed agents' network. The multiagent system is equipped with a self-evaluating capability, so that it is up to the system itself to predict its performance by computing its overall utility which depends on metrics such as end-to-end delay and latency. The main problem with such evaluation method is that it could not be generalized. In fact, there is no general definition of a utility function, it is system dependent and is strongly linked to the problem which the multiagent system is supposed to solve.

2.4.2 External performance evaluation

External performance evaluation, unlike internal one, means that the evaluation is done by an entity outside the system. Although there is a great need for developing multiagent systems evaluation tools, few studies have addressed this issue from a general point of view. In fact, most of the works found in the literature propose evaluation solutions which are either system dependant or specific to a given topic. For instance, in (O'Malley et al., 2000) a comparison between mobile and static multiagent systems is done. For this purpose, the performances of two distributed text search systems were evaluated using a single performance metric which is search execution time. In (Helsingier et al., 2003), a performance measurement tool for large scale multiagent systems built into the Cougaar agent is presented. (Hu et al., 2004) examines how local behaviours of agents can affect the global multiagent system's performance of RoboNBA which is a basketball game platform for autonomous robots. Local behaviours studied in this work are very specific to the target system. They include, for instance, strategies to pass the ball, strategies to defend or to attack, etc. So it is for global performance indicators which are ball control time, pass accuracy, etc. (Babczyński et al., 2005) presents a performance analysis and comparison of two information retrieval multiagent systems. The first is composed of only stationary agent while the second contains a mobile agent. Performance evaluation is carried out through simulation and the considered performance metrics include probability and mean time of receiving the good response which are very specific metrics.

3 PROPOSED APPROACH FOR MULTIAGENT SYSTEMS EVALUATION

Through the previous study of the literature we showed that existing works on evaluation in multiagent domain are essentially oriented toward design methodologies and development platforms. The originality of our contribution is that we are interested in performance evaluation of MAS from a general point of view and regardless of its used methodology or platform.

In our research works, MAS are evaluated by measuring their functional characteristics. In fact, MAS have very interesting properties that may impact their global performances. These characteristics are identified and explained in (Boissier et al., 2004). Some of them can be presented as follows:

Autonomy: It consists in three important points: the agent's independent existence, its viability out of external control and its decision according only to perceptions and knowledge.

Distribution and Decentralization: Distribution means that knowledge, processing, tasks and resources are distributed among agents in order to achieve a common goal. While distribution concerns tasks and resources, decentralization means control distribution. In a multiagent system there is no global controller but the several agents participate to the control of the whole application.

Communication and Interaction: The communication between agents provides coherence to the multiagent system in spite of decentralization. It could be performed directly by exchanging messages or indirectly by acting on the common environment. Agents interact in the environment in which they progress. Interactions between agents are point to point and include cooperation, collaboration, competition, negotiation, and delegation politics.

Organization: Organizations allow formalizing relationships between agents and offer a mean to specify and design a multiagent system structure that defines agents' roles and relations between these roles.

Openness and Adaptation: Openness is the functional evolution of the multiagent system. This evolution corresponds to the dynamic add, modification or removal of entities of the system. Adaptation is the ability of the multiagent system to modify its behaviour in order to evolve in a dynamic environment which is subject to many constraints.

In our research works we are especially interested in structural properties of MAS, which are evaluated following a specific process. The proposed evaluation method includes three major steps which are observation, modelling and measure, as shown in figure 1.

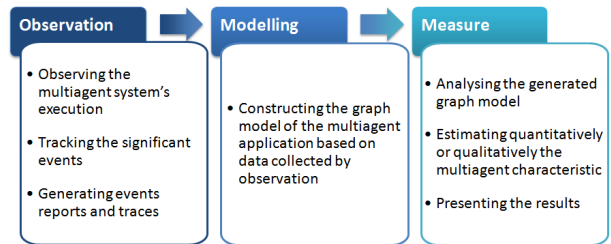


Figure 1: the evaluation system architecture

In the following paragraphs, the several steps of the evaluation process are detailed.

