Cohesion as a Tool for Maintaining the Functional Integrity of a Multi-agent System

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Abstract: In a context of open systems, agents can work with other unknown agents. They must therefore be able to dynamically adapt their behavior to ensure that the system functions properly for all times. Bringing together these open groups of agents and humanities and social sciences groups opens up new perspectives in how to maintain the functional integrity of an artificial system. We propose then to draw inspiration from mechanisms of cohesion resulting from HSS in order to improve the resilience of these systems.

1 INTRODUCTION

Today, a large majority of digital systems are highly distributed and open involving heterogeneous entities that interact and have advanced decision-making capabilities. Considering these artificial systems as societies of intelligent systems or objects opens up wide perspectives through the analogy we can make with social organizations. These systems are composed of groups of agents who may need to work as a team to achieve a common objective. These groups need cohesion to maintain their agents united and achieve their objectives. Cohesion is a concept that refers to the mechanisms that connect a small or large set of units. In computer science, the notion of cohesion has so far been mainly limited to structural aspects of group organization resulting in the maintenance of connectivity in relationships between individuals (swarm of robots (Manning et al., 2015), software components (Rathee and Chhabra, 2018), networks (Torrents and Ferraro, 2015)). Maintaining functional integrity in a decentralized artificial system represents the ability of a multi-agent system to achieve its objective (Piętak et al., 2009). Different factors such as the number of agents in the system or the number of inter-agent communications can make a system inefficient or even fail, and therefore threaten its functional integrity (Kisiel-Dorohinicki and Nawarecki, 1998),(Wallach, 1981).

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To avoid failure, a multi-agent system must be able to self-organize in order to maintain the unity of its members and thus restore its performance. Maintaining the integrity of these artificial societies is then close to maintaining cohesion (Carron, 1982) in human societies and we can benefit from studies conducted in the Humanities and Social Sciences (HSS). The notion has been discussed very recently for modeling in behavioural simulations within an multi-agent system (MAS) (Adam et al., 2019). While much work is being done on fault tolerance, few use behavioural concepts related to group dynamics. Some studies address the self-evaluation of an agent in relation to members of its group through the notion of social diagnosis (Kalech and Kaminka, 2003)(Rooy et al., 2016). They only approach the notion of cohesion from the point of view of its individual evaluation. In this article, we propose an agent model based on the cohesion mechanisms of HSS in order to improve the functional integrity of MAS.

This document is organized as follows: part 2 introduces the notion of group cohesion as seen in HSS as well as a list of cohesion criteria that can be integrated into artificial systems to improve their resilience. Section 3 presents a case study and describes how to integrate cohesion criteria into it. Section 4 describes the cohesive agent model we propose. Section 5 presents the experimental environment and specifies the methods of evaluating the system on the study case and the associated results. Finally, we conclude in the part 6.

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2 COHESION

2.1 Group Cohesion

2.1.1 Definition

Cohesion is defined by Festinger as the sum of the forces that act on members in order to maintain the group (Festinger, 1950). These forces depend on the attraction and repulsion of several criteria such as the prestige of the group, its members, or the tasks the group is working on. Later, (Carron, 1982) adds the notion of unity and describes cohesion as a dynamic process that reflects the tendency of group members to stay together and maintain unity in the pursuit of common goals.

2.1.2 Cohesion Measurement

Mikalachki suggests that cohesion can be divided into two components (Mikalachki, 1969) : task cohesion and social cohesion. He argues that task cohesion occurs when group members come together around the task they are supposed to perform, while social cohesion occurs when they come together around a social function. Several models have been created to break down group cohesion.

The first presents the two main categories suggested by Mikalachki, task cohesion and social cohesion. The second figure 1, presented by (Carron, 1985), takes into account the individual's attraction to the group as well as its integration into the group. It presents two dimensions of cohesion: the Group Integration (GI) and the Individual Attraction To Group (ATG). The first (GI) represents the way individuals perceive the group (similarity, proximity, etc.), the second (ATG) represents the satisfaction of the expectations that the group brings to individuals (interactions with others, productivity, objectives, etc.). As shown in figure 1, the model decomposes again these two dimensions as Mikalachki did in order to split them into social and task components. Therefore, Carron proposes a multi-dimensional model where the cohesion criteria are divided into the dimensions GI-S, GI-T, ATG-S and ATG-T.

