Holonic Stigmergy as a Mechanism for Engineering Self-Organizing Applications

Stefan Grobbelaar
Institute of Computer Technology

Vienna University of Technology, Vienna, Austria
madani@ict.tuwien.ac.at

Mihaela Ulieru
Canada Research Chair
Director Adaptive Risk Management Laboratory
University of Brunswick
ulieu@unb.ca

Key Words: Holonic Stigmergy, Agent Architecture, Context Model, Imposed vs. Intended Goals, Power-Saving Holarchy

Abstract: We introduce the concept of holonic stigmergy as a mechanism for tuning the emergence of optimal organizational structures and illustrate how it works on a power network energy saving example.

1. BASIC CONCEPTS

1.1. Holons and Holoarchies (Imposed Goals)

The word holon is made up of the Greek word "holos", meaning whole, and the suffix "on", suggesting a particle or part, and can thus be described as a part-whole. According to Koestler [1], this part-whole can be viewed as nodal point in at a certain level of a nested hierarchy (holarchy), describing the relationship between a set of dependant entities that are self-complete wholes and entities which are considered other dependent parts (located at lower levels in the holarchy). A holarchy, then, is a nested hierarchy of holons (Fig. 1 [14]), and, e.g. according to the Holonic Manufacturing Systems Consortium [2], is a system of holons that can cooperate to achieve a goal or objective. The holarchy defines the basic rules for cooperation of the holons and thereby limits their autonomy. Extensive work on self-organising holarchies applied to various domains has been done by Ulieru [10, 11]. In this paper we extend the holarchic self-organising model introduced by Ulieru [12] by adding to it stigmergic capabilities, which will further increase the flexibility of the emergence model by eliminating the need for a mediator holon (which encapsulates the optimal clustering mechanism in Ulieru's work [13]) through the power of swarm intelligence optimal clustering.

We start by adding the holarchic context dimension, that is we say that holons, in the same holarchy, are groupings of parts which share a similar context and are dependent on holons at higher levels of the holarchy. Context is usually created around a user need – and is used by the holarchy to deduct a user's need which the holarchy could fulfil in an optimal manner by self-organising its resources appropriately. Holons at the higher levels in the holarchy usually undertake the user's need as a holarchic goal thus imposing it over the holons at lower levels in order to fulfil it in an optimal way.

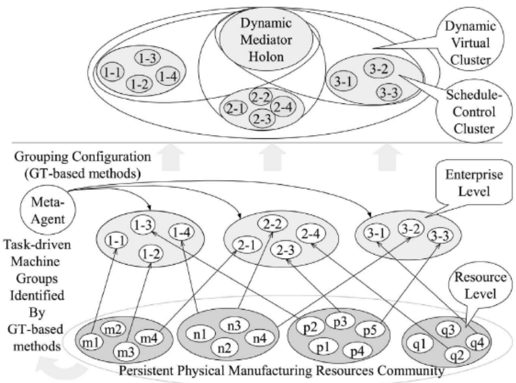

Fig. 1: Mediator-Based Holarchy (from [14])

We define an *imposed goal* with an associated *high priority* to be a goal which limits a holon's autonomy, and as a result, limits its ability to group freely with other holons on its level. An imposed goal usually comes from a higher holarchic level or directly from a user.

1.2. Stigmergence and autonomy

According to Parunak [3], stigmergy is a method of communication in a system in which the individual parts of the system communicate with one another by modifying their local environment (which includes other parts, e.g. how termites communicate by leaving pheromone trails encoding various 'meanings'). This modification of the environment may unknowingly lead to the emergence of groupings amongst parts (not necessarily dependent on each other), and a likely driving force of this grouping is the perceived benefit of parts associating with other parts which have similar intended goals and priorities associated with these goals – having as end result an optimal configuration around fulfilling a certain task (e.g. finding the shortest path from the food source to the nest in case of termites.).

We define an *intended goal* with an associated *high priority* to be a goal which increases a holon's autonomy, and hence increases its ability to group freely with other holons on its level. An intended goal may sometimes coincide with a user's goal or a holarchic goal imposed from the higher levels.

2. STIGMERGIC HOLARCHY: Balancing Imposed and Intended Goals

A stigmergic holarchy, as defined by us, describes a system of holons which belong to a holarchy and have stigmergic properties. In our view, the system is always created around user needs, and the user needs translate into context to become either *intended or imposed goals*.

