Modeling Holonic Systems with an Organizational approach

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Abstract

Complex Systems often exhibit hierarchical structures and multiple levels of abstraction, and MultiAgent Systems, even if they have proved their adequacy to model such systems, still remains in their larger part at one or two abstraction levels. It seems uncertain in this context that MAS will be able to catch efficiently the whole complexity of such systems. Holonic Multi-Agent Systems and their intrinsic hierarchical structure appears as a natural alternative. In this paper we propose a generic framework for HMAS modeling based upon an organizational approach. The means to model a compound holon using organizations and how to conciliate in a generic way the holonic structure with problem-dependent behaviors, are detailed. Different aspects related to the holon dynamics : holon creation, members integration and self-organization are also studied.

1 Introduction

Multi-Agent systems are growing, both in size and complexity [14]. Such systems are considered today to be well suited to model and simulate complex systems. However, in Complex Systems we usually find a great number of entities in interaction, acting at different levels of abstraction. In this context, it seems improbable that MAS will be able to faithfully represent complex systems without multiple granularities.

For this reason, holonic systems have attracted the attention of researchers. And we can count today an important number of works dedicated to their study. Their domains of application range from Manufacturing systems[13], Transports[3], cooperative work[1] or yet radio mobile mesh dimensioning [18].

The term *holon* was coined by A. Koestler in 1967. A holon is a self-similar structure composed of holons as sub-structures. This hierarchical structure composed of holons is called a *holarchy*. A holon can be seen, depending on the level of observation, either as an autonomous "atomic" entity, or as an organization of holons. This duality is sometimes called the *Janus Effect*[1], in reference to the two *faces of a holon*. A holon is a whole-part construct that is composed of other holons, but it is, at the same time, a component of a higher level holon. Considering the interest Holonic MAS have suggested, it is not surprising that a number of models and frameworks have been proposed. However, these models are usually strongly related to their domain of application and based on specific agent architectures. Few approaches propose a methodology of engineering for such systems. In [7] authors adopt a methodology inspired from INGENIAS [8] but they lack support for self-organization and do not detail the interactions dedicated to the holonic point of the view of the system. In this paper we propose a generic framework for HMAS modeling based upon an organizational approach. This organizational framework emphasis the separation between holonic aspects and application dependant aspects. Moreover, the organizational concepts used enable MAS modeling without making assumptions on agent architecture.

Indeed, several approaches have been inspired from a Social Metaphor, where terms like "role", "group", "community" represent the main concepts of the model. We can realize the usefulness of these concepts when we consider the number of methodologies (e.g. GAIA[20] or MESSAGE [4])

[1]Roman god with two faces. Janus was the god of gates and doorways, custodian of the universe and god of beginnings

and (meta-)Models (e.g. AGR [5], RIO [11] or MOCA [2]) using them. By considering organizations as blueprints that can be used to model a solution to a problem, we believe that an organizational approach encourages a modular and reusable model [12]. Based on these elements, we have selected the RIO model [11, 10]. This model offers the advantage of providing a formal specification of its main concepts using the OZS formalism [9].

In this paper we propose a generic framework for HMAS modeling based upon an organizational approach. This framework has been formalized using RIO and OZS. The formal specification of this framework is out of the scope of this article, for more details the reader can refer to [16, 18, 15]. The paper is organized as follows. First, in section 2, we will discuss how can we model a super-holon using organizations, and how to represent its structure as well as the goal-dependent behaviors of the members. Section 3 discusses how to integrate new members and how to create this type of entities. Finally, section 4 concludes and presents future research directions.

2 A Generic Framework for Holonic Systems Modeling

Our framework is based on an organizational approach to minimize the impact on the underlying architecture. However, in order to maintain this framework generic, we need to distinguish between two aspects that overlap in a holon. The first is directly related to the holonic character of the entity, i.e. a holon is composed of other holons. And the second is related to the problem the members are trying to solve. For example, lets consider a research laboratory in a university. The holonic aspect makes reference to the fact that the researchers compose and manage the laboratory. We call this a *holonic aspect* since every holon, no matter the application, is always composed of other holons. On the other hand, the laboratory is created with a specific purpose and, thus, to fulfill a number of goals/tasks in the system (e.g. complete a research project). How the members organize and interact so that the super-holon can achieve its goals is specific to the application or domain of application. Even more, the members of two different super-holons may follow different interaction patterns to achieve the same result.