3.1 Observation

Observation consists in collecting information related to the execution of a given system. It includes essentially detection of significant events in the system's execution and generation of traces (Jain, 1991). In our evaluation approach, observation is performed through software probes (Ben Hmida et al., 2008). The observation probes' design and implementation are based on Aspect Oriented Programming (AOP) which is a very promising software engineering technology (Kiczales et al., 1997). Figure 2 shows the proposed observation architecture.

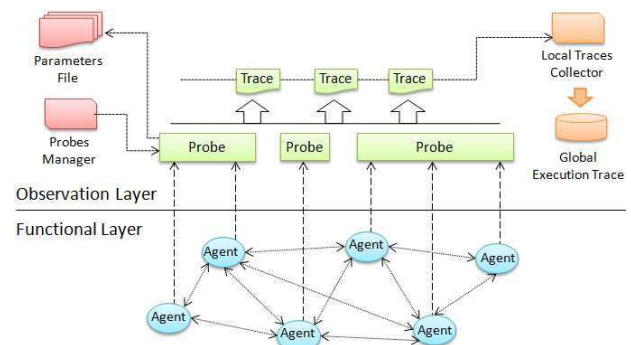


Figure 2: the aspect-based observation architecture

The probes are activated each time a significant event occurs in the MAS. For instance, each time an agent interacts with another agent, the event is detected and processed by a probe. So that all the agents' interactions are captured and saved in a traces file. The information contained in this file is used to generate the interaction graph of the MAS and compute the metrics.

3.2 Modelling

To evaluate properly the structural aspect of a MAS, we need to develop its formal representation. Using graphs to model such systems constitutes a very appropriate issue. In fact, graphs are commonly used to represent and study various types of computer networks and offer a strong abstraction and modelling tool for the real entities composing those networks. The study of graphs and their properties is done according to graph theory. Thus, the evaluated MAS is modelled by an oriented graph where the nodes represent the agents and the arcs represent the communication links between agents.

According to (Gondran and Minoux, 1995) an oriented graph $G = [X, U]$ is defined by:

- a set X of nodes, where $|X| = N$
- a set U of oriented pairs of nodes, where $|U| = M$

There are several possible representations of a graph. Here, the adjacency matrix is used.

$$A = \left(A_{ij} \right)_{\substack{i=1..N \\ j=1..N}} \quad (1)$$

In an adjacency matrix, each line (respect. column) corresponds to a node in the graph.

$$A_{ij} = 1 \text{ if and only if } (i, j) \in U \left(A_{ij} = 0 \text{ otherwise} \right) \quad (2)$$

Thus, the proposed solution consists, first in modelling the interaction network of the MAS through an oriented graph, and then identifying the properties of this graph to evaluate it.

3.3 Measure

In this step, the generated graph representing the evaluated MAS is analysed according to specific criteria. To each criterion are associated measures which are then estimated. In previous works, we focused on communication as it is a very important property of multiagent systems (Ben Hmida et al., 2011). It is measured according to three main aspects which are: structural, syntactical and statistical aspects. Some of the used metrics are presented below:

- solicitation / participation degrees of each agent
- complexity and connectivity of the MAS communication network
- average amount traffic per agent
- load of the network
- messages typology and complexity

Communication is a central aspect, at the basis of the agents' interaction, and essential to realise the social attribute of the MAS. Besides, communication level in the MAS is one of the most important factors likely to affect its performance. However, it is not the only criterion according to which MAS could be evaluated. In fact, in (Ben Hmida et al., 2011) interpretations of the obtained measures related to communication led us to evaluate other properties such as autonomy and organization. Thus, based on our previous works, our long-term goal is to propose an evaluation system allowing measuring several multiagent characteristics, and testing it on real world applications. This will greatly help promoting application of MAS especially in industry.

