Metrics for Evaluating Modularity and Extensibility in HMAS Systems

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ABSTRACT

Nowadays, software systems are more and more frequently designed in order to realize complex dynamical behavior for solving complicated problems. Holonic Multi Agent Systems (HMAS) is spreading for the development of such systems since they allow to manage system requirements in terms of behaviors and organizational patterns. Traditional software engineering metrics are not useful for measuring HMAS architectures since they do not consider different nested levels of organizational structures. We want to contribute to this issue proposing some metrics for evaluating modularity and extensibility of HMAS architectures.

Categories and Subject Descriptors

D.2.8 [**Software Engineering**]: Metrics—*complexity measures*

General Terms

Measurement

Keywords

Metrics; Holonic Multi Agent System; Holon

1. INTRODUCTION

In several software engineering paradigms, for instance the object-oriented one, designers may rely upon strengthened metrics for evaluating and assessing, in a quite early stage of design, the quality of the architecture they are using; indeed, literature provides metrics for several quality attributes [8][4][21].

The same situation is not present in Agent Oriented Software Engineering (AOSE) and in particular in one of the most promising AOSE paradigm for facing problems related to modeling and developing complex systems, that is the Holonic Multi Agent System (HMAS) paradigm. Multi Agent Systems (MASs) have been often used as a software paradigm for developing complex systems due to the particular features of their components. The increasing complexity of the systems in terms of behaviors and organizational patterns makes the multi agent design paradigm unable to manage alone different nested levels of organizational structures. In recent years, HMAS is spreading for the development of complex systems. But, because of the wide range of holonic architectures, in the same way of other SE areas, an open question is: how can we choose the most useful one? Which are the quality attributes that may be useful for evaluating HMAS architectures?

In [12] Magariño et al. defined a set of metrics with the aim of measuring some quality attributes of MAS architectures such as: extensibility and modularity. *Extensibility* indicates how much MAS architectures are suitable for answering to extensions and enhancing without heavy changes in their infrastructure. *Modularity* indicates whether, and at which degree, architectures (hence MAS components) may be divided and recombined without great cost.

In order to evaluate these quality attributes, [12]'s authors used a selected set of metrics coming from object oriented software engineering such as *cohesion*, *coupling*, *Fan-in* and *Fan-out* to name a few. These metrics refer to the concepts of *modules*, *components* and *dependencies* that are natively object oriented and Magariño et al. found the analogous concepts in the agent oriented architectures redefining object oriented metrics in order to be applied to MASs.

This paper starts from this work and aims at identifying metrics for evaluating *modularity* and *extensibilty* quality attributes for HMAS architectures. In this work we present a deep analysis made on the HMAS systems showing that the metrics defined for MASs are often not suitable for HMASs. Thus, we propose what are the holonic concepts corresponding to the module, component and dependency to be considered in order to evaluate extensibility and modularity of HMASs. Hence, we define the coupling and cohesion metrics for HMASs.

The paper is organized as follows: section 2 illustrates the background and motivations of our work. Section 3 shows the basic concepts of object oriented metrics, their mapping to the agent oriented one and then to the HMAS paradigm. In sections 4 and 5, the HMAS metrics are presented and then some discussions and conclusions, in section 6, are drawn.

2. BACKGROUND AND MOTIVATION

A MAS is a system composed of autonomous, reactive and proactive entities (i.e: agents) that by means of interactions allow the whole system to exhibit complex behaviors that satisfy system goals.

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The design of complex systems requires the management of different levels of granularity that usually have a direct consequence in the organization design. In recent years, a new design paradigm is spreading for the development of complex systems: the holonic multi agent (HMAS) design paradigm [13][11]. *Holon*, which derives from the combination of *holos* whole and the suffix *on* part, is the term, coined by Arthur Koestler in his fundamental work *The Ghost in the Machine* [15], for indicating elements of nested hierarchies of self-replicating structures (i.e: *holarchies*). A holon is, commonly, defined as a self-similar structure composed of other holons as sub-structures. A useful way to implement holarchies in software system is by means of the HMAS paradigm [11]. It allows to represent a holonic system where individual agents are driven by coordination mechanism according to the cooperation rules of the holon the agent is member of. Describing a holon involves identifying and describing several organizations. An organization is used for implementing specific behaviors, tasks distribution, decision making, cooperation, etc....

In this context, it is very useful to be able to determine during the design phase, which is the most suitable holonic architecture to use in order to satisfy not only functional requirements but also some quality requirements such as having a system easily scalable and adaptable to new situations.

The main contribution of this paper is *describing and measuring quality attributes for evaluating HMAS architectures*.

We start our work from the one of Magariño et al. [12] that use a set of metrics coming from object oriented context for deriving metrics to measure some quality attributes of MASs. The core of that work is in finding a correspondence among the concepts of module, component and dependencies in the two contexts (OO and AO). Because of the intrinsic nature of HMAS paradigms we found the rationale Magariño et al. useful for analyzing HMAS systems features in order to retrieve the right concepts to be mapped onto the module, components and dependencies concepts for the holonic metrics.