So, the first aspect is common to all holonic systems, while the second is directly related to the domain of application.

These two aspects plus a third, HMAS Dynamics, constitute the three parts of our framework.

The first part is the holon's structure and management. A super-holon is an entity in its own right, but it is composed by its members. This part of the framework consider how the member organize and manage the super-holon. The second part is goal-dependent interactions. Super-holons are created with an objective and to fulfill certain tasks. To achieve these goals / tasks, the members must interact and coordinate their actions. Our framework also offers means to model these aspects of the super-holons functioning. Eventually, the third part is Dynamics. It is an inherent characteristics of MAS. The framework considers in particular two of the most attractive characteristics of Holonic MAS : Merging (Creating and Joining a super-holon) and Self-Organization.

These three parts of our framework will be successively detailed in the following section.

2.1 Holon's Members Modelling

The first question to tackle is how are holons organized internally to generate and manage a super-holon. Three different structures were proposed by [6] for holonic multi-agent systems : Federation of autonomous agents, Moderated Group and Fusion [2].

In our approach we have adopted the moderated group as management structure. This decision is based on the wide range of configurations that are possible by modifying the commitments of the members toward their super-holon (see figure 1). Indeed, if all members can moderate the group than it is equivalent to a federation and if a single member has all power over the members than it is equivalent to fusion.

In a moderated group, we can differentiate two status for the members. First, the *moderator* or *representative*, who acts as the interface with non-member holons, and, second, *represented* members, who are masked to the outside world by their representatives.

[2] Originally called a *Merge into one* in [6]

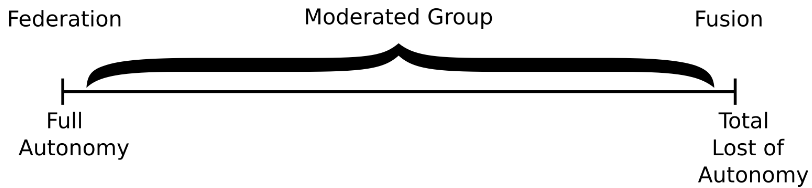

Figure 1: Autonomy of the members

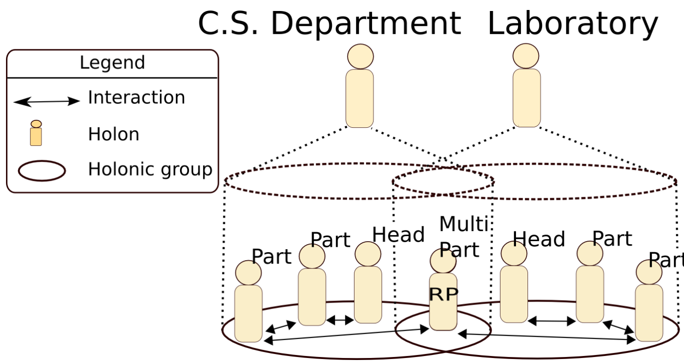

Figure 2: Department and Laboratory Holons

Even if we use the name "*Moderated Group*" for compatibility with earlier works in this domain, it can be misleading. As we see it, the structure does not necessarily introduced any authority or subordination. The term "*Moderated*" makes reference to the different status found in the group. We can then adapt this organization by giving the representatives specific authorities according to the problem or constraints.

In order to represent a moderated group with an organizational approach, we need to identify a set of roles that can represent these concepts. We have chosen to use four roles to describe a moderated group as an organization : *Head*, *Part*, *Multi-Part* and *StandAlone*. The three first roles describe a status of a member inside a super-holon. The *Stand-Alone* role represents, on the other hand, how non-members are seen by an existing holon.

Inside a super-holon, members can play three different holonic roles: *Head*, *Part* and *Multi-Part*. The *Head* role is the *representative* or *moderator* of the group. Represented members can either play *Part* or $MultiPart$ role. *Part* role is played by those holons belonging to only one super-holon. And *Multi-Part* role by those holons shared by more than one super-holon. We call these roles *holonic roles*. The adjective "holonic" is used to distinguish these roles (present in every holon) from the roles used to model application-dependent behaviors.

