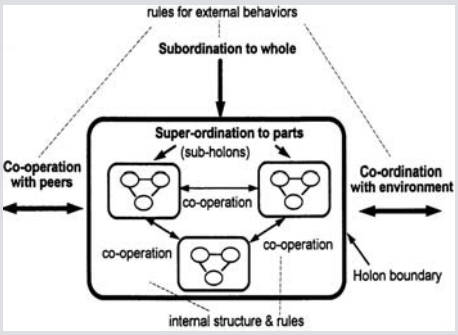
Self-organizing Cybersystems as Infrastructure for Optimizing Power Distribution Networks

We use stigmergy to tune the degree of autonomy in holonic cybersystems as foundation for controlling large scale power distribution networks.

Holons and Stigmergy

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 this part-whole can be viewed as a nodal point 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 and defines the basic rules for cooperation of the holons, thereby limiting their autonomy.

"We define an imposed goal with an associated high priority as a goal which limits a holon's autonomy"



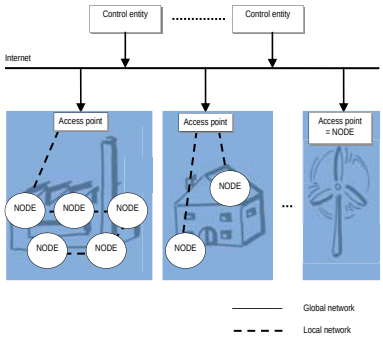
Holarchy as defined by the Holonic Manufacturing Systems Consortium (http://www.mech.kuleuven.be/goa/concepts.htm)

According to Parunak, 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.

"We define an intended goal with an associated high priority as a goal which increases a holon's autonomy"

Power Distribution Scenario

Our example draws from the Integral Resource Optimization Network (IRON) (Palensky) of distributed, intelligent field devices plugged into consumer electrical appliances. 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 optimize power consumption. In our example the duality imposed/intended goal is manifested as follows:



Friederich Kupzog, "Self Controlled Exploitation of Energy Cost Saving Potentials by implementing Distributed Demand Side Management", 4th Int. IEEE Conf. on Industrial Informatics; Singapur; 15-08-2006 - 17-08-2006; in: "Proceedings of INDIN 2006".

- The user need of the supplier (mirrored by the highest level in the holarchy) 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.

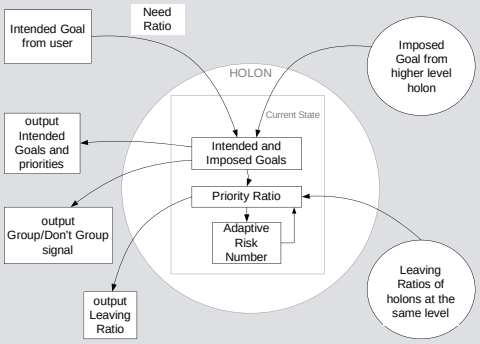
- The user need of consumers (appliances owners) would be to use appliances at preferred times and create groupings of consumers who could benefit from the associated cost-saving.

In the power saving holarchy the supplier (our control entity) 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



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:

Need Ratio: *need for grouping / 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.*

a. The holon decides on a need ratio.

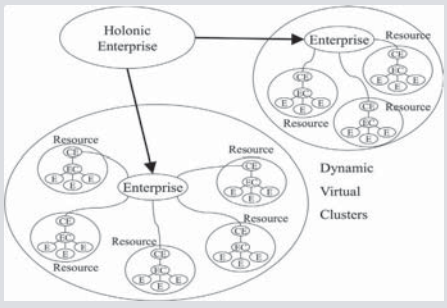
b. The holon joins a holarchy and receives an imposed goal (which may mirror for example another user's goal) from a higher-level holon.

c. It decides on a priority ratio comparing its intended goal to the imposed goal. The initial value of the priority ratio 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 and as many possible holons which share its intended goal.

e. According to its need ratio the top-level holon will eliminate lower-level holons.

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.



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.

Tuning the Degree of Autonomy

We use the concept of Holonic Enterprise (introduced by Ulieru) as enabling foundation for tuning the degree of autonomy of the holons. 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.

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