Another work on applying software metrics for multi agent system is that of Nunes et al. [17]. In this work, authors propose the use of existing metrics such as NOA (*Number of Attributes*), NOM (*Number of Methods*) and LOCs (*Lines of Code*) to evaluate design modularity and stability of an evolving MAS; the work explicitly addresses features of MAS product lines and refers to concepts of Aspect Oriented Programming (AOP). From these metrics we could derive some other ones taking into account the fact that modularization is intrinsic in AOP; moreover we could map the belief and plan of BDI architecture respectively with NOA and NOM, making somehow the same work we did with Magariño et al's metrics. This is, however, not sufficient to measure the quality of HMAS architectures. In fact, NOA, NOM, LOC and many other metrics that can be extracted from procedural program and from objects are useful for analyzing the structure of the atomic elements of the system (such as classes or agents). Other approaches consider measuring specific quality of agents, such as pro-activity or autonomy [1][2]. However they do not consider higher levels of granularity that should be considered when we deal with architectures. Conversely, the metrics defined by Magariño et al. consider specific concepts of software architectures such as module and component thus giving us a good starting point for reasoning about HMAS architectures.

3. FROM OBJECT ORIENTED TO HMAS PARADIGM

In this section, we show how we move from OO to HMAS paradigm by using the work of Magariño et al. [12] as a bridge between these two worlds. In particular, starting from the definitions of coupling and cohesion, we present an analysis made on OO concepts in order to retrieve their counterparts in the HMAS context.

Coupling and *Cohesion* [16][5][4] along with *Fan-in* and *Fan-out* [20][14] are steady metrics widely used in the object oriented paradigm in order to measure how strongly two or more elements depend on (or are related to) each other. In this work, we only refer to coupling and cohesion for measuring *Modularity* and *Extensibility* and for making some reasoning on the holonic multi-agent architectures. In order to do this, we need to resume the definitions of coupling, cohesion: *(i) Coupling* is defined as the degree of interdependence between modules; *(ii) Cohesion* is concerned with the interactions among components within a module. Trying to adopt such metrics to the HMAS paradigm, the first step is to understand the meaning of concepts like *Module*, *Component* and *Dependencies* in such a context.

Module - the definition proposed by Parnas in [18] states that "a module is considered to be a responsibility assignment rather than a subprogram". According to the same paper, a piece of a system may be considered a module if it exhibits the following properties: *(i)* one module may be written with little knowledge of the code in another module and *(ii)* one module may be reassembled and replaced without reassembly of the whole system. In the OO context a similar concept may be found for the subsystem: "subsystem is a replaceable part of the system with well-defined interfaces that encapsulates the state and behavior of its contained components" [7]. In the case of complex subsystems, we may recursively apply this principle and decompose a subsystem into simpler subsystems. Hence, we can affirm that subsystem may be seen as synonymous of module for our intended goals.

Components - A component is a self contained part of a module that does not verify the two properties required for a portion of a system to be considered a module. A system can be defined as a collection of components organized in a way useful for accomplishing a specific function or set of functions [6].

Dependencies - They can refer to dependencies among components of the same module (internal dependencies) and dependencies among components of different modules (external dependencies). In object oriented architectures, there are many kinds of dependencies such as one module controlling the flow of another, modules share data, one module modifies the internal content of another module and so on.

The work of Magariño et al. [12] moves from object oriented to MAS paradigm assuming *agents* as modules of a multi agent architecture and *agent tasks* (i.e: portion of agent behavior) as components. Moreover, they found similarities among OO and AO dependencies. In object-oriented architectures, some modules can share data types (i.e. data type coupling). In AO this is equivalent to several kinds of agents that share some languages referring to specific ontologies (i.e. ontology sharing). As well as, in OO some modules need to obtain data from other modules (i.e. data coupling). In a similar way, some agents may need to request informa-

Object Oriented Paradigm		Agent Oriented Paradigm *(Magariño et.al)*		Holonic Paradigm	
Name	**Description**	**Name**	**Description**	**Name**	**Description**
Data Type Coupling	Two modules use the same data type	Ontology Sharing	Two agents share knowledge for communicating	Ontology Sharing	Two holons share knowledge for communicating
Data Coupling	Data from one module is used in another	Knowledge coupling	An agent uses knowledge of another agent	Knowledge coupling	Holons use communication for exchanging knowledge
Control Coupling	One module may control actions of another	Behavioural coupling	An agent can control the behaviour of another	Goal Coupling	A holon depend on the goal of other holons in order to fulfill its goals.
Content Coupling	A module refers to internals of another module	Inner structural coupling	An agent uses internals of another agent	Inner structural coupling	One holon is contemporarly part of two super-holons

Table 1: Kinds of Coupling in OO, AO and Holonic Architectures

tion from other agents (i.e. knowledge coupling) and so on (see Table 1 column 1 and 2 for a complete mapping).

These similarities lead to the metrics reported in [12] for measuring the Extensibility of architectures; Extensibility is affected by the *cohesion within each module* of the architecture measuring the dependencies within a module, by the *cohesion of the whole architecture* measuring the average of the cohesion of each module and by the *coupling* measuring the dependencies among modules.

