Using Evolving Graphs to Evaluate Structural Openness in Multi-Agent Systems

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Abstract: The evaluation of Multi-Agent Systems (MAS) issue is invoked in the literature in a twofold manner: from an external point of view through the assessment of design methodologies and development tools and platforms or from an internal point of view by measuring the functional characteristics of MAS applications. The latter kind of evaluation is not sufficiently addressed and is mostly oriented towards structural properties. We believe behavioural characteristics may considerably affect MAS performances and have to be assessed in order to judge correctly the quality of the MAS. Thus, our aim is to propose an approach to evaluate one of the most important behavioural characteristics in MAS: openness. We focus especially on structural openness and we suggest for this purpose a three-step method: observation, modelling and measure. The modelling technique is based on an evolving graph whose properties are used to estimate metrics for the evaluation. Then, our approach is tested and validated on a road traffic application.

1 INTRODUCTION

Thanks to their ability to solve a huge number of complex problems, Multi-Agent Systems (MAS) have gained increasing interest in the scientific community. Such success has been accompanied with several issues have aroused the curiosity of researchers. We mention particularly the issue concerning performance evaluation which seems to become a more complex subject when it is related to MAS. This is what explains, hence, the limited number of works in the topic of performance evaluation. Through these few works, we can distinguish two categories of proposed approaches. The first treats the system from an external point of view like the evaluation of design methodologies and development tools and platforms. The second focuses on the evaluation of MAS through the assessment of their functional characteristics. Unfortunately, such kind of evaluation is not sufficiently addressed and is mostly oriented towards structural properties such as interaction, communication and organization. Behavioural and interface ones were rarely assessed.

This paper contributes in the enrichment of MAS evaluation field by focusing on their functional characteristics. We believe behavioural ones may considerably affect MAS performances and have to be estimated in order to well-judge the quality of the MAS. Thus, our long-term goal is to study and evaluate behavioural characteristics in MAS. At this stage, we focus on openness. We propose to put the spotlight on the structure of open MAS and its evolution in time, and we will propose an approach to evaluate structural openness.

The paper is organized as follows: in section 2, a literature review of multi-agent systems evaluation is presented, section 3 deals with openness in MAS and the related existing works. Our proposed evaluation approach is described in section 4. The application on which Experimentations were carried out is described in section 5. We finish by presenting our conclusions and perspectives in section 6.

2 EVALUATION OF MULTI-AGENT SYSTEMS

The existing MAS evaluation approaches and our work position are presented and criticized in Table1.

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Table 1: MAS evaluation works.

	Related works	Issue	Solution
Black-Box-Based approaches	They are studied independently of internal properties and functionalities: the evaluation of Agent-Oriented technology (Tveit, 2001), the evaluation of design methodologies (Cernuzzi and Rossi, 2003), the evaluation of development platforms and tools (Occello, 2002).	Such evaluation is done from an external point of view and does not address the running of the application, its internal properties or even the relationship between its components and their evolution in time.	The solution proposed in the literature is to take into account the internal evolution of MAS by evaluating implemented multi-agent applications. It aims to assess MAS performances regardless of the used design methodology and development tool.
The evaluation of multi-agent applications	The literature has revealed two categories of evaluations in this context: the evaluation of the functional adequacy (Kaddoum, 2009) and the evaluation of global performances. We mention as example the work of (Joumaa, 2008) that interests in assessing interactions in a robots' society.	Such evaluation is considered in (Ben Hmida, 2013) as system dependent and specific to a given topic.	The solution proposed by (Ben Hmida, 2013) is to evaluate MAS functional properties from a generic point of view. It takes into account three categories of characteristics: the structural properties describing how agents are organized in the system, namely: communication, interaction, organization, distribution and decentralization, the behavioural properties describing the way the system evolves in time and behaves towards itself, its components, its environment and other external systems : autonomy, openness, adaptation and emergence, the third is the interface properties focusing on the relationship between the MAS and the outside whether it is its environment, a different system or a human actor: personalization, delegation, intelligibility and the situation in the environment.
Generic Fuctional-Characteristics-Based approaches	We interest especially in Ben Hmida works in which structural properties are evaluated, more particularly communication (Ben Hmida, 2008) and organization (Ben Hmida, 2012). In this context, a graph-theory based approach is proposed. It follows a three-step process: observation, modelling and measuring.	The existing works are essentially oriented towards structural characteristics and neglect behavioural and interface ones.	Behavioural and interface characteristics are not yet evaluated from a generic point of view. We argue that behavioural properties may affect considerably MAS performances so that measuring only the structural characteristics seems to be not enough. Thus, our challenge is to propose an approach to evaluate behavioural properties, and then test it on real world applications. At this stage of our research work, we are interested in the evaluation of openness and its impact on the system.

