Emergent Holonic Organization by Stigmergy

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Abstract—**The goal of this paper is to bring forth a holonic organization for self-organization of holonic multi-agent systems with the support of stigmergy. An extension of the RIO model is confirmed by stigmergy to build self-organizing system that emphasizes the autonomy and cooperation of entities, thus more suited with a dynamic task environment. In this paper, a holonic stigmergy mechanism for tuning the emergence of organizational structures is introduced and it is illustrated that how it works on clustering process taking inspiration from the cemetery organization of ants.**

Keywords—emergent organization, holonic stigmergy, self-organization, holonic multi-agent systems, swarm robotics .

I. INTRODUCTION

In recent years, many research works have been carried out on self-organization of Multi-Agent Systems (MAS). The organizational approach of MAS can improve goal-achievement of the agent group.

The organization construction and rearrangement are based on self-organization mechanisms of MAS. Accordingly, self-organization mechanisms have been the point of focus in its design [1]. A particular class of self-organization mechanisms is based on meta-models of the agents' organization in MAS which is dynamically modified according to the requirements of the particular application. In holonic metaphor, a group of interacting agents are organized to form the holonic structure. Following environmental changes, holonic organization can alter; which means self-organization of Holonic Multi-agent Systems (HMAS). The organization has been discussed as an emergent phenomenon in complex problems [2], [3].

In natural systems, the complex problems at the social insect society's level emerge from actions of simple individuals. The colony of insects was first studied by biologists. Biologists attributed the collective behavior of insect society to the self-organization process. The individuals are assigned to work through the interactions with changing environment. This is an indirect interaction which is more commonly known as stigmergy. Stigmergy mechanism allows the MAS to self-organize through the entities' activities in the environment which is highly decentralized [4].

In this work, a holonic stigmergy mechanism for emergence of organizational structures is proposed and it is illustrated that how it works on clustering process taking inspiration from the cemetery organization of ants. The notion of stigmergy is applied to propose the organization model of HMAS. Furthermore, the concept of stigmergy makes the proposed model more flexible compared to existing ones to facilitate holon's self-organization. Therefore, stigmery is highly potent to deal with dynamic task environment.

II. BASIC CONCEPTS

In the approach adopted here, a holonic organization comprises of a group of cooperative agents, who form the holons.

A. Holon vs. Agent

An agent is an autonomous entity, which perceives the environment through sensors and acts on it by actuators. On the other hand, the term holon is a Greek word formed from holos 'whole' and suffix on 'part'. In 1967, Koestler expressed the concept of holon by studying self-similar structure in social organization and biologic systems [5], [6]. Rodriguez explains the relationship between agents and holon in this way [7]: "Holons are, by definition, composed of other holons, while agents are not necessarily composed of other agents. This does not mean that agents can not be composed of agents, but that "agents are atomic entities" is the general assumption. When we say holon, we know immediately that the entity is composed of other holons and is a part of a higher super-holon".

Therefore, agents operate as active entities in HMAS. In our model, a group of cooperative agents make up holons with a representative agent to perform tasks in the environment.

B. Organization

The organizational approach in MAS has been inspired of human societies. An organization is more persistent than a group of cooperative agents, because controls task assignment and aims of group and other constraints which are important for doing common goals. A holon in HMAS has been introduced with two aspects: "atomic" and "organization" [7], [8].

The organizational aspect refers to Holonic Organization that explains the holon's structure. Self-organization requires organization which presents an overall structure of agents' cooperating pattern.

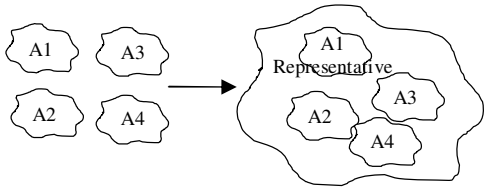

Figure 1. Holonic structure

Self-organization of HMAS in [6] has been offered without any use of self-organization mechanism. It's been seen just in capability matching process by role assigning in RIO model [9], which would be taken statically and with the pre-defined structure. So, it is not suitable to adapt with the changing environment. Also, the affinity and satisfaction are applied to self-organization of HMAS [7]. These two concepts are defined according to application's objective which holonic organization would be gained through direct interactions.

