Towards a Simulation Tool for Evaluating Dynamic Reorganization of Agents Societies

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Abstract

Reorganization of the structure of an organization is a crucial issue in multi-agent systems that operate in an open, dynamic environment. Currently, most coordination mechanisms are imposed upon the system at design time, and their modification implies the redesign of the system. However, autonomous agents must be able to evaluate and decide the most appropriate organization given the environment conditions. That is, there is a need for dynamic reorganization of coordination structures. In this paper, we propose a classification of reorganization types which considers two layers of reorganization: behavioral and structural. We further describe how simulations can help to determine whether and how reorganization should take place. Finally we present a simulation scenario that is used to evaluate the different reorganization forms.

1 INTRODUCTION

Establishing an organizational structure that specifies how agents in a system should work together helps the achievement of effective coordination in MAS (Barber and Martin, 2001). An organization-oriented MAS starts from the social dimension of the system, and is described in terms of organizational concepts such as roles (or functions, or positions), groups (or communities), tasks (or activities) and interaction protocols (or dialogue structure), thus on what relates the structure of an organization to the externally observable behavior of its agents.

Environments in which the MAS systems function are not static. Their characteristics can change, ranging from new communication channels to tasks that are no longer useful or are new. In such a changing environment, agents can disappear, be created or they can migrate. The organizational objectives can change, or operational behavior can evolve. Models for MAS must therefore not only cater for adaptive agents (Jennings et al., 1998) but also be able to describe dynamically adapting organizations to changes in the environment. Depending on the type of organization and on the perceived impact of the changes in the environment, adaptation is achieved by behavioral changes at agent level, modification of interaction agreements, or the adoption of a new social structure. Even though in most MAS, reorganizations are currently realized by re-engineering the system (i.e. external assessment and modification of a system), for a MAS to be truly autonomous, mechanisms for dynamic reorganization must be available. The concept of *dynamic adaptation* refers to modifications in structure and behavior of a MAS, such as adding, removing or substituting components, done while the system is running and without bringing it down (Valetto et al., 2001). Dynamic adaptation demands that systems can evaluate their own ”health” (i.e. success and other utility parameters) and take action to preserve or recover it, by performing suitable integration and reconfiguration actions. Reorganization of organizations should therefore allow both for changes of the operational behavior of the organization, such as admission or departure of agents, as well as for changes of the social structure of the society changes, that is, roles, relationships, norms or interactions.

In (Dignum et al., 2004), we discuss different types and motivations for reorganization and the consequences for MAS models of enabling dynamic reorganization at different complexity levels. Not every change in the environment or an agent will lead to an organizational change. But when and who will actually decide upon such a structural change?
When a decision is made to change the organization it should also be decided what and how the organization is changed. Are interaction patterns changed, do we change some roles, some constraints,...? Organizational success is brought about by the organization's ability to bring all its information and assets to bear, and the ability to recognize and take advantage of fleeting opportunities. In this sense, successful reorganization should lead to an increased utility of the system. That is, the reorganized instance should perform better in some sense than the original situation.

From the perspective of the individual agents, their participation in an organization also depends on utility factors. Utility is however appreciated differently from the perspectives of the society and of the agents. On the one hand, the organization will only admit an agent, if the overall utility of the society increases (Glasser and Morignot, 1997). On the other hand, assuming rational agents, the agent will only join an organization if its own utility increases.

In this paper, we will first describe a theoretical framework of the reorganization aspects discussed above. After that we will discuss how simulations can be used to discover some properties of the reorganization process. Finally we describe the first steps in this process, presenting a simulation environment in which reorganization can be studied.

2 SOCIAL ORGANIZATION

2.1 Organizational utility

One of the main reasons for having organizations, is to achieve stability. Nevertheless, environment changes and natural system evolution (e.g. population changes), require the adaptation of organizational structures. Reorganization is the answer to change in the environment. As reorganization is contrary to stability, the question is then: under which conditions is it better to reorganize, knowing that stability will be (momentarily) diminished, and when to maintain stability, even if that means loss of response success. In order to answer this question, it is necessary to define the *utility* of an organization. Reorganization is therefore desirable if it leads to increased utility of the system. That is, the reorganized instance should perform better in some sense than the original situation.