4 EVALUATION OF ORGANIZATION

At this stage of our research we are interested in the evaluation of the organizational aspect of multiagent systems.

4.1 Organization in multiagent systems

A multiagent system is a society of agents in a situation of mutual interaction sharing tasks, resources and/or knowledge. There is a large panel of possible interactions between agents which encompasses for example coordination, collaboration and negotiation politics (Ferber, 1995). The several interaction patterns in a multiagent system engender complex organizational structures and interrelated acquaintances networks. Organizations can be formed in two ways. They can be defined a priori by the system's designer, in this case we talk about pre-defined organizations; or a posteriori as a result of the agents' social behaviours and interactions; and in this case we talk about emergent organizations (Ferber, 1995). In the literature, many types of organizational structures are defined in multiagent systems. Generally speaking, these structures are groups of agents cooperating to realize their objectives. However, we can distinguish two categories of groups, namely teams and coalitions. In teams the agents are assembled together from the beginning in a way that their competences are complementary in order to realize the common objective of the team but not necessarily individual objectives. In coalitions the agents can come together promptly and collaborate to realize their individual interests in the absence of a common global objective (Legras, 2003), (Boussebough, 2011).

In multiagent systems, there are also subordination relationships between agents concerning control and decision making. These relationships can be egalitarian where the agents are considered at the same level and participate evenly to the decision making process. In an egalitarian organizational structure, an agent can ask any other agent to accomplish a given task, but the latter may refuse to do it. On the other hand, there are hierarchical organizational structures where relationships between agents are authoritarian.

Thus, organization is a very important characteristics and a basic concept of multiagent systems as it transposes the social dimension of such systems. The evaluation of organization is a very interesting issue; it allows developing an understanding of the multiagent system and its structure. (Ferber, 1995) defines the possible ways of analysing organizations in multiagent systems. From one hand there is functional analysis which aims to identify and describe the functions that the several entities of an organization are supposed to realize. From this prospect, organization is viewed as a set of roles and relations between those roles. From the other hand there is structural analysis which focuses on the interactions between agents trying to make sense to their complex interrelations and explain the resulting organizational structures.

In this work, great importance is accorded to the structural aspect of organizations, that's why the chosen representative model rely on graphs which expressively shapes the multiagent structure by drawing its entities

and their relationships. A similar representation is used in (Campagne, 2005). In this work, the author tries to develop a method to control massive multiagent systems organizations using morphology. For this purpose, graphs are used to describe the system's state. But in this representation, the nodes correspond to roles or groups' roles and the links correspond to mutual preferences between those roles. The analysis consists in states graphs comparison in order to make the system auto-adaptive (Cardon, 2005). In our work, graph modelling is used for an evaluation purpose; we do not address control issue. Besides, in our case, the nodes correspond to agents and the links correspond to interactions between those agents, which is a different representation. Based on this model, the evaluation of organization is done thanks to specific metrics of graph theory which are presented in the following paragraph.

4.2 Measures for the evaluation of organization

The presented following measures are in the majority based on node degrees.

4.2.1 Degree distribution

In graph theory, the degree of a node is the number of connections it has to other nodes. Here we designate by K_i the degree of a node i . In a graph, the several nodes may have different degrees. The degree distribution $P(K)$ is then defined to be the fraction of nodes in the graph with degree K :

$$P(K) = \frac{N_K}{N} \quad (3)$$

with N_K the number of nodes having a degree K and N the total number of nodes.

The degree distribution is very important in studying graphs structures and helps understanding their topological features. The different types of networks have different characteristic degree distributions $P(K)$. Thus, the shape of the degree distribution function allows distinguishing two main classes of networks (see figure 3).