Heuzé and Fontayne tried to define a French-speaking measure of cohesion (Heuzé and Fontayne, 2002). To this end, they examined the usefulness of the Group Environment Questionnaire (GEQ) (Carron, 1985) for measuring cohesion in French sports teams and the reliability of the Carron model. Their study presents a questionnaire similar to the GEQ called *Questionnaire sur l'Ambiance du Groupe* (QAG). Thus, about thirty criteria were rewritten on

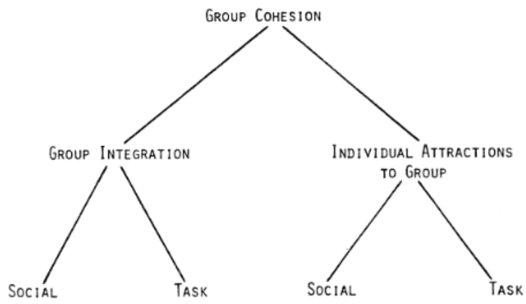

Figure 1: Proposed model by Carron (1958).

the QAG, and distributed over the four dimensions seen above: GI-S, GI-T, ATG-S, ATG-T. Each of them asserts a feeling about the group that the interviewee may or may not agree with, for example, *I don't like my team's playing style*, or *I have some of my best friends on the team*.

In addition to the QAG items, other factors are favourable to the creation of a team climate. Unlike the QAG, they rather focus on the state of the group itself than on the perceptions of individuals. Carless and De Paola are conducting a study similar to Carron's regarding the cohesion measurement in which they focus on work teams (Carless and De Paola, 2000). By seeking correlations between dimensions of cohesion and characteristics of working groups, they determine new criteria for assessing group cohesion. These are strongly correlated with the task cohesion: team interactions, team effectiveness, presence of social assistance, presence of team spirit.

2.2 Artificial Cohesion

In order to transpose the cohesion seen in HSS to artificial systems, it is necessary to extract quantifiable criteria from sociology to be able to reuse them in a decision model based on cohesion. We extract criteria from the QAG cohesion and add those of Carless and Paola (Carless and De Paola, 2000) (table 1), we retain a list of 18 items allowing the appearance of cohesion within a group. To give some examples of extracted criteria : *Satisfaction of the team's objective* (ATG-T), *Presence of affinities in the group* (ATG-S), *Cooperation in the team* (GI-T), *Interactions in the team* (GI-S), *etc.*. All these items represent a part of the QAG and assess both the social and task dimensions of the group. Each individual then builds a perception of its group that allows him to have or not a feeling of belonging to it. Although the QAG contains 31 items, this list contains only 18. The main reason is that many of the QAG criteria are too social to be integrated into an artificial system. To illustrate : *I don't like to participate in my team's extra-sport ac-*

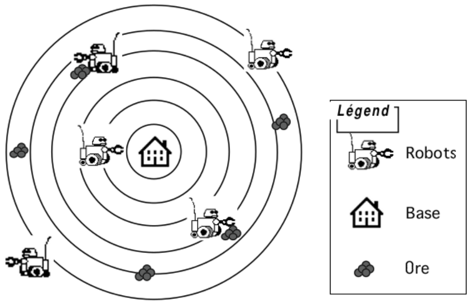

Figure 2: Mars exploration with agents.

tivities assumes that an agent can like or dislike a task and that its group can organizes extra-group activities. This kind of criterion requires a very cognitive agents' architecture in order to be used.

3 INTEGRATE CRITERIA INTO AN ARTIFICIAL SYSTEM

3.1 Case Study

Cohesion mechanisms must be evaluated on a case study in which coalitions of agents are formed. The chosen case study is about Mars exploration, presented in Ferber's book (Ferber, 1995) (figure 2). The objective is to collect mineral samples around a base on Mars using robots, each representing an agent. In Ferber's example, there are three types of agents: 1. detectors (which explore the planet in search of minerals), 2. drillers (which extract the ore from the ground), 3. carriers (which bring the ore back to the base).

By their nature, agents are interdependent, carriers cannot transport ore if drillers have not extracted it, and drillers cannot extract it if detectors have not found it. Each agent is constrained in its communications by a maximum emission range. In this practical case, a team of valid agents is composed of at least three members, one of each available type (detector, driller, transporter). This case study therefore requires agents to cooperate to achieve their personal goals. They must then organize themselves into coalitions to be able to help each other.