Given the assumption of agent autonomy, it is also necessary to define agent utility, as each agent should, in principle, be able to determine whether a reorganization results in increased utility for the agent itself. Utility is thus evaluated differently from the perspectives of the society and of the agents.

Society Utility We define the utility of an organization based on organization properties:

- *Interaction success*: how often do interactions result in the desired aim.
- *Role success*: how often do enacting agents realize role goals.
- *Structure success*: how well are global objectives achieved in an organizational structure.

For example, a given combination of structure and population is said to be successful if the overall success of the organization is higher in that situation than for others. Society utility depends also on the cost of the reorganization. That is, any function to measure organization utility must take in account both the success of a given structure, and the cost of any change needed to achieve that structure from the current situation (Glasser and Morignot, 1997).

Agent Utility is different for each agent, taking in account issues such as its own goals, resource production and consumption. Basically, we can assume that rational agents will participate in a society only if, in their own perception, their individual utility increases. Furthermore, different social attitudes will result in different evaluations of individual utility. That is, the utility function of a social agent may take on account some measure of society utility, whereas for a selfish agent only individual concerns matter.

2.2 Organizational Change

Change is a result of observation of the environment. Making sense of a situation begins by identifying relevant patterns and access current response possibilities. Sense-making is however more than sharing information and identifying patterns. It involves the ability to generate options, predict outcomes and understand the effect of particular courses of action. Such sense-making activities require to keep some sort of system history, also across different role enactors. These are capabilities that few software agents are endowed with. Hence, enabling dynamic reorganization has consequences for the capabilities required from the agents involved. Therefore makes sense to, firstly, identify which organization type is most appropriate for a given situation, , secondly, what is then needed to adapt the current organization to the one with the highest utility, and, finally, what is required from the individual agents to enable them to realize the reorganization.

A characteristic of reorganization is *timeliness*, that is adequate response at the appropriate time (not to be confused with speed). This implies the need to assess when and how often, and at which level to change. When change occurs too often and too quickly, the predictability of the system will decrease, but too slow and too late changes result in rigidness of the system. Both situations are usually not desirable. The characteristic to aim at is *resiliency*, that is, flexible but durable and consistent with the (meta) norms and objectives of the organization. An interesting study presented in (Carley et al., 2002), explores the resiliency of organizations by studying their performance when key leaders were removed . Different domains will have different appreciations of timeliness and resiliency. For instance, in rescue operations, timeliness is often directly related to speedy response. That is, a quick, even if sub-optimal, adaptation will be preferred over the optimal solution if that one only arrives after it is too late (e.g the house has already burned down). On the other hand, in institutions (such as an university department), timeliness is often related to consensus. That is, the good time to change is when all parties are conscious of the need to change and agree on the changed model.

3 A TYPOLOGY OF REORGANIZATION

In early work in reorganization, restructuring was only possible in the initialization phase of the system. During the actual problem solving phase, the structure was fixed. Currently, most dynamic approaches to reorganization consider only the behavioral aspects, that is reorganization only affects the current population of agents in the system, both at the social (i.e. interactions and relationships) (Carley and Gasser, 1999), as well as individual level (Hannebauer, 2002). Existing implementations of organizational adaptation include approaches based on load balancing or dynamic task allocation. The later is often the case in organizational self-design in emergent systems that, for example, include composition and decomposition primitives that allow for dynamic variation of the organizational structure (macro-architecture) while the system population (micro-architecture) remains the same (So and Durfee). Another common approach is dynamic participation. In this case, agent interaction with the organization is modelled as the enactment of some roles, and adaptation occurs as agent move in and out of those roles (Dignum, 2004; Glasser and Morignot, 1997; Tambe, 1997). However, few of these systems allow agents to change the problem-solving framework of the system itself (Barber and Martin, 2001).

Based on the above considerations, we identify the following reorganization situations:

Behavioral change: Change at behavior level, that is, organizational structure remains the same, but behavior of agents enacting organizational roles change. Examples are when agents join or leave the society, or when their characteristics change (e,g. more or less consumption or production of some resources) It does not affect future enactments and therefore there is no need for organizational memory.