The *cohesion within each module* and the *coupling* are given by the following equations:

$$Ch_m(M) = \begin{cases} \frac{IntDep(M)}{MaxDep(M)} & \text{if } NC \geq 2 \\ 1 & \text{if } NC = 1 \end{cases} \tag{1}$$

$$C_p(X) = \begin{cases} \frac{ExtDep(X)}{MaxDepX} & \text{if } N \geq 2 \\ 1 & \text{if } N = 1 \end{cases} \tag{2}$$

M is a module, IntDep(M) is the number of the internal dependencies, MaxDep(M)=NC*(NC-1)/2 and NC is the number of components of the module; X is an agent oriented architecture, ExtDep(X) is the number of the external dependencies, MaxDep(X) is the maximum number of possible ExtDep, N is the number of modules of the architecture.

The quality attribute on Modularity may be also measured by using cohesion, coupling.

Metrics identified in [12] are the starting point for applying object oriented metrics to other fields. Different architectural styles may have specific features that influence the identification of the concepts used for defining the before said metrics. In the following section we illustrate how we derived metrics for measuring modularity and extensibility of HMAS architectures starting from this work [12].

3.1 Architectural Styles

An architectural style is "a set of constraints on an architecture that defines a set or family of architectures satisfying them" [3]. According to this definition, major architectural styles include several options: layers, partitions, piper and filters, client-server, three/four-tiers, model-view-controller, and so on.

According to [6, p. 3-3], a software architecture is "a description of the subsystems and components of a software system and the relationships between them". We may regard subsystems as equivalent to the concept of module as defined by Parnas [18]. How can we map these concepts to the agent-oriented context and terminology? The easiest mapping subsystem/module we can find in an MAS is the agent itself. It naturally exhibits the two properties prescribed by Parnas and it is usually made of elements such as beliefs, rules and goals/plans that can be considered its components. Considering the agent as a subsystem/module brings a relevant consequence: software architecture overlaps agent organization. Why? According to [10]: "An organization is defined by a collection of roles that take part in systematic institutionalized patterns of interactions with other roles in a common context". According to [6, p. 3-1]: software architecture describes "how software is decomposed and organized into components and the interfaces between those components". Similarity between the two definitions is clear if we consider that interactions among agent roles are realized in form of communications and their specification constitutes the agent interfaces.

The holonic paradigm corresponds to the adoption of the holon as the founding element of the architectural style. In the adoption of the holonic architectural style we choose to organize the MAS according to "a self-similar or fractal structure that is stable, coherent and that consists of several holons as sub-structures and is itself a part of a greater whole" [15].

This lead us to redefine the kinds of coupling as it is shown in table 1 column 3. However these definitions are still too general for allowing us to define metrics for evaluating HMAS coupling. It might seem that the concept of holon may be directly mapped to the one of module (such as for AO context) but it not so because of some intrinsic aspects of a holon, such as its duality that we will detail later in the paper.

In the following subsection we provide some details about holonic multi-agent systems in order to detail and clear the mapping between objects and holonic agents concepts.

3.2 Redefining Concepts from the HMAS Perspective

The concept of Holon is based on the so called Janus ef-

Holonic Concepts				
Holonic Aspect	Government		Production	
	Social	*Functional*	*Social*	*Functional*
Module	Holonic Group	Holonic Group	Production Group	Production Group
Component	Role	Goal	Role	Social Goal, Goal
Internal Dependency	Communication	Goal Dependency	Communication, Compatibility	Goal Dependency
External Dependency	-	-	Communication, Compatibility	Goal Dependency

Table 2: Modules, Components and Dependencies for HMAS.

fect [15] that implies to see something from two different perspectives. In the case of holon, the Janus effect means to see holon as an autonomous atomic entity or as an organization of holons. A holon is a whole-part entity composed of other holons (sub-holons) and at the same time, a component of a higher level holon (the super-holon).

A holon basically acts as an autonomous entity, although cooperating to form self-organizing hierarchies of subsystems in order to achieve the *goals* of the holarchy. Each member of a holon may play *Roles*. A role is "*an expected behavior (a set of role tasks ordered by a plan) and a set of rights and obligations in the organization context. The goal of each Role is to contribute to the fulfillment of (a part of) the requirements of the organization within which it is defined. Roles may interact with other roles defined in the same organization. Roles interact by using communications within the context of the group they belong to*" [10]. Roles may be compatible, this implies two roles may be played by the same holon without conflict.

A useful way to implement holarchies in software systems is by means of the HMAS paradigm. There are basically three ways for realizing a holon in a HMAS, which differ in the degree of autonomy of its sub-holons [11]: *(i)* a holon realized as a federation of autonomous agents allows a full sub-holons autonomy, *(ii)* several agents merged into one realize a holon whose sub-holons totally lack their autonomy, *(iii)* a trade off of the previous ones is the realization of a holon as a moderated group.

In this work we consider a holon as a moderated group, where sub-holons give up only part of their autonomy to the super-holon. It is realized by: *(i)* at least one sub-holon playing the *Representative* role. It represents other members for making certain decisions or accomplishing certain tasks outside the super-holon. *(ii)* At least one sub-holon playing the *Head* role. The *Head* is the decision maker of the holon. It represents other members for making certain decisions or accomplishing certain tasks inside the super-holon. *(iii)* A set of sub-holons playing the *Peer* role. It identifies the default members, they generally perform tasks assigned by the Head. Commonly, Representative and Head coincide.