3.2 Criteria Integration Into this Case Study

Provided advantages by cohesion criteria :

- self-organization assistance: agents tend to self-organize into coalition;
- increased productivity: the system finishes its work faster by communicating less;
- increased resilience: the system better manages stress periods without failing;
- failure detection: the system better detects blocking malfunctions during the execution period.

The Table 1 illustrates the benefits provided by each cohesion criterion. Ease of implementation is taken into account to help system designers to choose which criteria to integrate first. Increasing resilience is not really useful in this table since it is the more or less direct consequence of each cohesion criterion.

Relatively few criteria are easily integrated into artificial systems. Indeed, most of them require a relatively complex cognitive agent structure in order to be implemented. For example, social assistance and the cooperation of agents requires having a memory on which they can reason to determine who should be helped, how, when, etc., but also specific communication protocols to act effectively. Similarly, team spirit is a complex element to put in place since it requires agents to plan actions according to their internal states. On the contrary, some criteria are more easily integrated, such as the satisfaction of the agent's involvement in its individual objective, or the quality of relationships through the agents' interactions.

In order to evaluate cohesion criteria into an artificial system, we give priority to those that are easily implemented and cover a wide range of benefits among those presented in the table 1 (allowing self-organisation, increasing productivity and resilience, and detecting failures). Finally, we retain all the criteria that can be easily implemented: 1. satisfaction of the member's involvement in the objective, 2. interactions in the team, 3. presence of affinities in the group, 4. satisfaction of the role played in the group, 5. satisfaction of the role acquired in the group. We have chosen to remove criteria #4 and #5 because both focus on the role that agents play and in our case study each agent have a fix role. However, if the case study uses multipurpose agents, criteria #4 and #5 would have a more important effect and could play a role in self-organization.

Finally, the cohesiveness criteria integrated into our case study are: *satisfaction of the member's involvement in the objective*, *interactions in the team* as well as *presence of affinities in the group*.

4 COHESIVE AGENT MODEL

In order to generalize the use of cohesion criteria, we propose a cohesive agent model, which, based on the

Criteria	Increased resilience	Ease of implementation	Increased productivity	Self-organization assistance	Fault detection
Satisfaction of the member's involvement in the objective	X	X	X	X	
Interactions in the team	X	X			X
Presence of team spirit	X		X		
Effectiveness of the team	X		X	X	
Presence of affinities in the group	X	X			
Satisfaction of the role played in the group	X	X		X	
Satisfaction with how the team performs its goal	X		X	X	
Satisfaction of the team's objective	X			X	
Ability of the individual to evolve within the group	X		X	X	
Importance of the social group to the individual	X				
Satisfaction with the role acquired in the group	X	X		X	
Cooperation in the team	X		X		
Involvement of group members in the activity	X			X	X
Appreciated atmosphere within the group	X				X
Presence of social assistance	X		X		
Satisfaction of team priorities	X		X	X	
Preference for activities of other groups	X		X	X	
Compatibility of individual objectives with the common objective	X		X	X	

Table 1: Advantages provided to artificial systems by cohesion criteria.

above criteria, requires the following characteristics:

- a representation of the environment;
- a representation of itself;
- social skills;
- the ability to reason on its knowledge.

These properties can be found in several known cognitive architectures such as Soar (Laird, 2012), ACT-R (Anderson et al., 1997), CLARION (Sun et al., 1998), LIDA (Franklin and Patterson, 2006), BDI (Bratman, 1991), or FORR (Epstein, 1994).

These six architectures meet our needs for representing the environment, itself and reasoning on knowledge. Some, such as Soar, BDI, ACT-R and CLARION, even make it possible to create social agents. Many of these architectures (Soar, LIDA, FORR) also have learning capabilities that are beyond the scope of this study. ACT-R and CLARION architectures are very time-consuming to compute, which makes them difficult to use on a large number of agents and would avoid scaling. A simple architecture based on the BDI model therefore seems to be the most representative of our needs among those studied. For this reason, we reuse and modify it in order to experiment with the effect of cohesion criteria in artificial systems.

The changes to the classic BDI model ensure that the agent can take into account the states of its acquaintances to sort incoming messages as well as its personal state to make a decision. Thus, the cohesive BDI model (figure 3) is modeled as the tuple:

$$A_{cohesif} = < \text{Messages}, S_M, \text{filter}, \text{Acquaintances}, \text{Implication}, \text{Desires}, \text{plans}, \text{ctx}, \text{Intentions}, S_I >$$

This model uses the same reasoning cycle as a classic BDI model with some modifications (highlighted on the figure 3).