Through mentioned methods, Holonic organizations are organized by moderated group in [10]. According to the three offered structures by Gerber, the paper is adopted a new structure as management one of the super-holon, inspired from stigmergy in insect colonies. A holon (super-holon) is composed of other holons (sub-holons or members). Self-organization refers to the organizational formation process from existing holons to a new holon. Then, we need to consider how representative agents organize the super-holon.

C. *Stigmergy*

In 1959, Grasse introduced stigmegy theory which refers to the local interactions of individuals through the environment. He expressed that environment changing by individuals motives others to work. The entity's actions alternate the environment that influences the local information of other entities and itself. Eventually, social organization emerges from simple agents' actions by indirect interactions with each other [11], [12]. Stigmegy is composed of the Greek words 'stigma' meaning sign and 'ergon' meaning action. So, agent's actions leave signs in the environment that stimulate other agents to work [13]. System organization emerges through stigmergy without central control which is robust and self-organized.

To apply this approach, the paper presents a holonic model that supports the use of stigmergy for building self-organizing systems which emphasizes the autonomy and cooperation of entities.

III. ORGANIZATIONE MODEL

The organization is formal structure that employs agents towards its goals. The RIO model is applied to analyze holonic organization of HMAS. The basic concepts in RIO model are the role, interaction and organization. The role is defined as "an abstraction of the behavior of an agent". The roles are related to each other through interactions. The organization emerges from the roles and their interactions [14-16].

In this section, we have proposed a new holonic structure and an extension of the RIO model with stigmergic contexts (SC). We have introduced the concept of stigmergic context, defined as the information used to describe the knowledge of representative entity for its local environment.

A. *Structure*

We have extended one of holonic structures offered by Gerber, which is depicted in Fig. 1. This is like moderated group but there are several differences between them. All the members of super-holon keep full autonomy and have cooperative behaviors. Members do not designate a representative of the super-holon. Representative agents only present local stigmergic context. One member of holon is predestinated as a representative. Holon formation performs to achieve representative agent's goals, so their autonomous would be protected. On the other hand, their cooperation takes place through indirect interactions and SCs in representative's local environment.

B. *RIO Model*

The Holonic Organization represents a new group in terms of roles (called holonic roles) and their interactions (Fig. 2). At the organization level, holonic organization contains three roles: representative, part, multi-part. Representative: it is visible stigmergic context of a super-holon, it receives information from other holons in its local environment. Part: it represents stigmergic context belonging to only one super-holon while multi-part indicates more than one. It should be noted that stand-alone role is not an organizational role but displays an alone representative agent.

In our approach, a group of SCs which are related to a representative agent construct a holonic organization of entities in the local environment. Each member plays at least one role in holonic group. SCs are used to describe the local environment for an entity.