Moreover, two overlapping aspects coexist in a holon: *Government* and *Production*. The *Government* aspect deals with the governance and the administration of a super-holon. It describes the decision making process and how members organize and manage the super-holon. Conversely, *Production* aspect relates to the problem to solve and the work to be done. It depends on the application domain and it describes action coordination mechanisms and interactions between members to achieve the objectives of the super-holon. Hence, a super-holon has to contain at least two groups in order to manage these two aspects [19]: *(i)* a *Holonic Group,* that is a single instance of a moderated group representing the government of the super-holon. It specifies how members govern and manage the super-holon. All members of the super-Holon must belong to this group. *(ii)* At least a *Production Group* relates to the problem the members are collaborating to solve. This group may contain only a subset of the members of the super-holon. It describes how members interact and coordinate their actions to fulfill the super-holon tasks and objectives. It is important to underline that at the finest level of granularity, a holon is atomic, and in HMAS it may be considered as a classical Agent. As a consequence, it does not contain any group.

All these HMAS concepts have to be mapped onto the subsystems/modules and components concepts; Parnas definition and the Janus effect guided us in doing this. The Janus effect can be observed in all the aspects of a holon. Indeed, if we consider the whole holarchy a holon is a whole from the viewpoint of the holons at the same holarchy level and a part from the viewpoint of its super-holon. If we consider the organizational schema, a holon can be seen from the government perspective, looking at its holonic group, and from the production perspective, looking at its production groups. Finally, both in the two aspects, government and production, a holon can be seen from the *social structure perspective*, looking at the roles played by the member of the production group and their interactions, and from the *functional perspective*, looking at the goals that the roles of the production group have to satisfy.

The metrics for HMAS we propose take into account these two overlapping aspects. Hence, we define metrics for the government and production aspects from both the social and functional perspective. As a consequence, the concepts for module, component, internal and external dependencies we have identified in HMASs are related to these features. In particular, from the social perspective of government a module is the Holonic Group whilst a component is a Role. Roles depend each other by means of communications. From the government functional perspective, a module is also in this case corresponding to the Holonic Group, whilst a component is a Goal. Goals may depend on another goal for their satisfaction. For space concerns, in Table 2 we list all the concepts useful for defining HMAS metrics.

4. GOVERNMENT METRICS

There is a wide range of government configurations for a super-holon starting from Apanarchy to Monarchy [11][9]. For the scope of this paper, we consider the most common forms of governance adopted in HMASs (see Table 3).

Government Type	Social Structure	Responsibilities
Monarchy	1 Head, N_P Peer	Exclusive command of the Head Peers depend on head's decisions No social exchanges\activities between Head and Peer
Oligarchy	N_H Head, N_P Peer	Command shared by a group of Heads Peers depend on head's decisions No social exchanges\activities between Head and Peer All Heads are engaged in social exchanges\activities
Polyarchy	N_H Head, N_P Peer	Command shared by a groups of Heads Peers depend on head's decisions Heads depend on Peers for certain decisions Peers and Heads are involved in social exchanges\activities All Heads are engaged in social exchanges\acivities
Apanarchy	N_H Head, 0 Peer	Command is shared by all members All Heads are engaged in social exchanges\activities

Table 3: Government Forms.

Social Cohesion	Functional Cohesion
$SCh_{Monarchy} = 0$ (3)	$FCh_{Monarchy} = 0$ (4)
$SCh_{Oligarchy} = \frac{n_{Head} * (n_{Head} - 1)}{(n_{Head} + n_{Peer}) * (n_{Head} + n_{Peer} - 1)}$ (5)	$FCh_{Oligarchy} = \frac{k}{k + (k-1)n_{Peer}}$ (6)
$SCh_{Poliarchy} = \frac{n_{Head}}{(n_{Head} + n_{Peer})}$ (7)	$FCh_{Poliarchy} = \frac{k + w * n_{Peer}}{k + (k-1)n_{Peer}}$ (8)
$SCh_{Apanarchy} = 1$ (9)	$FCh_{Apanarchy} = 1$ (10)

Table 4: Government Metrics

In particular, the two opposite government types are the *Apanarchy* and the *Monarchy*. In the former, the command is completely shared between all members of the super-holon. Everyone takes part to the decision-making process. Conversely, in the latter the command is centralized in the single hands of the Head. Decisions do not have to be validated by any other member. Between Apanarchy and Monarchy, we can find intermediate government configurations such as the *Oligarchy* where a little group of heads share the command without referring to the Peer members and the *Polyarchy* where a little group of heads share the command but they have to refer to the Peers for certain decisions.

In the following sections, we present the proposed metrics for cohesion and coupling (see eq.1 and eq.2) for the discussed four kinds of government, both from the social and the functional perspective.

Social Perspective.