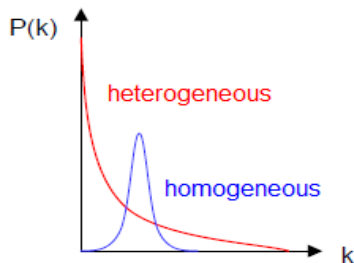


Figure 3: Homogeneous vs. Heterogeneous networks degree distributions

Homogeneous networks are characterized by a degree distribution that is concentrated around the degree mean value $\langle K \rangle$ given by:

$$\langle K \rangle = \sum K \times P(K) \quad (4)$$

In such networks, there are no highly connected nodes. On the contrary, heterogeneous networks are characterized by a degree distribution that generally follows a power law which is the case of most networks in the real world. This means that, in such networks, there is a large majority of nodes having low degree but a small number having high degree that greatly exceeds the average. Those nodes are thought to be special and having a specific function in their networks.

4.2.2 Assortativity

Assortativity is a characteristic of graphs which reflects the tendency of a graph's nodes to be connected to nodes having similar (or different) degrees. Assortativity is often examined in terms of correlation between nodes degrees. A simple characterization of the correlations between degrees of neighbour nodes is determined by the neighbourhood degree $K_{m,i}$ which expresses the average neighbours degree of a given node i .

$$K_{m,i} = \frac{1}{K_i} \sum_j K_j \quad (5)$$

Based on this measure, degree correlation is given by the mean neighbourhood degree of nodes with K degree.

$$K_{m}(K) = \frac{1}{N_K} \sum_{i/K_i=K} K_{m,i} \quad (6)$$

The behaviour of $K_{m}(K)$ defines two main classes of networks. We talk about assortative network when $K_{m}(K)$ increases with K . This is the case of social networks when high degree nodes are preferentially associated with other high degree nodes. And we talk about disassortative network $K_{m}(K)$ decreases with K , which is the case of hierarchic networks where high degree nodes are connected to many nodes with low degree.

4.2.3 Centrality

Centrality is a characteristic expressing the position of a node in the graph. It determines the importance of a node within the network and how much it is influent. This concept is inspired from the analysis of social networks. Many terms are used to measure centrality; here the degree centrality is used. $Cd(i)$ is the degree centrality of a node i .

$$Cd(i) = \frac{K_i}{(N-1)} \quad (7)$$

Where K_i is the degree of the node i and N is the number of nodes in the network.

4.2.4 Hierarchy

We talk about hierarchy in organizations if relations between the organization entities are determined by authority. In oriented graphs, hierarchy is defined as follows:

$$Hierarchy = 1 - \left[\frac{V}{MaxV} \right] \quad (8)$$

With V the number of unordered pairs of nodes symmetrically connected, meaning that both of the nodes can reach each other, and $MaxV$ is the total number of unordered pairs of nodes (Krackhardt, 1994).

This measure is interesting to express structural hierarchy of the network but does not reflect hierarchy degree in multiagent systems as it does not consider semantic meaning of a link. In fact, hierarchy degree in multiagent systems should reflect the existence of dominant agents. For this reason, we propose to examine the nature of the several links between agents to determine whether there is any power relationship. The better way to do that is to pick up the nature of the message, and to deduce the existence of power relationship if the message is an order. Thus, the proposed measure for hierarchy is:

$$Hierarchy = \frac{OrdV}{MaxV} \quad (8)$$

Where $OrdV$ is the number of unordered pairs related by power relationship (message subject is order).

4.2.5 Leadership

As explained in section 4.1, in a multiagent system several agents can come together into organization structures called groups which may be teams or coalitions. In both cases, there can be an agent having the special capability of coordinating the actions of the other agents. This agent is called "leader" (Legras, 2003). While in a team the leader represents a decision authority, in a coalition the leader does not have a real decisional power but is rather a point of information centralization. To pick up such agents using graph formalism, a group is assimilated to a star sub-graph, with the leader as a central node surrounded by the other group agents (Legras, 2003). A star graph Sn of order n , sometimes simply known as an n -Star, is a graph on n nodes with one node having the degree $n-1$ and the other nodes having the degree 1 (Harary, 1994). Figure 4 illustrates such graphs.