Structural change: Aims at accommodating long-term changes, such as new situations or objectives. Structural change influences the behavior of the current but also of future society instantiations. Examples of structural change are adding, deleting or modifying structural elements (e.g. roles, dependencies, norms, ontologies, communication primitives) Change at social level implies a need for society level learning. That is, by keeping an organizational memory, the society itself can reflect on the difference between desired and actual behavior and decide on social level changes (roles, norms, etc.).

Another perspective on reorganization, concerns the ways the reorganization decision is taken. Considerable work has been done analyzing the advantages and disadvantages of centralized and distributed problem-solving structures. In centralized situations, decisions are taken by one role in the organization. It corresponds to a master/slave relationship between agents acting at different levels of autonomy. Roles empowered with decision-making authority, *direct* change of other roles. In distributed decision-making situations that (all) roles are collectively responsible for a change decision. Changes are thus achieved by collaboration or consensus. In (Barber and Martin, 2001) three types of decision-making styles are identified, that relate to centralized and distributed decision-making situations:

- *Command-driven*: the agent does not make any decisions on how to pursue its (role) goals, and some other agent has authority over it (child in a hierarchical relation)
- *True consensus*: Agent works as a team member, sharing decision making control equally with other agents. (network relation)
- *Locally autonomous/master*: The agent makes decisions alone and may or not have control over other agents (parent or root in a hierarchical relation).

Related to the above, is work on the application of the military notions of Command, Control and Communications (C3) to MAS focuses on the authority to effect changes at different levels (Tidhar and Sonenberg, 2003). *Command* refers to the authority and responsibility to determine the objectives of the organization and update the social structure of the organization accordingly. *Control* refers to the authority to specify and modify detailed plans for achieving objectives, that is, the authority to modify interactions and behavior. *Communications* refer to sharing information about the environment, the state of the organization, the state of the achievement of objectives, and the state of execution of the plans. Figure 1 depicts the relations between the different perspectives on reorganization.

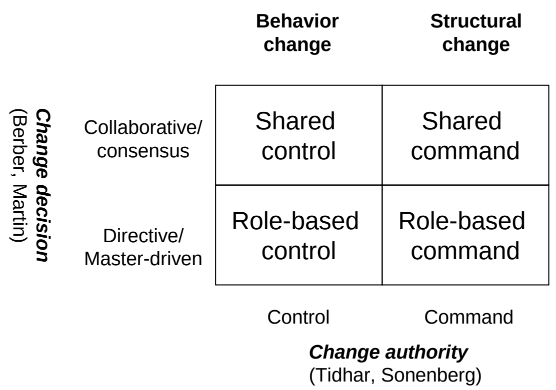

Figure 1: *Dimensions of change.*

In directive situations, agents enacting directive roles (or *directors*), must be able to monitor and evaluate the overall behavior of the system, according to some success factors and determine what adaptation is required. The need for communications is reduced as the directive agent forms its decisions independently from the information it receives from others. The director communicates, or otherwise enforces, changes in interaction or behavior to the other agents, but can only assume that the others will in reality realize those changes (because it cannot access internal behavior and motivations leading other agents' actions).

In collaborative situations, all agents need high meta reasoning and communicative capabilities in order to assess changed situation, communicate with others about its observations, and negotiate how the group should adapt to it. The need for communications is high as change decisions can only be achieved by negotiation between all agents, which form their own decisions based on their own evaluation of the environment, possibly benefiting communications with the others.

4 Objectives for Simulation of Reorganization

In the previous sections we have brought forward a number of aspects and ideas that play a role in the reorganization of MAS. In this section we will explain how we use simulations to substantiate the theory.
First of all we have to point out that a theory on reorganization brings together a number of aspects on different levels of the MAS that cannot be studied all in the same simulation. Therefore we have to divide the process in a number of steps, each building on the previous one. The main complicating factor is that we assume that the behavior of an agent in a MAS does not only depend on its own internal state and the state of the environment, but that it also depends on the organizational structure of the MAS in which it operates. Important point is that we cannot assume the organization to be just another part of the environment, because it cannot be changed in the same way as other parts of the environment by a single agent (we recognize that this is not a very strict distinction, but the important part is that the organization does have a special status when we take into account explicit reorganizations).