Let us consider a composed holon (super-holon, SH) with $n_M = n_{Peer} + n_{Head}$ members. In order to define coupling and cohesion for the SH's holonic group we have to determine the external and internal dependencies (see eq.1 and eq.2). By definition the holonic group is decoupled from the production groups. Indeed, the holonic group does not have any external dependency with other SH's groups (see Table 2). Hence, the coupling of any government form that can be adopted for the holonic group is [1] $SCp_{HolonicGroup} = 0$.

Conversely as regards the social cohesion of the holonic group, it measures the social engagement of the SH members in the governance. Hence, in the holonic group internal dependencies are represented by the social exchanges (i.e: communications) among members. Looking at table 3 we can see that: *(i)* in the *Monarchy* there are no social exchanges because all *Peers* depend on the decisions of the single *Head*; *(ii)* in an *Oligarchy* all *Heads* (and only them) are engaged in social exchanges (hence: $IntDep = n_{Head}*(n_{Head}-1)$); *(iii)* in a *Polyarchy*, social exchanges are established both among *Heads* and between *Peers* and *Heads* (i.e: $IntDep = n_{Head} * (n_{Head} - 1) + n_{Peer} * n_{Head}$); *(iv)* finally the internal dependencies for *Apanarchy* are $IntDep = n_{Head} * (n_{Head} - 1)$ because all members are *Heads* involved in mutual social exchanges. Hence, according to eq.1 and table 2, the social cohesion for each government configuration is given by the equations 3, 5, 7, 9 listed in Table 4.

In order to give an example, we assume to have a super-holon with five members and another with ten members. According to equations 3, 5, 7 and 9, Table 5 shows the cohesion values of the holonic groups of these super-holons when different types of governance are adopted.

Government Type	N_M=5	Social Cohesion	N_M=10	Social Cohesion
Monarchy	1 Head, 4 Peer	0	1 Head, 9 Peer	0
Oligarchy	2 Head, 3 Peer	0.1	2 Head, 8 Peer	0.02
	3 Head, 2 Peer	0.3	3 Head, 7 Peer	0.06
	4 Head, 1 Peer	0.6	4 Head, 6 Peer	0.13
Polyarchy	2 Head, 3 Peer	0.4	2 Head, 8 Peer	0.2
	3 Head, 2 Peer	0.6	3 Head, 7 Peer	0.3
	4 Head, 1 Peer	0.8	4 Head, 6 Peer	0.4
Apanarchy	5 Head, 0 Peer	1	10 Head, 0 Peer	1

Table 5: Social Cohesion for government type of two different super-holons.

These results show a set of cohesion values coherent with the kind of governance. Indeed, in the range of the government types, the social engagement grows according to the decentralization of the command, which increases the social exchanges. This means that a monarchic holonic group reduces the modularity of its super-holon conversely from the apanarchy. Moreover, as expected the cohesion of oligarchic and polyarchic government with 10 members is less than the one with 5 members. This is because there are more components (i.e: Peers) not involved in the decision process.

Functional Perspective.

The functional perspective for a holonic group concerns the goals its roles have to satisfy in order to govern its super-holon. For the sake of clarity, we use the term *goal* for indicating goals of Roles, *social goals* for goals of the holonic group and *super-holon goal* for indicating the goal of the super-holon the holonic group belongs to. We assume that each Role may contribute with its own goals to the achievement of the social goals.

Let us suppose to have a composed holon (super-holon SH) with $n_M = n_{Peer} + n_{Head}$ members. Analogously to social perspective, we have to determine the external and the internal dependencies in order to define functional coupling and functional cohesion for the SH's holonic group (see eq.1 and eq.2). By definition (see Table 2), the holonic group does not have any functional external dependencies with other SH groups (i.e: production groups). Hence, the functional coupling of the holonic group is $FCp_{HolonicGroup} = 0$.

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[1] Hereafter, the prefix S or F differentiates social metrics from functional ones.

Government Type	N_M=5	Functional Cohesion	N_M=10	Functional Cohesion
Monarchy	1 Head, 4 Peer	0	1 Head, 9 Peer	0
Oligarchy	2 Head, 3 Peer	0.31	2 Head, 8 Peer	0.14
	3 Head, 2 Peer	0.4	3 Head, 7 Peer	0.16
	4 Head, 1 Peer	0.6	4 Head, 6 Peer	0.18
Polyarchy	2 Head, 3 Peer	0.53	2 Head, 8 Peer	0.43
	3 Head, 2 Peer	0.6	3 Head, 7 Peer	0.44
	4 Head, 1 Peer	0.71	4 Head, 6 Peer	0.45
Apanarchy	5 Head, 0 Peer	1	10 Head, 0 Peer	1

Table 6: Functional Cohesion for government type of two different super-holons.

Conversely, the functional cohesion of the holonic group measures the social engagement of its members in terms of goals Roles have to pursue for contributing to holonic group's social goals. Looking at table 3 we can see that: *(i)* in a *Monarchy* there are no social activities between *Peers* and *Head*, the command (i.e: all government activities) is in the hand of the Head; *(ii)* in an *Oligarchy* only heads are involved in social activities for each goal (hence: $IntDep = k * n_{Head}$ where k is the number of goals to be pursed by the holonic group); *(iii)* in a *Polyarchy*, all *Heads* are involved in social activities for each goal and all *Peers* are involved in social activities with heads but only for a given number (w) of goals (hence: $IntDep = k * n_{Head} + w * n_{Peer} * n_{Head}$); *(iv)* finally in an *Apanarchy* the internal dependencies are $k * n_M$ because all members are involved in mutual social activities. Hence, according to eq.1 and to table 2, the functional cohesion for each government configuration is given by the equations 4, 6, 8 and 10 listed in Table 4.