We introduce here the concept of Holarchic Context, defined as the information used to characterize the situation or state of a user of a holarchy, specifically information of a particular user's goals and priorities and how these goals and priorities relate to the goals and priorities of the holarchy which undertakes the user's goals fulfilment. This is an adaptation to holarchic systems of the definition given by Dey and Abowd [4]: "any information that can be used to characterize the situation of an entity. An entity is a person, place or object that is considered relevant to the interaction between a user and an application, including the user and application themselves".

In the sequel we will use ontologies as a common vocabulary which enables all the holons of a particular holarchy to communicate consistently. Webster's [5] defines ontology as "a theory concerning the kinds of entities and specifically the kinds of abstract entities that are to be admitted to a language system". For the purpose of knowledge representation, this definition was further adopted as follows:

- According to Gruber [6], an ontology is "an explicit specification of a conceptualisation", conceptualisation being a set of extensional relations describing a particular state of affairs - Genesereth and Nilsson [7].
- Guarino [8] adds to this interpretation a set of explicit assumptions regarding the intention of an entity.

3. A CONTEXT MODEL FOR HOLONIC STIGMERGY

We consider a holarchy having holons whose contexts are described by their goals and the priorities associated with these goals. All goals are classified as either *intended* or *imposed*. We distinguish between holons at a high level of the holarchy and holons at a low level, and define the following ratios:

Need Ratio: need for grouping (never 0, otherwise holarchy collapses into total stigmergy) / desire to follow intended goal

Priority Ratio: The ratio(s) of Intended goal priority(s)/Imposed goal priority(s)

Leaving Ratio: The priority ratio of a holon at a time of leaving the holarchy.

Adaptive Risk Number: A risk of leaving percentage, comparing the priority ratio of the holon to the leaving ratios of holons in the same holarchic cluster.

We are using these ratios to tune the degree of autonomy of individual holons in a holarchy emerged around a user's need (aiming to fulfil it with some degree of optimality). For this we introduce a holonic context model (Fig. 2) which uses the inputs and outputs described in Table 1.

Observations (Inputs)	Signals (Outputs)
- Intended goals from user - Intended goals of surrounding holons - Imposed goals of higher level holons - Leaving ratios and priority ratios of surrounding holons	- Intended goals (as information to surrounding holons and imposed goals to holons at a lower level) - Group/don't group signal - Leaving ratios and priority ratios of the holon

Table 1. Inputs and outputs of a holon

The methodology for tuning the self-organising (or emergence) capability of a holarchy around a user's need is presented in the sequel.

Let's consider a low-level holon which has one intended goal (which may mirror a user's goal) and a need to join a holarchy to achieve this goal.

a. The holon decides on a need ratio.

b. The holon joins a holarchy and receives an imposed goal (which may mirror for example another user's goal) from a higher-level holon.

c. It decides on a priority ratio comparing its intended goal to the imposed goal. The initial value of the priority ration may be set according to the value of the need ratio.

d. While in the holarchy, the holon observes holons on its level and according to its priority ratio, will:

- group with the number of holons needed to follow the imposed goal, as such create a cluster around that imposed goal fulfilment need, and
- group with as many as possible holons which share its intended goal. i.e. which have a similar or identical stigmergic context – as such cluster to fulfil its own desires as well.

This intrinsic duality cooperation/autonomy creates a tension aiming to fulfil both the imposed and intended (desired) goal as best as possible simultaneously. From this tension an optimal organisational structure will emerge in the particular holarchy which the holon(s) joined.

e. According to its need ratio the top-level holon will decide which holons will be eliminated from the holarchy (if they hinder the optimality of the particular solution). For example those holons who have high desired goals, respectively priority ratios for those goals will be eliminated because they may work against the overall holarchic goals.

f. The holon monitors the leaving ratios and priority ratios of holons in the surrounding area, adjusts its adaptive risk number, and hence may or may not eventually adjust its priority ratio.

The Adaptive Risk Number (ARN) is influenced by the need ratio which gives direction for the priority ratio, i.e. the need ratio sets the priority ratio when joining the network, which is then compared to leaving ratios of surrounding holons to determine an ARN. The ARN in fact quantifies the risk an individual holon undertakes in being eliminated from a holarchy (which provides certain benefits to this holon) because is 'misbehaves' by selfishly pursuing its own goals which may not resonate with the holarchic goal(s).