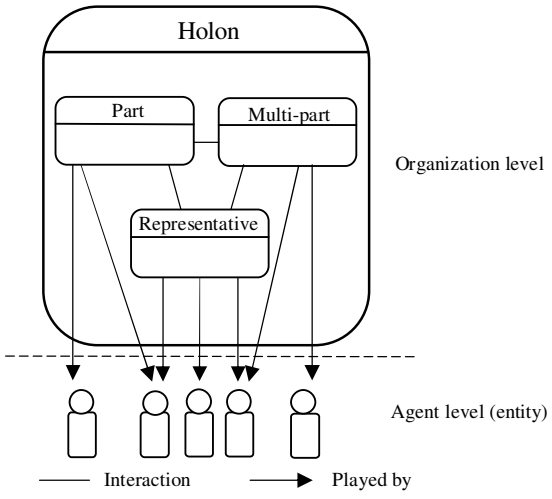

Figure 2. An extension of RIO model

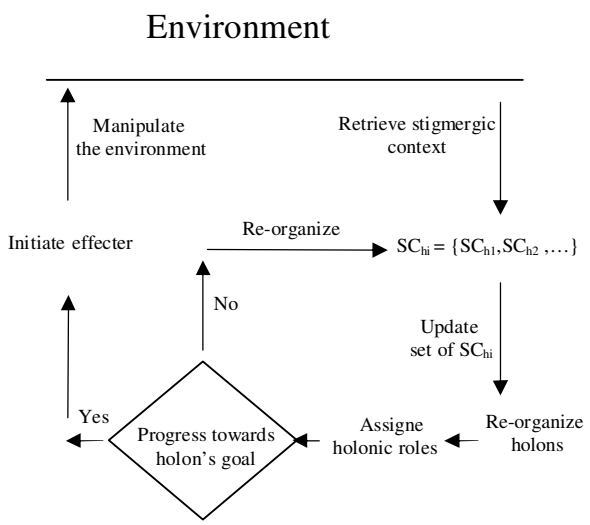

Figure 3. A holonic stigmergy model

IV. SELF-ORGANIZATION MECHANISM

This section will explain the generation of a holonic organization and its reorganization towards entities' goals.

The generalization of stigmergy theory, representative agents in holonic organization are equal to each individual in social insects. Examples of these individuals are autonomous robots or independent vehicles. When a group of SCs presents requirements information towards representative agent's goals, holon would be created. Holon formation improves decision making and members' actions, because the whole information is available for entities locally.

To determine how each of these entities is modeled in a holonic organization it is first necessary to understand how individual holons adapt their role to changes in the local environment. The model emphasizes on the stigmergy's ability to facilitate self-organization of holons. Fig. 3 provides an overview of this emergent process. It shows how each holon in the system can change its organization in response to environmental stimuli.

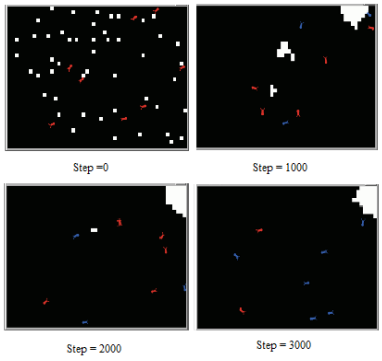

Figure 4. Creation of emerging clusters

The first step is to retrieve SCs of local environment. The representative entities perceive environment locally and collect its SCs that other representatives have left (SC_{hi} is stigmergic context of i^{th} super-holon). How this information is retrieved is out of scope here. In the next stage, set of SCs belonging to each entity would be updated and if SCs be useful for entity, creating new holon's organization would be followed, it means self-organizing. Information in a holon's local environment can motivate a representative agent to work in order to progress towards holon's aims. At the last stage, entities decide based on holon's persistent organization and act on environment. These environmental changes affect other entities' actions and initiate a stigmergic response. If holon does not get enough stigmergic context or after initiating effecter[1], it should be reorganize.

V. SIMULATION

The approach proposed in previous section provides a mechanism to enable self-organization in HMAS by defining the stigmergic context of holon local environment.

Complex problems can be modeled through definition of the stigmergic contexts within holon's local environment based on the domain of application. In order to illustrate this approach, we will take a case clustering process taking inspiration from the cemetery organization of ants. "Clustering is a collective task, which groups a class of objects within a continuous area that is small fraction of the area of the available environment. In multi-robot system, a collective clustering task means that the robot can move or carry the isolated objects distributing in a closed environment into one or more clusters" [17]. Clustering is simulated by robots that have holonic organization without direct communicate and centralized control and global environmental representation.

A. *Implementation*

We have selected NetLogo (Uri Wilensky, 1999) as platform for our implementation mainly for simulating natural and social phenomena.

The simulated robots have been used in experiments are all identical, and they are representative agents, like an ant in colony. The behavior of robot in the environment is very simple; it allows the search of objects either for taking or for deposit. When robot finds them in her proximity, it diffuses stigmergic context for other robots according to its mode (taking or deposit). In this case, stigmergic context is the local density of objects. Then, robots retrieve stigmergic contexts from their local environments by using stigmergic model. The role assignment algorithm is described in RIO model as below:

If robot gets other stigmergic contexts then
    Creates holon
    Holon's Role: representative
Else if robot's context is perceived by other
    Holon's Role: part or multi-part
Else
    Role: stand-alone

[1] Effecter acts on environment [18].