Table 6 shows the results of functional cohesion for the same example of the previous section. In this case we consider $k = 4$ the number of goals to be pursed by the holonic group and $w = 1$ the number of goals in which Peers are involved. In this case too, the proposed metrics give values coherent with the expected ones. In fact, functional cohesion values grow up according to the decentralization of the command that increases the social activities.

5. PRODUCTION METRICS

A Production Group of a super-holon is related to the problem its members are collaborating to solve. As well as in the holonic group, a production group is characterized by its social and functional aspect, hence we defined metrics for cohesion and coupling for each of them.

Social Perspective.

The (production) social structure describes the way the group is organized according to specific roles played by the members of the super-holon. We have seen that in a holonic group these roles are established, we can change only the way they are organized according to the type of governance we want to implement. Conversely, in a production group the roles and their internal and external dependencies have to be wholly defined by the designer according to the problem requirements the super-holon has to satisfy. Although the number and the kind of role depend on the choice of the designer, the type of dependencies are known (see Table 2).

Let us suppose that N_R is the number of roles inside a production group then its social cohesion, according to eq.1 is given by eq.11 in Table 7. Moreover, let us suppose that N_G is the number of production groups inside a super-holon, the social cohesion of the production as a whole is given by eq.13 in Table 7.

From the social perspective, conversely the coupling measures the dependencies among production groups of a super-holon. Let N_{R_i} and N_{R_j} be the number of roles inside the *i-th* and *j-th* production group, their coupling is given by eq.12 in Table 7. Whilst, let us suppose that N_G is the number of production groups inside a super-holon, the social coupling of the production as a whole is given by the eq.14 in Table 7 where $\binom{N_G}{2}$ is the number of possible pairs of groups.

Functional Perspective.

The functional perspective for a production group concerns the goals its roles have to satisfy in order to reach the social goals. The social goals of a production group are goals that contribute to the achievement of super-holon goal. As previously said, we use the term*goal* for addressing the goal of a Role, the term *social goal* refers to goals of a production group and *super-holon goals* to goals of the super-holon the production groups belong to.

Let us suppose N_{SG} be the number of social goals related to a production group PG, N_g the total number of goals of Roles and $GoalDependency_{ij}$ the internal dependencies between the *i-th social goal* and *j-th goal*, then the PG functional cohesion is given by the eq.15 in Table 7. Whilst, let N_G be the number of production groups inside a super-holon, the functional cohesion of the production as a whole is given by the eq.17 in Table 7. Analogously, we define the functional coupling between the *i-th* and the *j-th* production groups as reported in eq.16 in Table 7, where N_{SG_i} and N_{SG_j} are the number of social goals related to the *i-th* and *j-th* production group of the super-holon and $GoalDependency_{ijkw}$ is the external dependency between *k-th* social goals of the *i-th* production group and the *w-th* social goal of the *j-th* production group.

Whilst, let N_G be the number of production groups inside a super-holon, the functional coupling of the production as a whole is given by eq.18 in Table 7 where $\binom{N_G}{2}$ is the number of possible pairs of groups.

Applying the proposed metrics in a design problem.

Let us suppose to design only the production part of a super-holon for solving the following problem: *to unload goods from a lorry in order to send them toward new destinations.* We can do this by adopting different design solutions for the super-holon, for our purposes we might consider three different organizational structures (see Fig.1).

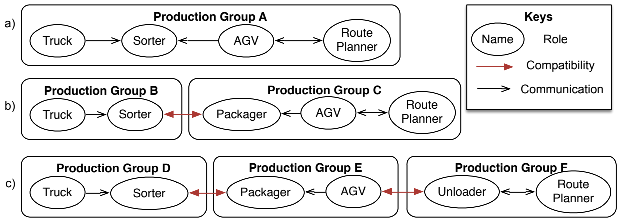


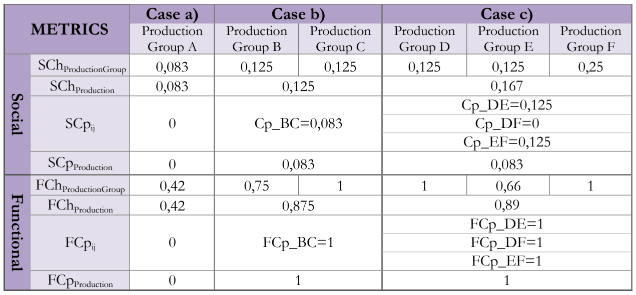
Figure 1: Social design choices for production groups.