Message Management (Messages, S_M). The Messages module is a buffer in which all messages received by the agent are stored. These messages are stored before being processed by the agent. The message selection function allows to choose which message will be processed by the agent. In this case, the messages are processed in their order of receipt (FIFO) but it is possible to design a heuristic to adapt

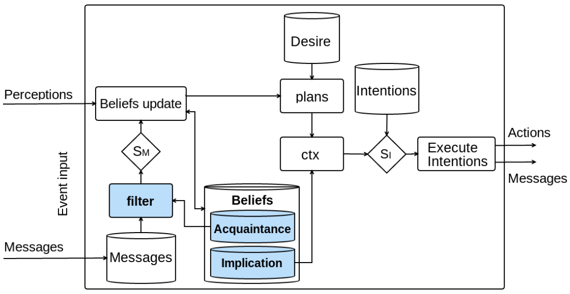

Figure 3: Reasoning cycle of the suggested modified BDI model.

the agent's behavior to the needs.

The Belief Update Function. The belief update function provides the agent with new information built by its perceptions or by messages received from other agents. The updating of beliefs impacts the plans module, which will allow the agent's behaviour to be modified according to his knowledge.

Implication, Acquaintances. The agent's belief status is enhanced by the addition of involvement and bridging modules. The first is a self-assessment by the agent of the quality of its involvement in its work. Involvement allows cohesive agents to notice a lack of activity and react accordingly via the ctx module. This first mechanism provides agents with a means of self-diagnosis of a dysfunction, which improves their individual resilience and the system resilience.

The Acquaintances module associates a relational score with each acquaintance, which makes it possible to estimate the quality of each relationship. Since the Acquaintances module has an effect on the message filter function, this score is an analogy of trust. By quantifying the reliability of an agent's acquaintance, this second mechanism allows an agent to detect dysfunctional agents with which it is in contact. The detection of these agents then allows the system to isolate them and thus improve its resilience.

The Filter Function. The filter function is used to filter messages in relation to the agent's connection module. Relational scores of acquaintances are compared to a threshold used to determine whether a relationship is bad enough or not in order to ignore the sender's messages. Therefore the filter function plays an important role in the recognition of dysfunctional agents and therefore in maintaining the functional integrity of the system agents.

Desires, Intentions. Desires are the agent's motivations. They represent objectives or situations that the agent would like to see accomplished. Intentions represent what the agent wants to do. Unlike desires, agents check the feasibility of intentions. Intentions are achievable, some of which can already be started.

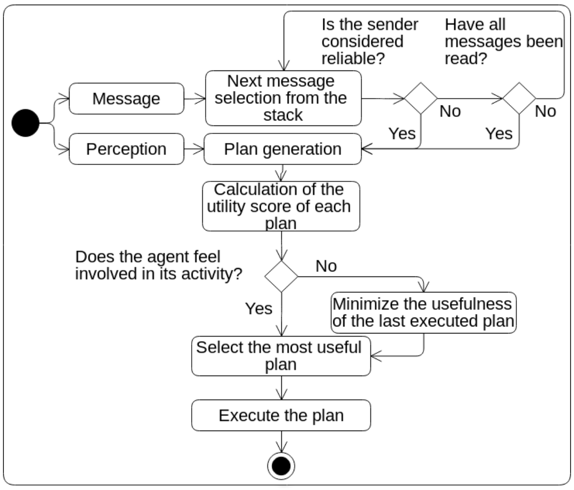

Figure 4: Activity diagram of a cohesive agent.

Plan Generation (Plans, ctx). In order to act, agents generate several plans linked to their desires. The context function prioritizes plans according to the situation by assessing their usefulness and selects only those that are applicable. At the end of this step, the agent has an overview of the achievable plans and their usefulness.

Intentions Management (S_I, Execute Intentions). At this level, all feasible plans are selected. The selection of the intention will therefore make it possible to keep only one plan and choose an action to execute. The selected plan is the one with the highest utility score.