If we isolate the Computer Science Holon, the Laboratory Holon and their components from the university example and we add these holonic roles, we obtain the figure 2. *Part* role players for the laboratory represent researcher that belong only to the laboratory, e.g. full time researchers. On the other hand, some researcher may, in addition to their activities in the laboratory, give lectures in the computer science department. These holons, like holon RP in figure 2, belong to both holons simultaneously and thus they play the $MultiPart$ role. In this example, the department and laboratory directors would be the *Heads* of the C.S. Department and the Laboratory respectively.

Lets now consider only the members of one super-holon. We can see the super-holon as a set of sub-holons in interaction. If we only look at the holonic related interactions, we obtain the RIO Diagram shown in figure 3. This organization, called *Holonic Organization*, makes abstraction of application-dependent interactions to concentrate solely in the status and behavior of the members from the super-holon point of view. An instance of this organization is called a *Holonic Group*. As for the roles, the term "holonic" is intended to distinguish this group (present in every holon) from other groups used to describe goal-dependent interactions. Every member of a super-holon must play at least one role in the holonic group. Like this, a super-holon contains at least one group that identifies the status of its members. We detail now each of these roles.
The representatives of the super-holon play the *Head* role. A *Head* member becomes then part of

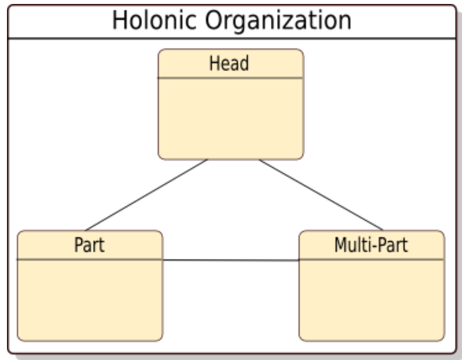

Figure 3: RIO Diagram of the Roles played by members

the visible face of the super-holon. This means that the *head* becomes a kind of interface between the members of the holon and the outside world. The *head* role can be played by more than one member at the same time.
The members can confer the *head* a number of rights or authorities. According to the level of authority given to *heads*, super-holon can adopt different configurations. Thus, the $Head$ role represents a privileged status in the super-holon. *Heads* will generally be conferred with a certain level of authority. However, these members have also an administrative load. This load can be variable depending on the selected configuration. Several *Heads* may be present in a same holon. They constitute the interface of the holon with his environment. For example, in the university department example of figure 2 the head role may be played simultaneously by the director and the secretary. Depending on the external stimulus one or the two will be influenced and they can interact so as from the external point of view there only exist one *head*.
It is important to remark that when a set of holons merge into a super-holon a new entity appears in the system. In this case, they are not merely a group of holon in interaction as in "traditional" MAS theory. The super-holon is then an entity of its own right. Thus, it has a set of skills, is capable of taking roles, etc. At the same time, as $Heads$ constitute the interface of the super-holon, they are in charge of redistributing the information arriving from the outside. And, thus to "trigger" the (internal) process that will produce the desired result. We will discuss this issue further when we introduce how task-related interactions can be modeled (cf. 2.2, page 5). The $Part$ role identifies members of a single holon. These members are represented by $Head$s within the outside world. While the holon belongs to a single super-holon, it will play this role. However, when the holon is not satisfied with its current super-holon it has two possibilities. The first is to quit its super-holon entirely and try to find a new holon to merge and collaborate with. The second is to try to merge with a second super-holon while remaining as a member of the first super-holon. In this case the holon will change his role to $Multi - Part$.
The $Multi - Part$ role is an extension of the *Part* role. It puts emphasis on a particular situation when a sub-holon is shared by more than one super-holon. Examples of this type of situation can be easily found. For instance, in our University example, holon *RP* is a researcher in the laboratory and at the same time a lecturer in the Computer Science Department (c.f. figure 2) There are several reasons to differentiate the *Part* from the *Multi-Part* role. First, a set of problems can arise from the fact that the shared holon is represented by more than one *Head*. Imagine for instance that a holon offers services that are conflicting, e.g. a create/access/destroy mechanism to a resource. If this holon is shared by several super-holon, it might be possible that it receives a contradictory request from its *heads*, like destroy / access the resource at the same time. We could say that three types of conflicts can arise from a shared member :

- Interest conflicts : The super-holons do not share the same goal, or they have contradictory objectives.
- Authority Conflicts : The representatives of the super-holon request contradictory action to the shared member.
- Unbalanced Authority Conflicts : One of the super-holon's *Head* has more power than the

other over the shared member.