Social Perspective	
Social Cohesion	**Social Coupling**
$SCh_{ProdGroup} = \sum_{i=1}^{N_R} \sum_{\substack{j=1 \\ i \neq j}}^{N_R} \frac{(Compatibility_{ij} + Communication_{ij})}{4N_R * (N_R - 1)}$ (11)	$SCp_{ij} = \sum_{k=1}^{N_{R_i}} \sum_{\substack{w=1 \\ w \neq k}}^{N_{R_j}} \frac{(Compatibility_{ijkw} + Communication_{ijkw})}{4N_{R_i} * N_{R_j}}$ (12)
$SCh_{Production} = \sum_{i=1}^{N_G} \frac{SCh_{ProductionGroup_i}}{N_G}$ (13)	$SCp_{Production} = \sum_{i=1}^{N_G} \sum_{\substack{j=1 \\ j \neq i}}^{N_G} \frac{SCp_{ij}}{\binom{N_G}{2}}$ (14)
Functional Perspective	
Functional Cohesion	**Functional Coupling**
$FCh_{ProdGroup} = \sum_{i=1}^{N_{SG}} \sum_{j=1}^{N_g} \frac{GoalDependency_{ij}}{N_{SG} * N_g}$ (15)	$FCp_{ij} = \sum_{k=1}^{N_{SG_i}} \sum_{\substack{w=1 \\ w \neq k}}^{N_{SG_j}} \frac{GoalDependency_{ijkw}}{N_{SG_i} * N_{SG_j}}$ (16)
$FCh_{Production} = \sum_{k=1}^{N_G} \frac{Ch_{ProductionGroup_k}}{N_G}$ (17)	$FCp_{Production} = \sum_{i=1}^{N_G} \sum_{\substack{j=1 \\ j \neq i}}^{N_G} \frac{FCp_{ij}}{\binom{N_G}{2}}$ (18)

Table 7: Production Metrics

In the first case (see Fig.1 a)), we designed one super-holon with only one production group including four roles: an *AGV* role devoted to unload goods from a lorry and to transport them to the sorter; a *Route Planner* that manages the routes the AGV uses to move toward/from the lorry to be unloaded; a *Sorter* that packages goods and gives them to the proper Truck (see next role), and finally a *Truck* that transports packages to their destination (several trucks leave the yard at the same time, the Sorter sends each parcel to the right one). Moreover, we established that four communication links are necessary among these roles for exchanging information. In the second case, we designed the super-holon with two production groups (see Fig.1 b)) including five roles. In so doing, we have extracted the packaging tasks from the previously defined *Sorter* role and we have delegated them to a new role, the *Packager*. As a result, the production group C is responsible for unloading cargo and packaging accordingly to destination while production group B is responsible for delivering packages to their destination. Finally in the third case, we designed the super-holon with three production groups (see Fig.1 c)) with six roles, where we have extracted the task of unloading goods from the AGV role delegating them to a new role labelled *Unloader*; the AGV role remains responsible for delivering goods to the *Packager* only. Fig.2 shows three different functional design choices related to the three previous organizational structures. For space concerns, we omit the description of each goal also because for our purposes we are interested only to the number of goals and their dependencies.

The resulting values of social/functional cohesion and coupling are shown in Table 8. It is worth to note that these values are not very useful when interpreted as absolute values on a single design solution. They become meaningful for making a choice among different alternatives. Specifically, in accord to quality requirements prescribed by software specifications of the system to be realized, the designer can make comparisons among different architectural styles by using these values as guidelines to choose appropriate design solutions. For example, the design solution represented by the case c) of Fig.1 may provide a better modularity than the others, because it has the greatest social and functional cohesion and the same social and functional coupling of the case b) (see Table 8). Vice versa, although the design solution represented by the case a) has a zero coupling it is not a good choice for modularity, because everything is encapsulated within a single great module. Naturally, the choice of case c) is not always the right solution to be adopted. It depends on the requirements of the system to be realized.



METRICS		**Case a)**	**Case b)**		**Case c)**		
		Production Group A	Production Group B	Production Group C	Production Group D	Production Group E	Production Group F
Social	$SCh_{ProductionGroup}$	0,083	0,125	0,125	0,125	0,125	0,25
	$SCh_{Production}$	0,083	0,125		0,167		
	SCp_{ij}	0	Cp_BC=0,083		Cp_DE=0,125 Cp_DF=0 Cp_EF=0,125		
	$SCp_{Production}$	0	0,083		0,083		
Functional	$FCh_{ProductionGroup}$	0,42	0,75	1	1	0,66	1
	$FCh_{Production}$	0,42	0,875		0,89		
	FCp_{ij}	0	FCp_BC=1		FCp_DE=1 FCp_DF=1 FCp_EF=1		
	$FCp_{Production}$	0	1		1		

Table 8: Social cohesion and coupling for different design choices of Production.