To illustrate the behaviour of one of the three types of agents, the figure 4 shows the activity diagram of a drilling agent. This diagram represents the mechanisms for involvement and evaluation of acquaintances explained above. The first cohesion mechanism is involved in the selection of the message to socially isolate agents who do not do their work properly. The second, on the choice of a plan, allows the agent to change its behaviour in case of dissatisfaction with the work previously done. These two complementary mechanisms both contribute to improving the resilience of the system by making it possible to self-diagnose a malfunction or by isolating agents from the system that have a failure. We will show in the section 5 the effect of these mechanisms on the case study.

5 SYSTEM EVALUATION

5.1 Experimentation

The experiment is built on the MASH software (Jamont and Occello, 2015). MASH (Multiagent Software / Hardware simulator) is a tool for simulating and executing multi-agent embedded systems. Agents are implemented in Java and are executed by this simulator. We use MASH to reproduce the case study and test different solutions built from configuration files, themselves generated pseudo-randomly using Python scripts. Agents work with the cohesive BDI model explained in the previous section. As seen, the reasoning cycles between the classical BDI model as we introduced it and the cohesive BDI model are very similar. This similarity allows us to compare the effectiveness of the two models and see what benefits cohesive agents can bring to the system.

In the following sections, we will assess the resilience of the cohesive system to see if the cohesion mechanisms have resulted in an improvement in its resilience. We will also compare the performance of these systems to see if the addition of these mechanisms changes their effectiveness.

5.2 Insertion of Faults

Failures are inserted in some agents of our simulated systems. The objective is to see the effects of these dysfunctions on these systems composed either of cohesive agents (implementing cohesion mechanisms) or of conventional agents (without cohesion mechanisms). The effect of these failures on each system is then compared to see the benefits that cohesive agent mechanisms can provide.

5.2.1 GPS Malfunction

In this scenario, agents continue to behave normally and try to get the ore drilled by the drilling agents to the base. Carriers have a faulty GPS that prevents them from time to time from moving to the desired position. The self-assessment mechanism of their involvement is then useful to correct their behaviour.

The figure 5 compares the duration of the experiment (in seconds) between a system composed of classical agents (classical system) and a system composed of cohesive agents (cohesive system) with different numbers of ores. Naturally, the more minerals there are in the environment, the longer it takes for agents to pick them up. Similarly, it is natural that the two types of agents in the systems evaluated are

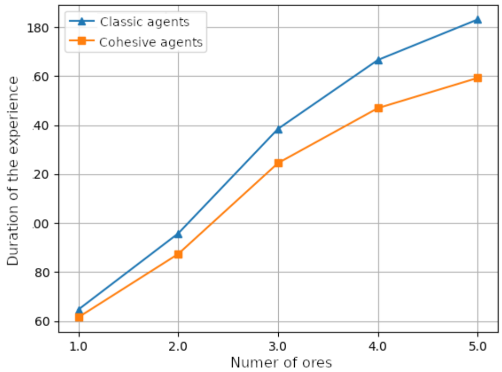

Figure 5: Duration of the experience depending on the type of agent and the number of ores in the environment.

not quite as fast as each other. It is therefore interesting to note that the gap between the two curves is not constant but is gradually widening. This difference is explained by the difference in reactivity of cohesive agents compared to conventional agents. Indeed, as explained in the previous sections, cohesive agents integrate an involvement mechanism that allows them to self-assess their activity. Thus, when a transport agent goes to the wrong coordinates, it is unable to recover the ore from the driller who contacted it. Unable to fulfil its role, the agent's involvement decreases to a certain level which leads it to search a new task. A conventional transport agent without this type of mechanism goes to the wrong coordinates and waits a long time for the driller to give it the ore. Finally, the transport agent is unblocked through a reset mechanism that allows the blocked agents to return to the base to continue their work. In short, in this scenario the cohesive agent system is more reactive to errors, agents recover more quickly and dynamically by estimating their involvement in their activity through a ratio between inactivity time and working time. On the contrary, the conventional agent system is not very reactive to failures, which can be seen by a more rapid evolution of the duration of the experiments.