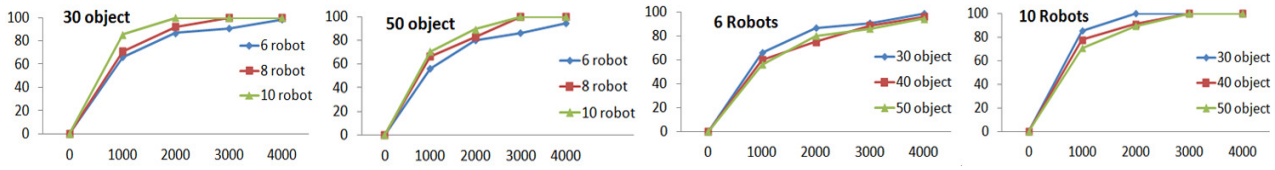

Figure 5. Comparison under various conditions, vertical axis is 'Acommplishment Ratio (%)' and horisontal axis is 'Steps'

The robots choose the behavior according to their roles. The holonic organization of representative robots emerges to create a large number of clusters scattered in the environment. The environmental conditions of experiments are stated similar to [17], also results are compared with it. At the start, the arena contains only single objects and the robots are distributed randomly.

Fig. 4 shows the three distinct phases of this simulation, this experiment is not best or worst. In the beginning, Small clusters are formed, then some clusters grow rapidly and the environment becomes more heterogeneous. Finally, the competitions between large clusters lead to clustering of all objects in one pile. All of the experiments were run for 4000 steps, but almost 70% of them were reached to one cluster before 2000 steps. In the Fig. 5, the curve steep explains it.

B. Simulation Results

In Fig. 5, the performance of the holonic stigmergy is presented. The numbers of robots involved in the experiment are various. The ratio of accomplishment is "the percent of objects that have been put around the final cluster" [13], which is an average over thirty repetition of experiment. Each ant is a representative agent of a holon, so its fixed field of vision is equal to local environment of holon. Complete process is highly dependent on local environment of holons, location of representative agents, scattering objects.

Representative robot can use global stigmergic context for decision making by achieving stigmergic contexts from its parts, so performance would increase. Therefore, in Fig. 6, we show the destructive behavior with increasing number of robots can be reduced and performance will increase. Thus, reducing the performance due to destruction of clusters with more robots is solved. As a result, we can say that the holonic stigmergy allows creating just one cluster with fewer steps.

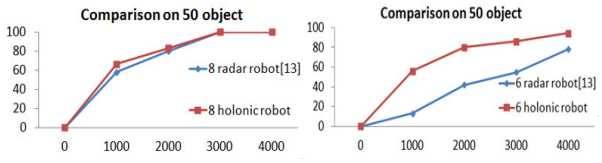

Figure 6. Influence of holonic organization on clustering task in comparison with [17] , vertical axis is 'Acommplishment Ratio (%)' and horisontal axis is 'Steps'

VI. CONCLUSION

This paper has argued that the use of swarm intelligence techniques, such as stigmergy, can help in the construction of holonic organization. We have illustrated how we can generate an emergent organization based on stigmergic context. We have presented the concept of stigmergy to enable an indirect communication and decentralized model of organizations.

Aim of the paper has been to develop a highly decentralized approach to self-organizing components of a HMAS that supports the indirect interaction between entities and provides robust system. The use of stigmergy has provided a means to achieve it. The proposed approach allows holons to dynamically reorganize themselves, as a reaction to change environment. Finally, a case is provided to illustrate our ideas. The holonic organization of clustering task facilitates the behavior of robot to pick up an object and put it down.

This work confirms stigmergy mechanism in self-organizing of HMAS to tackle complex problems, and further works will be applying other known mechanisms in self-organization of agency organization.

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