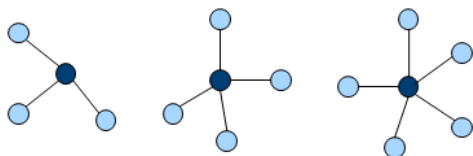


Figure 4: Illustration of a star structure

Thus, to recognize the leaders in a multiagent system, we have to identify the star sub-graphs in the whole representative graph.

5 EXPERIMENTATION AND RESULTS

The proposed evaluation system is tested on three versions of a supply chain control multiagent application.

5.1 Agent-based test application

The tested multiagent application is the implementation of a test-case considered in (François, 2007). As shown in Figure 5, it is a multi-products supply chain network in the domain of furniture manufacturing. Two families of products are manufactured: tables and shelves. In a first step, wood trunks, delivered by the wood suppliers, are transformed by the sawmills into wood furniture components (trays, legs and boards). In a second step, shelves and tables are assembled by the assembly factory. Shelves are delivered to final customers, and tables are passed to the painting factory to be painted in a third and final step before being delivered to final customers.

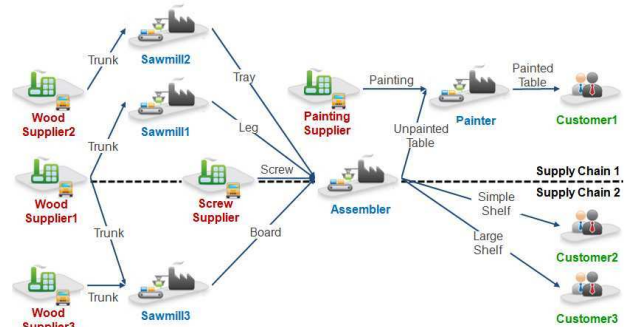


Figure 5: Test-case supply chain network

Each enterprise of the supply chain includes four services: distribution, production, procurement, and decision making which are represented by the following agents:

Distributor: this agent is responsible for the reception and the management of the customers' orders. It is also responsible for managing the products' stocks and deliveries.

Producer: this agent manages the material flow and ensures the effective production process; it transforms the received material into products according to composition rules defined by the nomenclature.

Provider: this agent is responsible for contacting suppliers and making orders whenever some components are required.

Decider: this agent synchronises the other agents' actions. It also realises the production and the material requirement planning. The distribution of the decider agents over the supply chain defines the control architec-

ture. In the case of a distributed control architecture, each decider agent is responsible for the decision making process in its enterprise; whether in a centralized or mixed control architecture, the enterprise's decider agents rely on a common decider of a higher level.

Customer: this agent represents a final customer which is wishing to buy some finished product.

Supplier: this agent represents a supplier putting on sale some raw material.

The development of procurement, production and delivery plans requires the implementation of a decision-making system defining the organization of the decision units through which the supply chain is controlled. The decisional pattern of the production planning and control activity can be organized according to different architectures which are distributed, centralised and mixed one.

In the distributed control there is a single decision making level. In such control architecture, each enterprise of the supply chains network is totally independent and manages locally its own resources. In each enterprise, control is done through a decision making center.

To overcome the lack of global visibility of information induced by the distributed control, an alternative is to make information accessible to all the actors of the supply chains network and to centralize its processing. In fact, in centralized control architecture, there is a supplementary higher decision making level with a single decision center which is responsible for production planning and resources management of the overall supply chains network. The different decision centers of the lower level are reduced to entities relaying information to the central decision making entity.

To find a balance between local autonomy induced by distributed control and global optimisation induced by centralized control, a third control strategy is proposed in (François, 2007). Such mixed control architecture is based on many decision making centers of a higher level instead of a single one. In fact, to each supply chain of the network is associated a decision center which centralizes information and processing within that supply chain. In this case, the information exchange between decision centers of the higher and the lower levels are the same as in centralized control.