The first step in the exploration of the reorganization process is thus to find out exactly what is the influence of the organization form on the behavior of the MAS in a certain environment. In order to make this more precise we have to indicate which are the elements of the organizational form that we consider.

Without claiming completeness, we consider the following aspects to be the most important ones:

- The type of goal of the organization. Is it a very simple, unrestrictive goal or a hard to achieve, very limiting goal.

- Which are the roles to be distinguished. I.e. how are the organizational goals divided over roles. In the extreme cases all agents play the same role or all play a different role.

- Related to the previous point is how the roles are instantiated with agents. How many agents play the same role.

- The interaction between the agents playing roles. This concerns both the interaction patterns (communication protocols) as well as role dependencies (does a role have power over resources, task allocation, etc. and can thus steer other roles).

Given a certain environment and agents with fixed capabilities we can use simulations with differently organized MAS to find out which of the organizations performs ”best” in such an environment. In such a way it will be possible to make a match between organizational form and type of environment. The research question here is thus ”Which type of organization structure performs best given a certain environment and organizational objectives?”

The next step in the exploration process is about the actual reorganization itself. In this step we want to find out how an organization should be reorganized from one form to another to best suit an environment that changed (drastically). So, in this step we actually explore the possibilities for reorganization given in the previous section. Aspects that will be important here are how quick an organization can react to a changing environment and how big are the ”costs” of the reorganization. If a certain mechanism takes too much time the MAS might not recover in time to survive. On the other hand, the costs of a reorganization can be so big that it is better to quit the organization and start all over from scratch. The aim of this step is thus to evaluate the different possibilities for changing into a more adequate structure given a change of environment characteristics.

In the previous we assumed that all agents within the organization somehow will know that the environment changed and a certain type of reorganization has to be performed. In the last step we will look at cases where certain agents will discover that the environment changes and the reorganization has to be initiated through communication. This is a very typical scenario for crisis management in which teams of agents have to react to changing circumstances that are detected by one or more members of the team. Especially in this last step we will look at the reasoning and communication capabilities of the agents in the MAS and the influence this has on the reorganization possibilities.

In summary, the three steps in the reorganization simulation process are as follows:

1. Identify the match of organizational structure or behavior to environment characteristics

2. Reorganization of system to adapt to (drastic) changes. Also, evaluate the advantages and disadvantages of structural and behavioral change, role-directed or collaborative.

3. Investigate the communicative requirements to reason about change. Also, evaluate the influence of reasoning with limited knowledge.

5 Initial Simulation Setup

As described in the previous section, the aim of our research is to develop a simulation tool that enables the study of the effects of reorganization strategies on the performance of societies consisting of multiple agents. We are interested in investigating both the properties of systems that exhibit reorganization possibilities and the degree of complexity necessary to build agents that are able to reason about social reorganization. The development of the simulation game, VILLA, follows the three steps described in the previous section, and was further designed to meet the following requirements:

- The system must be simple enough to enable empirical evaluation of the results.

- The system must be complex enough to emulate situations where reorganization really matters.

VILLA simulates a community inhabited by number of Creatures, divided into three groups: the Gatherers, the Hunters, and the Others. The unique goal of the community is to survive. All creatures must eat in order to survive. When creatures don’t eat, their health decreases, until health is 0, when they die. Gatherers and Hunters are responsible to keep the food stack supplied. Gatherers and Hunters should eat more than Others to allow for the effort of collect food. Furthermore, the health of Gatherers and Hunters determines how much food they can collect.

That is, the healthier a Hunter or Gatherer is the more food it can collect. However, food collection is not always guaranteed and Gatherers or Hunters may only sporadically be successful. The probability of success of Gatherers is higher than that of Hunters. On the other hand, when successful, Hunters can collect more food than Gatherers. Gatherers find food on their own but Hunters must hunt in groups (two or more). Therefore, Hunters must be able to move in order to find other Hunters with whom they can hunt. The hunting capability increases with the size of the group. Other Creatures can be seen as the elderly and children of the society, they only eat and are not in state of contributing to the food collection effort. Formally, a VILLA community can be defined as:

$Villa = \{C, G, H, FS, F0, E, T, mE, ME, R\}$, where:

- $C = \{c : c = (\{health, food-intake\}, \{eat\}, \{O(eat|food > 0)\})\}$, are the creatures. The obligation indicates that all creatures must eat if there is food available.
- $G \subseteq C, G = \{g : g = (\{health, foodintake, gatherpower, gather-probability\}, \{eat, gather\}, \{t < E, O(g, gather(g, t))\}\}$, is the subset of Gatherers. The obligation indicates that gatherers are obliged to gather food in each run. How much food is gathered is a function of its gather-power and the gather probability.
- $H \subseteq C, H \cap G = \oslash, H = \{h : h = (\{health, foodintake, hunt-power, position\}, \{eat, gather, observe, move\}, \{t < E, O(h, hunt \vee move))\}\}$, is the subset of creatures that can hunt food. The obligation indicates that hunters are obliged either to hunt or to move in each run. How much food is hunted is a function of the number of Hunters in a group, and the combined gather-power and gather probability.
- $FS = (\{food\}, \{\}, \{\})$ is the food stack agent, describing the amount of food available at any moment
- $F_0 \in Int$, is the value of the initial food stack
- $E \in Int$, is the number of runs
- $T \in Int$, is the number of ticks per run
- $m_E \in Int, m_E =< num(C)$, minimal number of creatures at time E
- $M_E \in Int$, maximal amount of food at time
- $R = \{r1, r2, r3, \}$ are the society rules, defined as follows

R1 $\forall c \in C, \forall i \leq E, eat(c, i) \rightarrow food(i) = food(i-1) - foodintake(c)$

R2 $\forall g \in G, \forall i \leq E, gather(g, i) \rightarrow food(i) = food(i-1) + gatherpower(g, t) \times gather-probability(g, t)$

R3 $hunt-group(p) = h_1, , h_n \leftrightarrow \forall h_x, h_y \in p, adjacentposition(h_x, h_y)$

R4 $\forall p : huntgroup, \forall i \leq E, hunt(p, i) \rightarrow food(i) = food(i-1) + hunters(p) \times ((hunt-power(h, t) \times huntprobability(h, t))$

R5 $\forall c \in C, (food(i) = 0) \rightarrow eat(c, i)$

R6 $\forall c \in C, noteat(c, i) \rightarrow health(c, i) = health(c, i-1) - 1$

R7 $\forall c \in C, health(c, i) = 0 \rightarrow dead(c)$

R8 $\forall g \in G, \forall i \leq E, gatherpower(g, i) = f(health(g, i))$
(i.e. gatherpower is a function of health)

R9 $\forall h \in H, \forall i \leq E, hunt$
$int - power(h, i) = f(health(h, i))$
(i.e. huntpower is a function of health)

R10 $\forall h \in H, \forall i \leq E, move(h, i) \rightarrow position(h, i) \neq position(h, i-1)$

R11 $\forall c \in C, dead(c) \rightarrow num(C) = num(C) - 1$

R12 $success(village, R) \rightarrow num(C, R) \geq m_R \wedge food(R) =< M_R$

The VILLA simulation game consists of a fixed number of runs. During each run, Gatherers and Hunters will gather food, and as many Creatures will eat as the food stack allows. Each run consists of a number of 'ticks'. Each agent can use each tick either to act or to reason (not both simultaneously). The objective is to have as many as possible creatures surviving at as low possible cost. [1] We have implemented the VILLA simulation game using the RePast simulation environment (Collier, 2003).

[1] In a possible future extension, the success probability of hunt-groups can be made to increase/decrease in function of the individual probabilities (good hunters together have more chance than bad hunters together).

5.1 Simulation without reorganization

The specification above describes the basic simulation setting. In this simple version without reorganization, simulation starts with a fixed number of creatures of the three groups and a initial amount of available food (possibly 0). In each step of the simulation, all Creatures eat, Gatherers and Hunters try to catch some food to replenish the common food stack. Furthermore, Hunters need to move around the field in order to became adjacent to other hunters and therefore be able to hunt. All other agents (Gatherers and Others) either gather food and/or eat in their own block.