Several problems can appear as a combination of these conflicts. For instance, in open systems, a self-interested *head* could use its authority over a shared member to avoid the progress of other holons.

Beside these problems, shared holons can be the cause of bottle-necks and performance issues. These cases must be analyzed in detail to maintain the coherence and stability of the designed system.

Even if we have only considered the possible disadvantages related to shared member, *MultiPart* holons offer also a great number of interesting possibilities.

One of such possibilities is *Message Forwarding*. This consists of allowing *MultiPart* holons to forward messages from the members of one super-holon to members of the second super-holon. For instance, if a researcher wants to delegate a task to a student, he could ask a share member (e.g. *RP* in figure 2) to look for a candidate and delegate the task. This could reduce the administrative load of *head* and avoid "formal requests" between the laboratory and the C.S. department.

Other possibility is to implement *trust mechanism* to accept members introduced by shared holons. This mechanism was used in [17] to describe the environment as a holonic organization.

2.2 Goal Dependent Interaction Modelling

The previous section introduced the *holonic organization* (fig. 3) that allows us to describe the different status of the members and how they manage the super-holon.

However, we can not neglect the fact that this description would be incomplete if it does not include the interactions of the members concerning goal-driven actions.

In order to achieve its objective, the super-holon will often need to accomplish a number of tasks. Thus, the members need to organize internally to distribute sub-tasks, exchange information, etc. These tasks are usually application dependent, and variate from holon to holon. These domain dependent organizations are called *Internal Organizations*.

Like this, the holonic non atomic agent (instantiating the model) contains :

- a unique Holonic Group, instance of the Holonic Organization, which defines how are organized the members. All members of the (super-)holon must belong to this group.
- a set of groups, instances of the Internal Organizations, created to coordinate the interactions of the members. These groups are created based on the objectives / tasks of the members. A group may contain only a subset of the members of the super-holon.

To clarify this idea, lets consider a Department of the university. The department is modeled using two internal organizations. The first, shown in figure 4, represents the Council, defining how decisions are taken and who is involved in the process. The second represents a specific Lecture, describing the interactions between the students and their professor, depicted in figure 5. A number of instances of this organization may be present in a department at the same time. Figure 6 presents an example of the groups instantiating the internal organizations of the Department holon. The sub-holons of the Department Holon are inside a dash line cylinder. Each sub-holon is tagged with the *Holonic Role* it plays. All members must play one of the holonic roles that defines its status in the super-holon. We find then two groups, noted $g1 : Lecture$ and $g2 : Council$. The denomination $g1 : Lecture$ indicates that group $g1$ is an instance of the Organization *Lecture*. The *head* of the super-holon plays the role *Member* in the group $g2$ and the role *Professor* in the group $g1$.

Using this approach, the behavior and interactions of the members can be described independently of their roles as a component of the super-holon.

The main advantages of this approach are :

- Clear separation between the *Holonic-related* (Holonic Organization) and the domain-specific behaviors (Internal Organizations).
- Modularity in the description of the different Organizations. We can associate an organization to each task / goal without modifying existing ones.