3 OPENNESS IN MULTI-AGENT SYSTEMS

Openness in MAS has been identified in the literature regarding two aspects:

- Structural aspect: It considers openness as the ability to deal with inconstant entities that leave and enter to the system causing a change in its structure (Valckenaers, 2007). In this case, openness is called structural openness.
- Functional aspect: openness here is based on the internal evolution of agents and interactions and considers the modification of their content, goals, attributes and functionalities (Boissier, 2004). In this case, openness is called functional openness.

The evaluation of such property is not well explored in the previous researches. The existing related works do not evaluate openness as a set of additions, removals and internal evolution of entities.

But, they take into account other associated aspects. For example, (Vercouter, 2001) evaluated the approaches dedicated to managing openness in MAS namely the centralized and the distributed approaches. Both of them were compared to identify the more advantageous one by using few criteria, namely the number of agents to communicate with, the relevance of other agents representation and the robustness of the system. In (Berreur, 2005), openness is measured by referring to three aspects:
openness on the environment, openness to the user and openness to other agents. To this end, an evaluation criterion was proposed. It consists in quantifying each aspect depending on the number of exchanges between the agent and one of the three facets. Other efforts are devoted to assessing trust level in open MAS. Trust is, in fact defined as a relationship between two agents where a trustor agent performs for estimating the credibility of the trustee. In this context, (Khosravifar, 2009) provides a trust assessment process to evaluate the trustworthiness of the participating agents. In the present work, we interest in structural openness. We aim to evaluate the latter property as defined in the literature and bring, as a consequence, added value to the field of MAS evaluation.

4 PROPOSED APPROACH FOR STRUCTURAL OPENNESS EVALUATION

The addition and removal of entities in MAS make its structure difficult to analyse. Thus, it is necessary to reduce this complexity by using an easy to handle mean. Modelling represents an appropriate technique allowing the explanation of the structure and the determination of some important aspects. So, in order to evaluate structural openness in MAS, we propose to adopt the process of (Ben Hmida, 2013): observation, modelling and measure.

4.1 Observation

In our evaluation approach, observation consists in generating traces each time a significant event occurs in the MAS. That's to say, when an addition or/and a removal of agents or/and interactions is detected, a specific model is produced. Such operation is performed through software probes based on Aspect Oriented Programming (AOP). As for the generated model, it will be discussed and justified in the following paragraphs.

4.2 Modelling

Due to its dynamicity and strong evolution, structural openness in MAS requires a changing-nature model to be represented. In other words, the proposed model must be dynamic and have to allow highlighting the different events causing the observed modifications. Besides, whenever a system consists of many single components interacting together, it becomes natural to represent it as a graph where each node stands for one component and interactions are symbolized by edges.

Thus, a dynamic graph seems to be appropriate to represent the structure of open MAS. It is indeed a powerful mean that has interested many researchers i.e (Afrasiabi Rad, 2016), (Zaki, 2016) and (Beck, 2016). They all give a consensual definition of a dynamic graph and define a set of related metrics.: it is a sequence Γ := (G1,G2,…,Gn) where each static graph Gi := (Vi, Ei) models a set of objects Vi, called vertices or nodes and their relationships $Ei \subseteq \mathrm{Vi} \times \mathrm{Vi}$ called edges or arcs. The indices refer to a sequence of time steps $\tau := (t1, t2, \ldots, tn)$.The graph G_{i+1} is obtained from G_i by simple modifications: additions and removals of vertices and edges.