5.2 Results and interpretations

The experimentations carried out on the three versions of the described multiagent application pointed out the following results.

Figure 6 shows the generated graph corresponding to the distributed control architecture. Each one of the decision centers S1.dec, S2.dec, S3.dec, ASS.dec and PNT.dec

carries out locally the production planning and resources management of the enterprise to which it belongs.

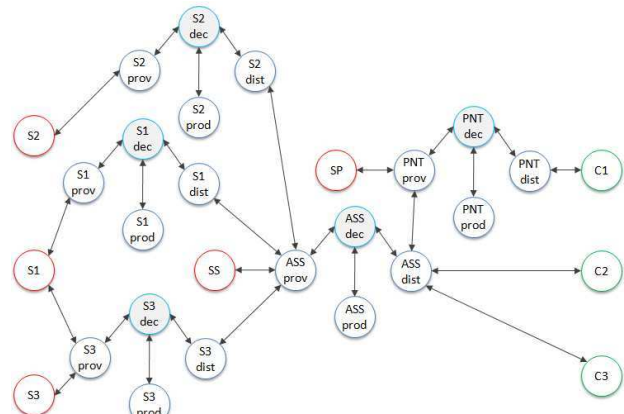


Figure 6: Distributed agent-based control architecture

Figure 7 shows the generated graph corresponding to the centralized control architecture. In this case there is a higher level decision center DEC which carries out all the production plans for the entire supply chain network.

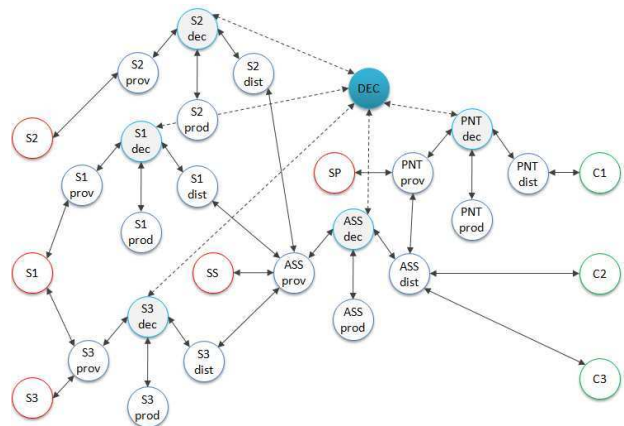


Figure 7: Centralized agent-based control architecture

Figure 8 shows the generated graph corresponding to the mixed control architecture. In this case, there is a higher level decision center for each supply chain: DEC1 and DEC2.

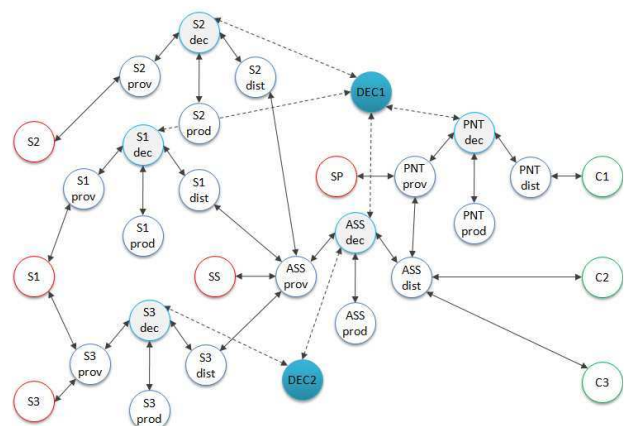


Figure 8: Mixed agent-based control architecture

The following figure expresses the several agents degrees K_i related to the three used control architectures.