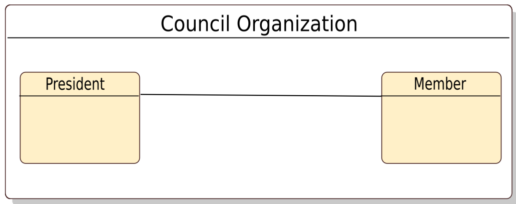

Figure 4: Council Internal Organization

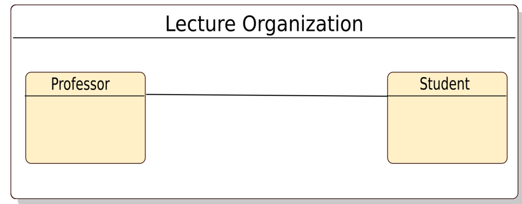

Figure 5: Lecture Internal Organization

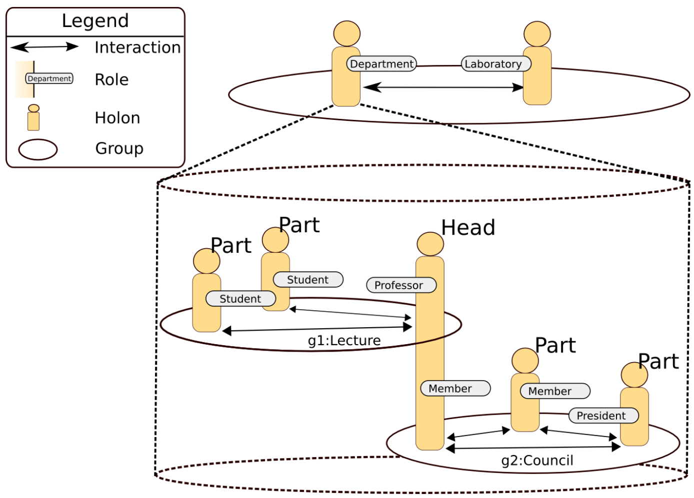

Figure 6: Computer Science Internal Organizations

- It encourages a reusable modeling through the use of organizations as description unit (favors the use of Organizational Design Pattern).
- This approach let us break the intrinsic recursivity of holons in the modeling phase. The designer can describe the interactions of the members without having to take into account whether that member is an atomic holon or not.
- Complex mechanism for task distribution, decision making, cooperation, can be easily introduced into holons.

The description of a holon involves then a number of organizations. The only mandatory organization is the *Holonic Organization* that describe the member's status. Others organizations can be added to describe additional behaviors required for the functioning of the super-holon.

3 Holon Dynamics

Our framework considers two important aspects of HMAS dynamics, (1) creation and integration of new members, and (2) self-organization. The self-organization module proposed for HMAS is out of the scope of this paper, interested readers may refer to [15] for details on the self-organization module. [16] introduces properties proofs about the self-organization module.

So, in this section, we will concentrate on the creation of new super-holon in the system and the integration of new member into existing holons. This process is called *Merging*.

New super-holons can be created either by a set of existing holons that *merge* into a super-holon, or by decomposing a holon into subcomponents. We will not detail further the decomposition of a holon, since in this case, the super-holon is capable of defining the intentions of its components. Thus, controlling how member will interact and even choose a specific architecture for the sub-holons. In this work, we are interested with the creation of super-holon from existing holons.

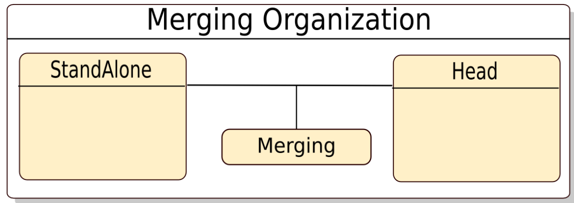

Figure 7: RIO Diagram of the Merging Organization

The Merging interaction is a particular interaction between two holons that want to create a new entity that assembles them. We can distinguish two types of merging : creation of super-holon and joining a super-holon.

3.1 Interacting with a Holon : Organization or entity?

Depending on the level of observation, a holon can be seen as a set of groups or as an "atomic" entity. So, the obvious question that comes to mind is : when does an outside holon see the super-holon as an autonomous (atomic) entity and when as a group of sub-holons that it can join?.

From a theoretical point of view, we do not need to make a difference, since the super-holon is an entity that can merge into a higher level holon. However, from a practical point of view, it may be desirable, even necessary, that external holons can integrate existing super-holons.

If we do not allow the inclusion of new members after the creation of the super-holon, every time two holons merge, a new level will be added to the holarchy. This could lead to a (very) high numbers of levels and could cause important overheads when members need to communicate.