Many dynamic graphs were studied and analyzed in the literature. We mention mainly: Complex Networks (Boccaletti, 2006), evolving graphs (Ferreira, 2003) and (Bui-Xuan, 2003), Re-optimization graphs and finally cumulative graphs and Space-Time Networks. These graphs are classified in (Pigné, 2009) following three criteria:

- Graph dynamicity: it refers to the ability of the dynamic graph to undergo modifications in its components. In this context, (Zaki, 2016) distinguishes between two types of dynamic graphs. The first is the fully-dynamic graphs allowing modifications in nodes, arcs and their associated attributes namely Complex Networks and evolving graphs. The second is the partially-dynamic graphs allowing changes only at some components namely Re-optimization graphs, cumulative graphs and Space-Time Networks.
- The knowing level of events evolution: According to this criterion, dynamic graphs are classified into two categories: those whom evolution is known in advance such as complex networks, Re-optimization graphs and cumulative graphs, and those whom changes are not initially known but progressively-revealed in time like evolving graphs and Space-Time Networks.

- The evolution process of the graph: this criterion distinguishes between dynamic graphs depending on how the events of the evolution are generated. In fact, the process to generate the events may be described in the model such as in complex networks or are simply the result of random applications, which is the case for other dynamic graphs

Actually, an open MAS is a strongly-dynamic system which permit any operation of addition and removal of agents and interactions. Its environment is so uncertain that it is impossible to know in advance which are the events responsible for the structural change or how are they generated. Therefore, the dynamic graph that we will base on should have the following properties: a full dynamicity, a progressively-revealed events evolution and an unknown evolution process. So, we say that an evolving graph is more appropriate to model structural openness in MAS.

Evolving graphs are studied in several works. We mention mainly (Ferreira, 2002), (Monteiro, 2006) and (Jarry, 2008). Its definition is given below:
Let be given a graph G (V, E) and an ordered sequence of its sub-graphs SG = $G_1, G_2, \ldots, G_T$ such that $\bigcup_{i=1}^{T} Gi = G$. Let $S_T = t_0, t_1, t_2 \ldots t_T$ be a sequence of time instants. Then, the system GE = (G, S_G, S_T), where each Gi is the sub-graph during $[t_{i-1}, t_i[$, is called an evolving graph. The graph G is called underlying graph. Figure1 shows an illustrating example of an evolving graph built from three sub-graphs G_1, G_2 and G_3.

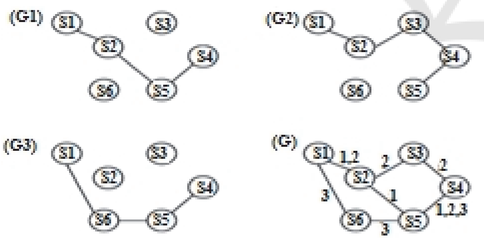

Figure 1: Illustrating example of an evolving graph.

Our evolving graph consists of a set of vertices V that represent the agents having existed in the system and a set of arcs E symbolizing the interactions having appeared over the time. Each edge stands for a transmitted message between two agents. Thus, our graph is directed for the simple reason that any message has a sender and a receiver agent. We propose to label each node of the underlying graph G with a vector < id, P_v, app_v, $disp_v$> where id is the identifier of the corresponding agent, P_v is the presence vector of the node, app_v is the number of appearances of the corresponding agent in the system and $disp_v$ is its number of disappearances. Similarly, each arc of the underlying graph G is labelled with a vector < SrcId, DesId, P_e, app_e, $disp_e$> where SrcId is the identifier of the sender agent, DesId is the identifier of the receiver agent, P_e is the presence vector of the arc, app_e is the number of appearances of the corresponding interaction and $disp_e$ is its number of disappearances. The generated graph will be exploited in order to propose measures to evaluate the structural openness in MAS. This is what we will detail in the next paragraph.

4.3 Measuring

In this section, we will analyse our model and estimate some appropriate measures.

4.3.1 Alpha Index α

Alpha index is the measure used to estimate the variation of the number of agents. It is applied on the underlying graph G and expressed as the difference between the total number of nodes' appearances and their total number of disappearances:

$$\alpha = \sum_v app_v - \sum_v disp_v \qquad (1)$$

α reflects the nature of the evaluated open MAS. In fact:

- If α>0 then MAS is said to be increasing.
- If α<0 then MAS is said to be decreasing.
- If α=0 then MAS is said to be conservative.