Figure 2 shows the initial settings of the simulation. Since Hunters can only start hunting after they have found at least another hunter, it is easy to see that in the first runs of the simulation only Gatherers are able of providing food to the community's stack, while all creatures are eating. Without reorganization, the chances of survival of the community are dependent on the initial food stack and on the probability of Gatherers to find food. In this situation, the community needs 40 units of food per step, and if only the Gatherers are collecting food in average only 18 units are collected per step [2]. This setting is thus an example of a organization structure with low utility given the aim of survival of as many Creatures as possible, By setting up many different possible organizational settings (e.g. varying number of Creatures, Gatherers and Hunters, collect probabilities and collect power, and initial food stack) we can empirically evaluate which organization is more successful given an environment situation.

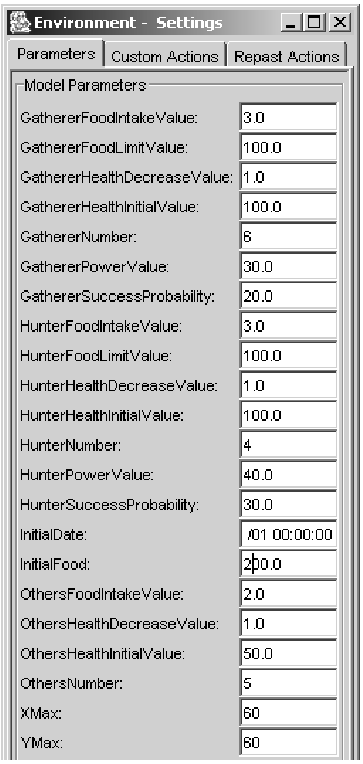

Figure 2: *Initial simulation settings.*

In the example above, reorganization decisions should lead to the determination that if the food stack decreases below a certain amount, then, for example, either the Gatherers should be able to gather more food (behavioral reorganization) or some of the Others or of the Hunters should be given Gatherer capabilities in order to increase the number of Gatherers (structural reorganization). In the following section, we describe how we have extended the simulation environment to simulate such reorganization strategies.

5.2 Reorganization Simulation

In the VILLA simulation scenario, the utility of the organization is described by the success of the community to survive. That is, a successful VILLA community is that which makes possible for as many as possible creatures to survive with as high as possible health. In order to be successful, communities must make sure that at any step there is enough food in the common food stack to feed the whole group. This can be influenced in several ways, e.g., either more food is collected (by augmenting the power of collection of Hunters and/or Gatherers, or by having more creatures hunting and/or gathering) or less food in consumed (in which case health still decreases but slower than when there is no food at all) Our objective is to use the reorganization environment described above to implement the 4 reorganization strategies described in section 3, as follows:

1. **VILLA1 - Role-based control**: a new role (the community Head) is introduced that can evaluate the overall utility of the society at any time and decide on behavior alterations for the next run (that is, food-intake and gather-power can be changed, number of creatures, and gatherers remains fixed)

2. **VILLA2 - Role-based command**: the role Head is introduced, as VILLA1, which can decide, based on its evaluation of the society utility, to increase or decrease the number of hunters

[2] Since hunters must hunt in groups and thus first have to find each other, in the beginning hunters will not be collecting no food.

and/or gatherers, by giving some of the other creatures Hunter or Gatherer capabilities in order to increase the number of Hunters and/or Gatherers.

3. **VILLA3 - Shared control**: Gatherers, Hunters and Others must all be able to evaluate the overall health of the society and communicate their solution to the others. A agreement strategy must be chosen using a (fixed) negotiation strategy (i.e. majority, unanimity). Decisions involve behavior changes (that is, food-intake and gather-power)

4. **VILLA4 - Shared command**: as VILLA3 all roles must be able to evaluate the society utility and achieve by common agreement a reorganization decision, involving structural change, that is, about increase or decrease the number of Hunters and/or Gatherers, by changing the capabilities of other creatures.

The current version of the simulation environment enables the user first to determine the change authority (shared or role-based) and then the focus of the reorganization (behavior or structure). For role-based reorganization strategies a new role is added to the community, that of Head, which is responsible to reason about the performance of the community and implement the required reorganization actions. In shared reorganization strategies, all roles must be extended to incorporate reasoning about the performance and the capabilities to modify the community. The current version of the tool supports the reorganization strategies VILLA1 and VILLA2. The shared reorganization options VILLA3 and VILLA4 are currently under construction.