5.2.2 Propagation of False Information

In this scenario, the detector is no longer able to distinguish between empty and solid ores. When it detects the position of an ore, it moves towards it and saves it's position. Then, it informs the driller of its position to recover it. A properly functioning detector updates its knowledge of minerals around itself. On the contrary, a defective detector agent is no longer able to distinguish empty ores from others. For example, it is asking for help from drillers to extract ore from sites where there is no ore left. Therefore, the traditional system cannot maintain its functional integrity since the defective agent constantly calls its acquaintances who try to help without ever questioning its requests. In short, the system falls into an endless loop and is unable to detect the end of the work. In this case, the failure is large enough to completely block the system so it is considered as a failure. The message selection mechanism then comes into play by allowing cohesive agents to maintain the system's operation. Indeed, in the case of a system composed of cohesive agents, the agents isolate the defective individual thanks to a confidence score held for each of their acquaintance. When an agent is defective and its behaviour is counterproductive to its peers, its relationships decrease its trust score. At a certain threshold, agents stop taking into account messages that the defective agent send. The cohesive system can therefore correctly estimate the progress of the work and maintain its functional integrity. It is then more resilient than the traditional system to failures of this type.

In this scenario, unlike the previous one, the node of the distributed system does not isolate itself, it is excluded by the system because of its deviant behavior. Generalizing, this type of mechanism would be useful in the case of an attack on the system. An externally controlled agent attempting to change the expected behaviour of the system would be automatically removed by the system, ensuring that the functional integrity of the system is maintained.

5.3 Comparison of System Efficiency

In order to compare the efficiency of systems, we compare the rate of ore recovery, the duration of experiments and the communications load. The figure 6 shows that cohesive agents have a very similar ore collection rate to conventional agents. While the mineral collection curve of conventional agents marks 2 large steps (both minerals are collected very quickly when found), cohesive agents tend to collect them in several stages. This is due to the configuration of cohesive agents that tend to change activity quickly when they are not working (when drillers are waiting for transporters, for example). Agents who have been inactive for too long return to the base and lose time in achieving the overall objective. However, the graph also shows that the execution of experiments with cohesive agents seems shorter than with conventional agents. Indeed, experiments composed of cohesive agents last an average of 67 seconds compared to 80 seconds with conventional agents. Cohesive agents reorganize more quickly when detectors no longer find minerals to drill and agents return to the base more quickly than in systems composed of conventional agents.

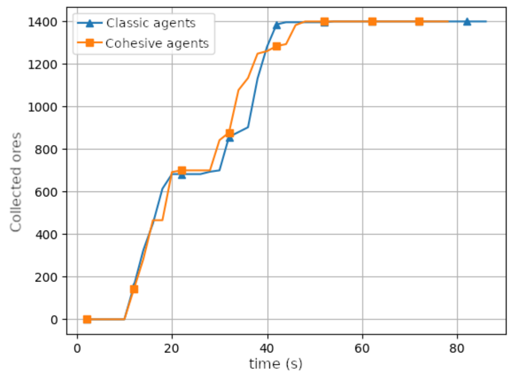

Figure 6: Ores reported as a function of time by agent type with an implication threshold of 0.6 for cohesive agents.

In the same way as the rate of ore recovery, the number of messages transmitted in the system is almost identical for both types of agents. However, cohesive agents send 2.8% more messages than classical agents, which may be explained by the fact that they take a little longer to collect the ore while having shorter overall experience execution times.

Finally, these experiments show that the cohesion mechanism does not improve the efficiency of the system, but that the cohesive system shows better resilience and failure resistance than the conventional system in the scenarios studied, without introducing any significant additional cost into its operation.

6 CONCLUSION

We presented how group cohesion mechanisms can guide a new approach to agent design in order to maintain the functional integrity of a MAS. These mechanisms were evaluated using a case study and compared to more conventional designed agents. As a first conclusion, we have seen that the integration of cohesion mechanisms into artificial systems has increased their resilience. We have not noted any degradation in the efficiency of the system in mineral collection or in the number of communications. In addition, the reactivity of the cohesive system is better than the reactivity of the conventional system, which reduces the average time of the experiments. In conclusion, cohesive agents have the ability to maintain the functional integrity of their system while limiting the negative impact of their behaviour compared to conventional agents.

Although increasing resilience is a relevant benefit, few cohesion criteria have been integrated and evaluated here. For future research, it would be interesting to try to integrate new cohesion criteria in different and more advanced cases to see, for example, whether cohesion mechanisms can improve productivity or whether they can generate (or improve) the self-organization of a system of multipurpose agents.

This model is currently being integrated into a decision support system for the Circular project. This project focuses on developing the necessary technologies and conditions to make new circular industrial systems able to transform post-used products into new products. Post-used components are avatarized as agents. These cohesion criteria can be integrated into the Soar architecture and used by the agents to form groups that represent the products to make.

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