4.3.2 Degree of Structural Extensibility χ

The degree of structural extensibility is proposed to evaluate how much the system is able to manage the free entering and leaving of agents. It is estimated through the renewal rate of the graph and applied on the sequence of the sub-graphs S_G. This latter is defined in (Pigné, 2009) as follows:
Let be a structure of a dynamic graph observed on two instants S_1 and S_2. The renewal rate tr (S_1, S_2) is the number of changes M between the two dates compared to the number of elements |S1| in the starting structure.

We consider that the sub-graph G_i is the structure on which we conduct our calculation and we interest only in the additions and removals of nodes. Thus, the renewal rate of G_i is defined as follows:

$$tr\,(G_{i-1}, G_i) = \frac{M}{Ord\,(G_{i-1})} \qquad (2)$$

M is the total number of appearances and disappearances of nodes and $Ord(G_{i-1})$ is the number of nodes in the sub-graph G_{i-1}.Then, we define χ as the average renewal rate of G_i.

$$\chi = \frac{\sum_{i=1}^{N} tr(G_{i-1}, G_i)}{N-1} \tag{3}$$

N stands for the number of sub-graphs in the sequence S_G.

χ may reflect the degree of scalability of the open MAS. This latter is defined as the ability of the system to adapt itself from a dimensional point of view as to larger sizes than to smaller ones while maintaining its efficiency. Therefore, when $\chi > 0.5$ i.e. when the number of entering and leaving agents between G_{i-1} and G_i exceeds on average the half of the existing agents in G_{i-1}, the MAS is qualified as highly scalable. On the opposite case, the system is low scalable.

4.3.3 Structural Impact π_j

Structural impact π_j is the proportion of time during which the agent j is functional in the MAS. Based on the sequence of sub-graphs S_G, we define it as the ratio between the cumulative age of the corresponding node S_j and the observation duration D. The cumulative age of an element in a dynamic graph is defined in (Pigné, 2009) as the sum of the durations of the time intervals during which it is present in the dynamic graph:

$$\forall S_j \in V, \pi_j = \frac{CA(S_j)}{D} \tag{4}$$

In open MAS where agents can be removed at any time, an agent that persists for a long time is said to be stable. It may acquire a significant amount of information and behave as a leader. Therefore, the structural impact π_j may reflect the degree of stability of the agent j in the evaluated MAS. The more π_j is elevated, the more the corresponding agent is stable and its convergence to the leadership is important.

4.3.4 Dependency Rate τ_j

We call the dependency rate τj the relationship between the number of added interactions by an agent j and the possible number of interactions could be added by the same agent. Indeed, the number of the established interactions by an agent j, symbolized by a node Sj, is the sum of the outgoing edges' activities. Actually, the activity of an edge e is denoted $\delta_E(e)$ and defined in (Ferreira, 2003) as the number of its presence intervals. The formula of τ_j is as follows:

$$\forall S_j, S_k, S_v \in V, \tau_j = \frac{\sum_K \delta_E((S_j, S_k))}{\sum_{i=0}^{i=T} \sum_{v \neq j} P_v(S_v, G_i)} \tag{5}$$

In open MAS, an agent has a partial view of its environment. It must cooperate and interact with other agents in order to acquire what it needs to achieve its goal. Thus, the dependency rate τj reflects the deficiency degree in terms of capabilities and resources that leads the corresponding agent to establish new interactions.

4.3.5 Lambda Index λ

Lambda index λ estimates the variation of the number of interactions. It is applied on the underlying graph G and expressed as the difference between the total number of edges' appearances and their total number of disappearances:

$$\lambda = \sum_E app_e - \sum_E disp_e \tag{6}$$

Lambda index λ reflects the effect of the structural openness on the abundance of communication between the agents. In fact:

- If $\lambda \geq 0$ then we say that the structural openness promotes the abundance of communication in the system.
- If $\lambda < 0$ then we say that the structural openness demotes the abundance of communication in the system.