In the case of a behavior-based reorganization, the user can describe which parameters should trigger the reasoning (e.g health or food stack are below a certain value) and what changes of behavior should be triggered (e.g increase collect power, decrease food intake). The reorganization settings window for this case is depicted in figure 3. In the same way, the user can also determine the triggers and effects (e.g increase/decrease the number of Gatherers or Hunters) of a structure-based reorganization simulation. The reorganization settings window for this case is described in figure 4.

In total, the simulation environment will implement different reorganization strategies. The following, are a few possibilities we consider for the reasoning capabilities on the different versions:

- In the case of role-based decision situations (VILLA1, VILLA2), different reasoning strategies are possible, depending on what the Head can observe. If the Head has total information and is endowed of algorithms that determine the optimal organization structure given a certain environment, the Head can achieve optimal decision. However, in more realistic situations, the Head has neither complete information nor complete knowledge.

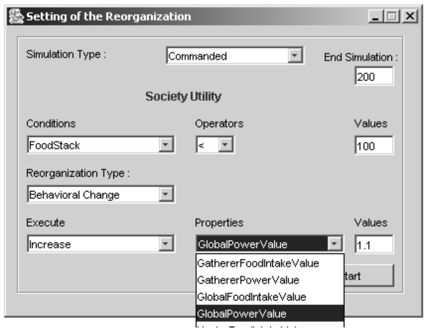

Figure 3: *Parameters for behavior-based reorganization.*

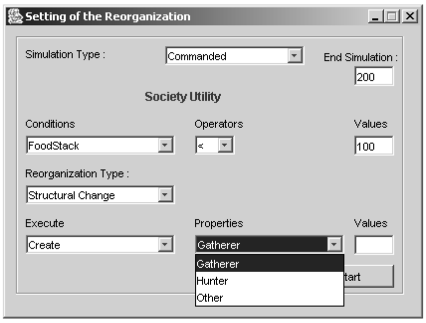

Figure 4: *Parameters for structure-based reorganization.*

- In shared decision situations (VILLA3, VILLA4) all agents have only knowledge about themselves. Different versions will include cooperative agents (comply to change requests from others) or uncooperative ones, or mixed.

- In structural reorganization strategies, Others can be asked to become Hunters or Gatherers, Hunters can become Gatherers (e.g. if hunt-probability very low, or unable to join a hunt group), and Gatherers can become Hunters (e.g. if adjacent to a high probability hunt-group).

We are currently implementing the settings to enable the above experimentations. In this work we concentrate on the effects of the reorganization strategy, in terms of effectiveness (how well does the decision achieve its aims), complexity (both of the reasoning process of agents and of the communication needs), and timeliness (how long does it take to reach a reorganization decision).

5.3 Evaluation of the VILLA Environment

We are currently setting up the empirical experimentation that will allow for the rigorous evaluation of the different reorganization strategies described above, and how they compare to the situation where no reorganization occurs. No statistical significant results are as yet available, but we already present a few examples of simulation runs that show the different behaviors related to the reorganization strategy chosen. All examples have a length of 200 runs and start from the same initial settings: 17 creatures (6 Gatherers, 6 Hunters, 5 Others) with 50% initial health; Gatherers have a success probability of 9% with gather power of 20 and Hunters have a success probability of 10% with gather power of 30; total food needed in each run is 58 4 units for each gatherer or hunter and 2 units for others; initial food stack is 500 units. Each Gath-

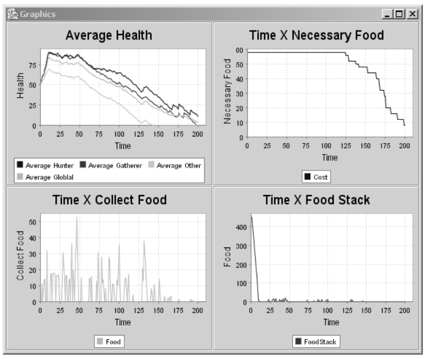

Figure 5: *Simulation with no reorganization.*

erer will collect 2,7 units in average and each Hunter 3 units (increased by the size of the hunting group). While Hunters are not hunting, the average collected food is thus 16.4 units. That is, even if Hunters start hunting, the community will most likely have trouble collecting enough food to keep all creatures healthy and alive. Figure 5 refers to the simulation with no reorganization. As expected, this community was not able to keep all creatures alive, and after consuming the initial food stack, they were hardly able to keep any food reserves. All creatures were dead by the end of the 200 runs.