6. DISCUSSIONS AND CONCLUSIONS

Metrics for evaluating system architectures provide useful guidelines to the designer for choosing the appropriate design solution that meets certain quality attributes. Unfortunately, relationships among metrics and quality attributes are often complex to capture and the study of such relationships is out of the scope of this paper. Traditional Object Oriented metrics as well as MAS ones are not useful for measuring HMAS architectures because they lie on different concepts of module and component that in the HMAS paradigm must take into account the holon's nested levels of organizational structures. This motivated us, to conduce a deep analysis about HMASs in order to retrieve the right elements to be mapped onto the module, components and dependency concepts. Hence, we defined the metrics to be

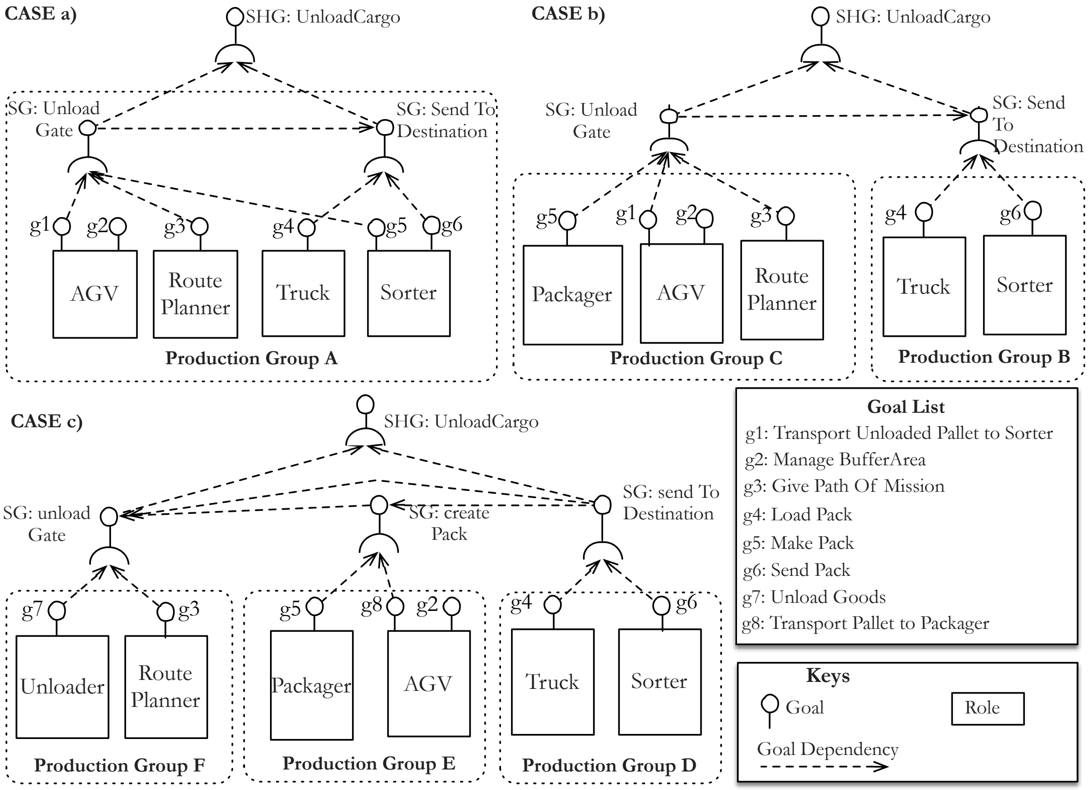


Figure 2: Different functional design choices for Production of a super-holon.

applied in order to determine the cohesion and coupling for a given (super-)holon. Now, in order to give a complete view on the entire holonic architecture, it is necessary to further define the metrics for determining the cohesion and coupling measures for the whole holarchy. We deduced those directly from the previous ones.

Let us consider a holarchy with N_{SH} super-holons, the social cohesion of the whole holonic architecture is given by:

$$SCh_a = \sum_{w=1}^{N_{SH}} \frac{SCh_{SH}}{N_{SH}} \tag{19}$$

$$SCh_{SH} = \frac{\sum_{k=1}^{N_G} SCh_k + SCh_{HolonicGroup}}{N_G + 1} \tag{20}$$

where SCh_{SH} is the social cohesion of a super-holon, N_G is the number of production groups inside the super-holon, SCh_k is the cohesion for each production group given by eq.11 and $SCh_{HolonicGroup}$ is the cohesion for the holonic group of the super-holon given by one of eq.3 - 9 according to the type of government adopted for the super-holon.

Analogously, let us consider a holarchy with N_{SH} super-holons, the social coupling of the whole architecture is given by:

$$SCp_a = \sum_{w=1}^{N_{SH}} \frac{SCp_{SH_w}}{N_{SH}} \tag{21}$$

$$SCp_{SH} = SCp_{Production} \tag{22}$$

where Cp_{SH} is the social coupling of a super holon equals to $SCp_{Production}$ because $Cp_{HolonicGroup} = 0$. As concerns functional cohesion and coupling of a holarchy, they are analogous to the previous ones.

It is also worth to point out that these metrics can be effectively employed as a part of a methodological approach for designing holonic systems. For instance, by using an iterative and incremental approach these metrics may provide the designer a step by step measure of the satisfaction of quality requirements imposed for the system to be realized. Moreover, assuming the metrics integrated in a CASE tool for designing holonic systems, a designer could be able to immediately know the impact of an architectural change on the whole system thus having the possibility to make a correction if the new choice should negatively affects some quality requirements. By now, we are working on a suite of metrics for evaluating other quality attributes for HMASs in order to provide useful means for supporting design choices. This metrics suite will be incorporated into a HMAS design tool that will provide functionalities for automatically calculating them.

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