4.3.6 Transitivity T_j

We define transitivity T_j as the ability of an agent j to acquire data from the other agents. We express it as the relationship between the number of existing journeys between the corresponding nodes S_i and S_j denoted N_{ij} and the number of all the existing journeys in the graph N_J. In (Ferreira, 2003), a journey in an evolving graph is defined as follows:

Let R be a path R = $e_1, e_2 ... e_k$ with $ei \in E$. Let $R_\sigma = \sigma_1, \sigma_2, ..., \sigma_k$ be a time schedule indicating that edge e_i is to be traversed at time σ_i. A journey J = (R, R_σ) is defined if and only if R_σ is in accordance with R and GE i.e., J allows for a traversal over time from u to v in GE.

The formula we propose in order to calculate T_j is:

$$\forall S_j \in, T_j = \frac{N_{ij}}{N_J} \tag{7}$$

In this case, an interaction is seen as a trust relationship. It is progressively acquired by agents thanks to the MAS openness. Thus, the more Tj is elevated, the more agent j is trusted. The agent having the greatest transitivity is said to be the more stressed to the communication over the time.

4.3.7 Structural Distribution ρ

In open MAS where agents and interactions can freely enter and leave, coalition structures can be progressively created. In other words, agents having compatible goals form a group and cooperate together in order to perform a common task (Hasan, 2013). Thus, we define ρ as the number of maximal time-connected components. This latter is defined in (Ferreira, 2003) as follows:

A maximum time-connected component (MTCC) in an evolving graph is the maximum set of vertices $U \subseteq V$ such that for any pair of u, v $\in U$, there exists a journey from u to v and a journey from v to u using only vertices in U.

According to (Gruszczyk, 2008), When agents cannot complete their tasks individually they may exchange information and form coalitions which gives them best efficiency in terms of solved problem. Thus, structural distribution ρ allows determining the effect of the structural openness on the system's performance. We say, the more the number of obtained MTCC is elevated, the faster agents are able to achieve their local goals.

5 EXPERIMENTATION AND RESULTS

Our approach is tested on a multi-agent road traffic application described as follows.

5.1 Agent-Based Test Application

The tested multi-agent application is a road traffic simulator. It allows, at any time, the addition and removal of agents and interactions. We believe that testing such application is much more useful for MAS community when it is used to compare coordination strategies in dynamic scenarios. But, it is also beneficial for us in the sense that we can take advantages of its dynamicity and openness to conduct our calculation and validate our evaluation approach. Actually, our road traffic simulator is developed upon the JADE framework and made of several agent types:

- Driver: this agent is able to stop, to forward, to choose a path, to change its position and to respect the lights at intersections. It can communicate with its predecessor, its pursuer, the road on which it is moving and the intersection met in its movement. Its identifier is prefixed by the word "Cond:".
- Road: this agent interacts with drivers providing them with information concerning their predecessors and pursuers. Its identifier is prefixed by the word "Route".
- Intersection: this agent conveys information concerning lights' states and drivers at the same intersection. Its identifier is prefixed by the word "Carrefour".
- Light: this agent has for role to inform drivers and pedestrians about its current state. It has an identifier prefixed by the word "Feu".
- Pedestrian: it aims to cross a road while taking into account the lights state. It has an identifier prefixed by the word "Pieton".

5.2 Results and Interpretations

Due to its strong dynamicity, our simulator generates evolving datasets: the user can't predict neither the number of appearing and disappearing agents nor the way they coordinate. That's why, it seems judicious to present a test case and analyse its results which are with no doubt real datasets. As explained in section 4.2, we base on a directed evolving graph where each edge is a transmitted message between two agents. Figure 2 shows the sub-graphs S_G representing the evolution of the system during 4 seconds. The different sub-graphs are generated using Graphstream, a java library that focuses on the dynamic aspects of graphs.

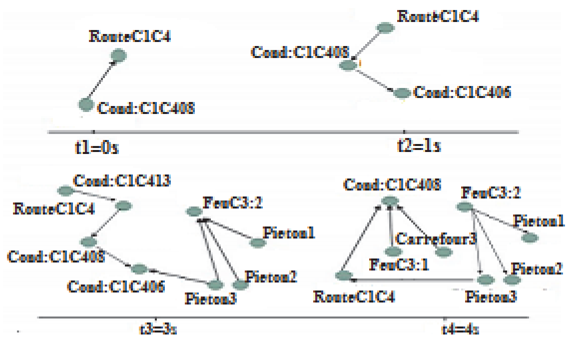

Figure 2: The set of sub-graphs S_G generated during 4 seconds.