In our model the priority ratio is a performance measure, because we assume intended goals change over time, and hence a priority ratio would give the best indication of a holon's performance over time in pursuing and fulfilling its goals.

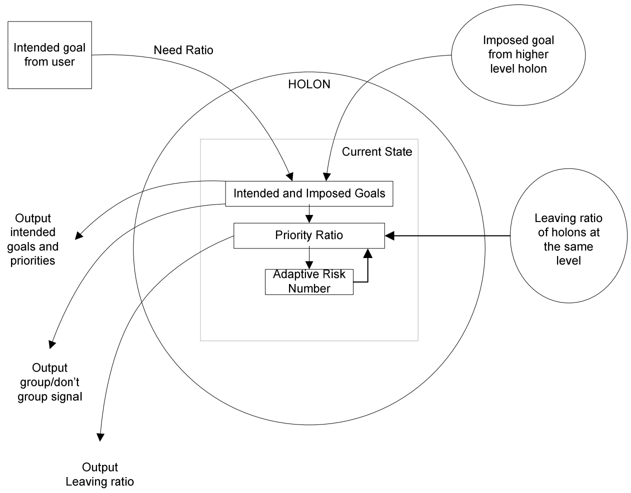

Figure 2. A context model for holonic stigmergy

4. APPLICATION SCENARIO

In this section we illustrate how holarchic stigmergy works on a power saving holarchy example (Fig. 4). Our example draws from the Integral Resource Optimisation Network (IRON) (Roesner and Palensky [9]) of distributed, intelligent field devices plugged into consumer electrical appliances (Fig. 3.) The field devices receive pricing information from an electricity supplier (control entity), and based on this information, are requested to shift electricity consumption to times when electricity is cheaper, in order to optimise power consumption. In our example the duality imposed/intended goal is manifested as follows:

- The user need of the supplier (mirrored by the highest level in the holarchy illustrated in Fig. 4) would be to group appliances over certain geographical areas, e.g. an industrial area, and have these appliances shift their consumption to match more cost-effective supply times.
- The user need of consumers (appliances owners) would be to use appliances at preferred times and create groupings of consumers who could benefit from the associated cost-saving.

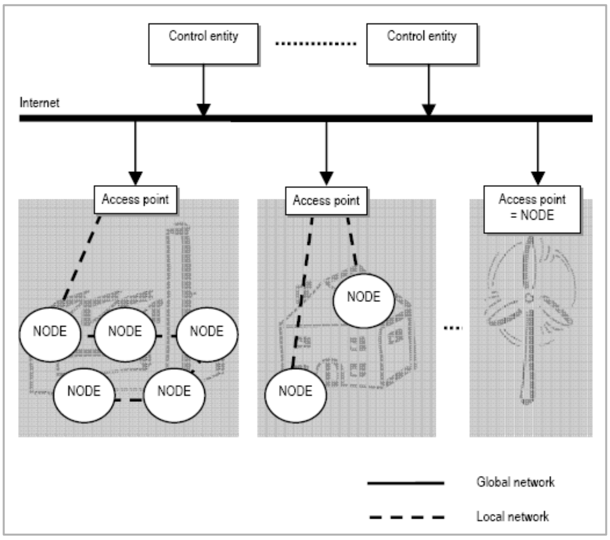

Figure 3. IRON Network (taken from Palensky et al)

In the power saving holarchy (Fig. 4), the supplier (our control entity in Fig. 3) is viewed as a high-level holon that would benefit from a high degree of hierarchy (that would secure the holons compliance to its interests). The consumer appliances are low-level holons who would benefit from a high degree of autonomy and the ability to stigmergically group with other low-level holons according to individual preference. The high-level holon's intended goal to shift consumption of devices in a lower-level grouping to a specific time of day is imposed on to the lower-level holons. The Need Ratio of the high-level holon will be in this example *The number of required participant holons / number of participant holons required to follow its intended goal.*

The low-level holons have an intended goal to shift consumption to another time of day (which may coincide with that of the high-level holon). Their Need Ratio of low-level holons is:

The need of a holon to belong to the holarchy / need of the holon to follow its intended goal.