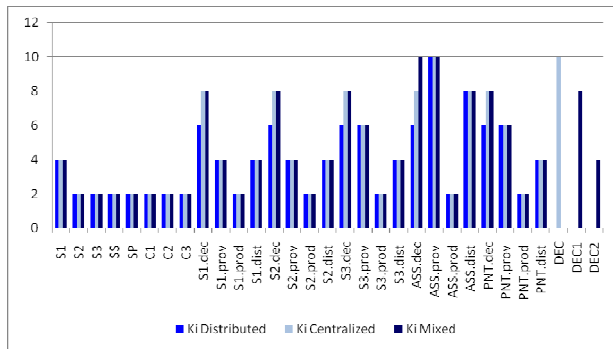


Figure 9: Agents degrees

We distinguish two categories of agents :

- those whose degree has not changed such as clients, suppliers and operating agents (production, distribution and procurement)
- those whose degree has increased with the centralization, especially in mixed control architecture. Degree increase concerns only decision centers as the centralization strategy is about the decision making system.

Besides, we notice that high degree agents are either decision centers (S1.dec, S2.dec, S3.dec, ASS.dec, PNT.dec) or operating interfaces agents in relation with many enterprises (ASS.dist and ASS.prov). By interface agent we mean distributor or provider as those agents are in relation with other enterprises agents.

Figure 10 below illustrates the aspects of distribution degree functions related to the several control architectures.

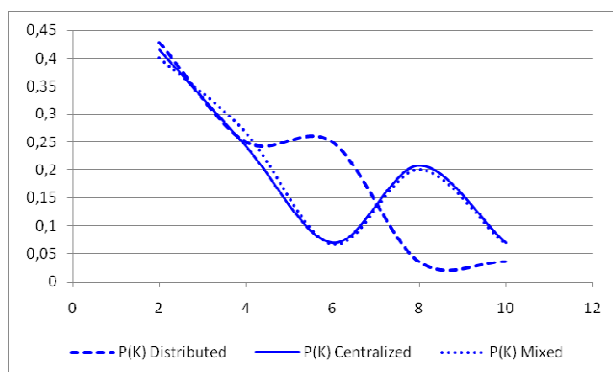


Figure 10: Degree distribution

All of the three generated graphs correspond to heterogeneous networks since there is no significant degree mean value around which the distribution degree is concentrated. In the three cases there is a majority of nodes having low degree but a small number having high degree that exceeds the average. But what we can notice here is that the degree distributions of centralized and

mixed architectures are very similar and notably different from distributed one.

This is also what we notice through the following figure 11 which draws the degree correlation for the three control architectures.

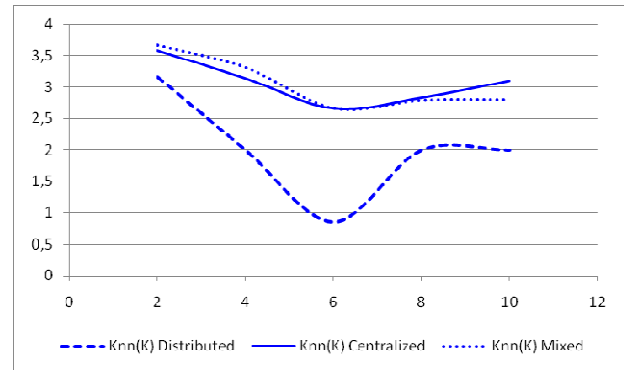


Figure 11: Degree correlation (Assortativity)

Degree correlation expresses the Assortativity of the system. The three control architectures are disassortative. Disassortativity is a characteristic of hierarchical systems where high degree agents tend to be linked to lesser degree agents. This can be explained by the existence of dominant agents. Here also we notice that assortativity of the distributed architecture is different from the centralized and mixed architectures which are very similar. In the two latter cases disassortativity is reinforced by the addition of a higher decisional level of agents. In fact dominance relation is accentuated through the centralization of control.