The first reorganization example concerns a behavioral reorganization. In this case, depicted in figure 6, when the food stack drops below 250 units, the Head will increase the gather power of Gatherers by 1. In this way, the community manages to keep healthy and maintain food reserves. However, because food stack stayed under 250 for many runs, the gather power increased from the initial 20 to almost 100, which can be argued to be not very realistic. Figures 7 and 8 re-

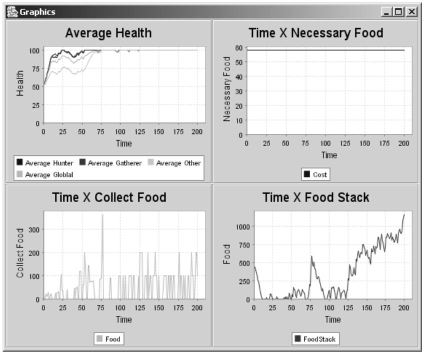

Figure 6: *Behavioral reorganization: Gather power increases by 1 if food stack reaches below 250.*

fer to structural reorganization strategies. In the simulation depicted in figure 7, if the food stack drops below 250 units, then a Gatherer was added (that is, an Other creature was given Gatherer capabilities), while in the simulation depicted in figure 7 a Hunter was added. In both cases food needs per run increase to 68 units, due to the fact that collecting creatures need more food that Others. In the case Gatherers were added, the average collecting power of all 11 gatherers is 30 and therefore not enough to keep the community alive, but still better in average than the case of no reorganization. In the second case, Hunters were added. Because there are more Hunters in the field, the probability they find each other increases, as in the case depicted. Once Hunters start collecting food, because of their larger power and higher collecting probability, in average more food will be collected and as such the community survives. In situations were Hunters do not manage to find each other, the behavior of the simulations tends to resemble the no reorganization case.

6 CONCLUSIONS

Reorganization of the structure of an organization is a crucial issue in multi-agent systems that operate in an open, dynamic environment. In this paper, we presented a classification of reorganization types which considers two layers of reorganization: behavioral and structural. We further described how simulations

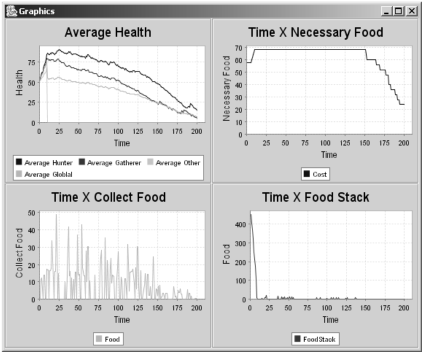

Figure 7: *Structural reorganization: Gatherer added if food stack reaches below 250.*

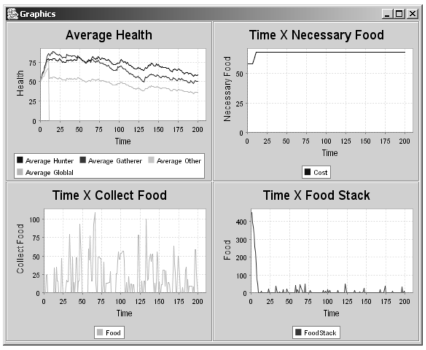

Figure 8: *Structural reorganization: Hunter added if food stack reaches below 250.*

can help to determine whether and how reorganization should take place. Finally, we presented current work on the development of a simulation scenario that is used to evaluate the different reorganization forms.

Our current research on the development of a simulation tool for reorganization experimentation will enable to identify conditions and requirements for change, ways to incorporate changes in (running) systems, how to determine when and what change is needed, and how to communicate about changes. We are currently setting up empirical experimentations to this effect. Another important future research direction (following the simulation work), is the development of conceptual formal models that enable the specification of dynamic reorganization of agent societies.

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