5. DESIRED VS. IMPOSED GOALS (Balancing total stigmergy vs. degree of holarchy)

As previously mentioned, within the holarchy the degree of autonomy of individual holons ranges from total stigmergy/autonomy (independence of the higher holarchic authority) to total(itarian) hierarchy (absolute obedience to the fulfilment of the holarchic goal(s) and as such absolute dependence on the higher level(s) goals. Adjusting the need ratio to give priority to either the intended or imposed goal tunes the degree of autonomy of holons within the holarchy as follows:

Giving more power(greater influence) to the intended goal of a holon at a specific level, will force lower priority ratios on all holons below that level**.** Hence, the holarchy will become more hierarchical. This will cause holons at the level and above to become more stigmergent. By adjusting the influence (power) to the intended goals of holons at a specific level, we are able to vertically shift the holonic/stigmergent balance throughout the holarchic levels.

6. CONCLUSIONS

The need ratio was defined as the need for clustering / desire to follow intended goal (need for independence). When the need for clustering of a group of holons is reduced to zero, the holarchy will either collapse or the holons who have a zero need to belong to the holarchy will break away from the holarchy and could possibly evolve into the emergence of a new holarchy (in case a new goal/user enters the picture).

Our results are easily extensible to AmI applications which target user goal fulfilment in a natural way by having the intelligent environment assess user's context and act accordingly to meet user's needs [relevant AmI reference!], a such endowing SOAs with a robust easily implement able mechanism for controlling the degree of emergence via holarchic self-organisation through different degrees of stigmergy.

7. References

[1] Koestler, A, "The Ghost in the Machine", *Arkana Books*, 1967.

[2] Holonic Manufacturing Systems Consortium, "Holonic Concepts", *http://hms.ifw.uni-hannover.de/*

[3] Parunak, H.v.D., "Making Swarming Happen", *In Proc. of Conf. on Swarming and Network Enabled Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR)*, McLean, 2003.

[4] Dey, A., Abowd, G., "Towards a better understanding of context and context-awareness", *Proceedings of the CHI 2000 workshop on The What, Who, Where, When and How of context-awareness*, 2000.

[5] Webster's Third New International Dictionary, Mirriam-Webster publishing

[6] Gruber, T. R., "A translation approach to portable ontologies.", *Knowledge Acquisition*, 5(2):199-220, 1993.

[7] Genesereth, M. R., Nilsson, N. J., "Logical Foundation of Artificial Intelligence", Morgan Kaufmann, Los Altos, California.

[8] Guarino, N., "Formal Ontology, Conceptual Analysis and Knowledge Representation"

[9] Roesner, C., Palensky, P., Weihs, M., Lorenz, B., Stadler, M., "Integral Resource Optimization Network – a new Solution on Power Markets", *in proc. of 3rd International Conference on Industrial Informatics*, Perth, 2005

[10] Mihaela Ulieru and Paul Worthington, "Adaptive Risk Management System (ARMS) for Critical Infrastructure Protection", *Integrated Computer-Aided Engineering, Special Issue on Autonomic Computing in Engineering in Integrated Computer-Aided Engineering; ISSN: 1069-2509; IOS Press; expected publication volume: 12:2 (January 2006), pp. 63-80.*
[11] Mihaela Ulieru, Adaptive Information Infrastructures for the e-Society, in Engineering Self-Organizing Systems: Methods and Applications, Giovanna DiMarzo Serugendo and Anthony Karageorgios (Eds.) Springer Verlag – LNAI 3464, Berlin 2005, ISBN: 3-540-26180-X , pp. 32-51

[12] Mihaela Ulieru, "Emergence of Holonic Enterprises from Multi-Agent Systems: A Fuzzy-Evolutionary Approach", Invited Chapter in *Soft Computing Agents: A New Perspective on Dynamic Information Systems*, (V. Loia – Editor), IOS Press -Frontiers in AI and Applications Series 2002, ISBN 1 58603 292 5, pp. 187-215.

[13] Mihaela Ulieru and Rainer Unland, "Enabling Technologies for the Creation and Restructuring Process of Emergent Enterprise Alliances", International Journal of Information Technology and Decision Making, Vol. 3, Issue 1, March 2004, pp. 33-60.

[14] Mihaela Ulieru, Robert Brennan and Scott Walker, "The Holonic Enterprise – A Model for Internet-Enabled Global Supply Chain and Workflow Management", International Journal of Integrated Manufacturing Systems, No 13/8, 2002, ISSN 0957-6061, pp. 538-550.