On the other hand, if we allow non-members to merge with existing super-holons, we can considerably reduce the number of levels in the resulting holarchy.

Even if in both approaches the highest level holons may exhibit the same capacities and behavior; in practice, costs associated with the first configuration may prove inefficient or improper for the problem's constraints.

3.2 Integrating new members

In order to support the integration of new member, we need to provide external holons with a "standard" interface so they can request their admition. From the super-holons point of view, external holons are seen as *StandAlone* role players.

When a super-holon is created, only *Heads* belong to the interface of the super-holon. Thus, other members (*Part* and *MultiPart*) should not be visible by external holons. This is modeled by the organization presented in figure 7. In this organization, *StandAlone* holons may interact only with the *heads* of the super-holon.

This organization enables *StandAlone* holons to interact with the representatives. In this organization we find the *Merging* interaction that provides means for a holon to request admition as a new member.

The *StandAlone* role represents a particular status inside a holonic system. In contrast to the roles presented previously, this role represents the way an existing super-holon sees a non-member holon.

Until now we have discussed roles that are present inside a super-holon. But a holon may also interact with other holons without necessarily creating / merging into a higher-level entity. In this context, a holon is seen as an autonomous, atomic entity. This brings us to an important concept, the different faces of a holon are independent. This means that even if a holon is seen as a *Stand-Alone* at one level, it can be composed by substructures at another level. We use the term *Face* with correspondence to Koestler's Janus Face characteristic of holons. In this sense, one face -looking up- presents the holon as an autonomous entity, the other -looking down- as a group of sub-holon in interaction.

An interesting characteristic of this approach is that *Stand-Alone* presents a standardized view of non-members.

3.3 Creation of new Holons

The merging process may also be used between holons to create a new entity (super-holon) in the system. In this case, all rules that will govern the life of the super-holon have to be defined. From an engineering point of view, different approaches can be used.

The first approach is to predefine the holarchy. The holons were conceived so that the rules for the construction of the super-holon are predefined and known by members in advance. This approach may be usefull when developping closed application or when the constraints are known in advance [17]. The adaptivity of these types of system will remain constrained to the anticipated cases only, and will probably prove impossible to use in large open environments.

The second approach is based upon negotiation. The Merging process foresees a mechanism to negotiate the configuration of the super-holon. This approach allows a wider range of applications, and improved adaptive capabilities. But the negotiation process may induce important overheads. A combination of this and the previous approach could help reducing the overhead.

Eventually, the third approach is evolutive. The super-holon is created with a minimum of engagements of the members. The members can then increase their commitment toward the super-holon when they consider it useful. The minimal rules set contains only one rule, which defines how new engagements (rules) are adding the super-holon. Using this rule with a voting mechanism, any new rule or modification of it can be obtained. The FORM framework proposed by [19] describes such a method for task-oriented systems.

A Predefined mechanism can be useful for closed, rather small, systems. However, it seems improbable that such a mechanism can be used in an open untrusted environment.

The Negotiation is what we might call a "generic" approach. However, other problems are to be considered, for instance, the communication language used in the negotiations. In addition, trying to define all rules of a super-holon may prove to be a consequent task, introducing an enormous overhead to the creation of the super-holon.

4 Conclusion

In this paper we have presented a novel way of modeling holons and holonic systems. In contrast to current trends in holonic systems modeling, we have selected an organizational approach. This allows us a flexible, yet powerful, way of describing holons.

We take advantage of the organizational approach at different levels. First, the model in not specific to any particular domain of application. Second, it encourages well-known software engineering good practices, like separation of concerns, modularity, etc.

In addition, we can profit from the experience and research in the field of organizational modeling. Indeed, we can easily imagine to adapt existing organizational-based methodologies such as GAIA or MESSAGE. In fact, we are already working in the first steps towards such a methodology for HMAS[15].

This framework has already been used to address real-world problems such as the Adaptive Mesh problem [18, 16] and large scale simulations [17]

Forthcoming works will address the development of a methodology for holonic multi-agent systems integrating Organizational Design Patterns. In addition, the significant future task is the development of CASE tools for the design, modeling and deployment of HMAS. We are currently working on an Eclipse plugin for this purpose.

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