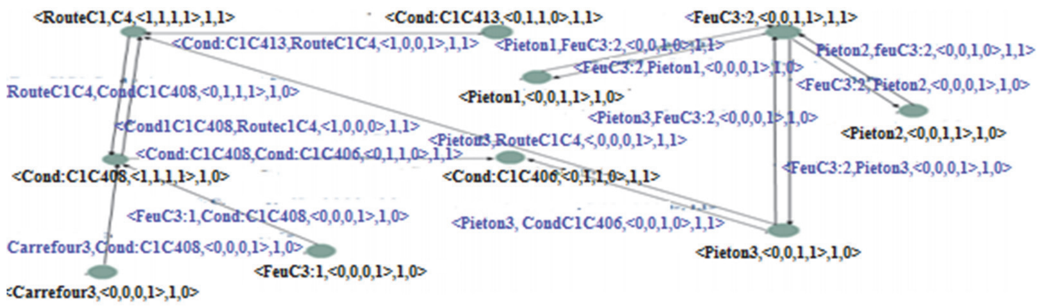

Figure 3: The underlying graph G.

Figure 3 shows the underlying graph G, the aggregation of the previous sub-graphs.

Now, we can calculate our measures. The global ones are presented in Table2.

Table 2: Global performance metrics.

Property	Measure	Value
Nature of the open MAS	Alpha Index α	7
Degree of scalability	Degree of structural extensibility χ	0.89
The effect on the communication abundance	Lambda Index λ	5
Open MAS' performance	Structural Distribution ρ	4

As for the local measures, they are illustrated in Figure 4.

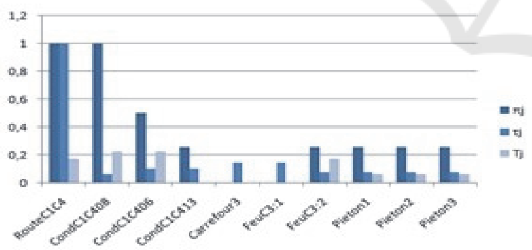

Figure 4: Local performance metrics.

According to the obtained results, we have an increasing trafic flow. Having a degree of structural extensibility greater than 0.5, our system is said to be high scalable. Its ability to manage the free entering and leaving of drivers and pedestrians, is elevated which reflects a high congestion level supported by the simulated roads and helps to think about new policies to make better the transport infrastructure. Besides, the communication between the agents is abundant and promoted in time. Thus, our road trafic simulator is an interactive application that puts together a set of social agents. The structural openness of the application caused 4 coalitions. We say that vehicles and infrastructure have a great ability to communicate in order to get an optimal transport network with efficient movement of traffic. CondC1C408 have the highest value of π_j. It is the more stable agent in the system and the elected one to be leader in the future. We can say also that CondC1C408 is the more cost-effective in terms of travel time and delay. RouteC1C4 have the greatest dependency rate τ_j which means that it has to interact with other agents in order to overcome the issue of capabilities insufficiency and avoid as a consequence serious problems like accidents . Having the more elevated transitivity T_j, CondC1C406 and CondC1C408 are the more trusted and the more stressed to the communication over the time. Besides, Route C1C4 is the road having the greatest transitivity. This latter is then usually used by drivers and pedestrians and that can be subject to traffic jam.

6 CONCLUSION

In this paper, we presented an evaluation approach of structural openness in MAS. The proposed method follows three steps: observation, modelling and measure. The modelling technique is based on an evolving graph which is used to estimate metrics to get a clear idea about the quality of the open MAS. The tests and experimentations were carried out on a road traffic simulator, an open multi-agent application which puts together a set of volatile and persistent agents. The obtained results allowed us to validate the proposed evaluation model and to give some interpretations related to the underlying road traffic state. As a perspective of this work, we aim to focus on two points. The first consists in working on the functional openness interesting in the internal evolution of agents and interactions. The second is to evaluate the behavioural characteristics in MAS: adaptation, emergence and autonomy.

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