The following figure 12 shows the centrality degrees of the several agents using the three control architectures.

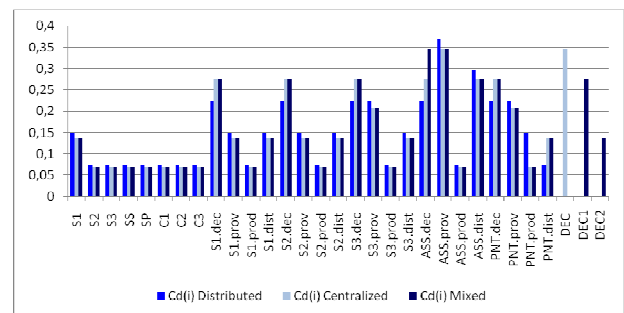


Figure 12: Centrality degree

We notice that for all agents except decision centers centrality decreases when passing from a distributed architecture to centralized or mixed one. This is naturally due to the add of agents to the system which are not linked to those agents. In the contrary all of the decision centers centrality is higher in centralized and mixed cases than in distributed one. Here again, this is due to the addition of a supplementary higher decision level whose agents are directly and only linked to decision centers.

Table 1 below presents the measured hierarchy degrees for the different studied agent architectures.

Control Architecture	OrdV	MaxV	Hierarchy Degree
Distributed	15	28	0,535
Centralized	20	33	0,606
Mixed	21	34	0,617

Table 1: Hierarchy degree

Hierarchy degree can vary from 0 to 1. In the three cases, its value is superior to the mean value 0.5 which indicates that the different studied agent applications are characterized by hierarchical tendency which is more marked when it comes to centralization that concerns both centralized and mixed architectures. This is also due to the addition of decider agents which have control over the other agents.

All the previous results indicate the presence of leadership in the studied multiagent applications. This is also confirmed by the analysis of their representative graphs which points out the existence of star structures. Star sub-graphs were identified. The highest order star structures corresponds either to decision centers or to high connected operating interfaces agents.

Significance of the measures

In conclusion, the obtained results help understanding the organizational structures and identifying different categories of agents present in the several analysed multiagent applications. In fact, in the case of distributed control architecture, agents characterized by high degree are either decision centers or operating agents connected to great number of enterprises. High degree agent which is also decider is necessarily a leader, and high degree agent which is operating agent are in situation of dependency with other agents, especially resources dependency. On the contrary agents characterized by low degree cannot be deciders, they are necessarily operating agents having certain autonomy of action and somehow isolated, and this is the case of all the production agents. In centralized and mixed control, high degree decider agents are of two categories: the greatest degree agents are leaders of a higher decision level and the others are leaders of a lower decision level. The other high degree agents are operating agents with great connectivity. Whereas low degree agents are operating ones as it is the case in distributed control architecture.

6 CONCLUSION

In this paper we presented an evaluation approach to measure organization in multiagent systems. The proposed method follows a three step process: observation, modelling and measure. The modelling technique is based on graph theory which is used to define and estimate metrics for the evaluation of structural properties of multiagent systems. In this paper, we focused especially

in organization as evaluation criterion as it is a very interesting characteristic transposing the social dimension of multiagent systems. Therefore, specific metrics based on graph theory were proposed to analyse agent organizational structures. The tests and experimentations were carried out on a multiagent application for the simulation of production planning and control in supply chains. The evaluation allows the practitioners to have a clear idea on the organizational structures of the different control architectures. It pointed out that centralized and mixed controls have almost the same organizational properties. The advantage of the evaluation presented through this work is that it's done on a real world application rather than a case study. It allows providing practitioners a clear vision about the global manufacturing organization which can help analysing and eventually improving the enterprises strategies. Our future works includes two points. The first consists in extending the test application in order to move to a larger scale and thus reconsider the evaluation results. The second point is to focus on the evaluated system's dynamics and the evolution of the proposed measures over time.

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