

Exploring congruence between organizational structure and task performance: a simulation approach

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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. Ideally, 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 describe how simulation studies could help to determine whether and how reorganization should take place, and present a simulation scenario that can be used to evaluate the congruence, or fit, between organizational structure and task performance. Preliminary results using a simulation environment illustrate how one can explore triggers for reorganization and compare strategies.

1 Introduction

Establishing an organizational structure that specifies how agents in a system should work together helps the achievement of effective coordination in Multi-Agent Systems (MAS) [1]. 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). The structure of an agent organization significantly influences its performance characteristics {in different environments and on different tasks [16].

Environments in which MAS 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. In addition, organizational objectives can change, or operational behavior can evolve. Models for MAS must therefore not only cater for adaptive agents [17] but also be able to describe organizations that can adapt dynamically to changes in the environment or to accommodate changes in the organizational objective(s) [7]. We are interested in mechanisms for an organization to evaluate its own "health" (i.e.

success and other utility parameters) and to action to preserve or recover it, by performing suitable integration and reconfiguration actions.

Many applications require a set of agents that are individually autonomous (in the sense that each cognitive agent determines its actions based on its own state and the state of the environment, without explicit external command), but corporately structured. As such, there is a growing recognition that a combination of structure and autonomy is often necessary. More realistic models for the simulation of organizations should also be based on cognitive agents. In fact, greater cognitive realism in social simulations may make significant differences in terms of organizational performance. [21] present a study showing that different combinations of social structure and individual cognition level influence organizational performance. In this work we do not address these key issues of the interplay between individual autonomy and the pursuit of organizational goals. Rather we focus at the organizational level, in particular at aspects of how and why organizations should seek to restructure.

In [7], we discussed different types and motivations for reorganization and the consequences for MAS models of enabling dynamic reorganization at different complexity levels. We also described an abstract framework for classifying reorganization and discussed how simulations could be used to discover some properties of the reorganization process. Here we build on that framework, to draw from a discussion of related literature from the study of adaptability in human organizations, to make more precise some elements of that framework, and also to present some initial illustrations of working with a simulation [8] to tease out relevant characteristics of organizational adaptation.

The paper is structured as follows. In section 2 we discussed organizational frameworks. Organizational change is discussed in section 3 and motivations for the use of simulations to study reorganization are presented in section 4. Section 5 introduces the VILLA simulation tool which use on the exploration of reorganization strategies is discussed in section 6. Conclusions are presented in section 7.

2 An Organizational Framework

In the remainder of this paper, we assume a basic organizational model containing roles, agents and interactions [7].

- *Organizational structure* consists of roles, their relationships and pre-defined (abstract) interaction patterns. Organizational structure must reflect and implement the global objectives of the organization. *Roles* are characterized by their properties, objectives and norms. Role objectives are determined by the global aims of the organization and determine possible dependencies between different roles. Roles describe classes of agents, their activities, and possibly their norms and behavior rules. Roles are related to other roles by *dependency relations*. Desired *interaction patterns* between roles can be specified.
- An agent participates in the organization (system) by playing one or more roles. Role enactment is achieved either by allocation by the system developers that determine which available agent is the most adequate for a task, or is decided by the agents themselves. In both cases, analysis techniques are needed to support en-

actment decision, which compare and evaluate different role allocations [19]. The set of agents that at a given moment is active in an organization is called the *population*. An agent population achieves the animation of organizational structures.

- *Interaction* between different agents realizes the organizational objectives. Activities in a society are the composition of multiple, distinct and possibly concurrent interactions, involving different agents, playing different roles. Actual interactions form the *behavior* of the organization.

Even though not all MAS models recognize explicitly these concepts, we feel that by raising these concepts to the status of first-class modeling entities [18], we allow for the specification of open systems, and can describe both emergent and designed organizations. Similar modeling approaches have been advocated in [6, 13, 23].

2.1 The Agent Society

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 or the organizational goals. 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, utility must be able to be evaluated differently from the perspectives of the organization and of the agents. Here we focus on the organizational level:

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

- *Goal Success*: how well are global objectives met?
- *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. Organizational 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 [14].

3 Organizational Change

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 are concerned with the change of the *behavior* of the organization. That is reorganization affects the current population of agents in the system, both at the social (i.e. interactions and relationships) [2], as well as individual level [15]. 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 [20]. Another common approach is dynamic participation, in which agent interaction with the organization is modeled as the enactment of some roles, and adaptation occurs as agent move in and out of those roles [3, 6, 14, 22]. However, few of these systems allow agents to change the problem-solving framework of the system itself [1]. Basically, reorganization is a response to two different stimuli: a reaction to (local) changes in the environment, or as the means to implement modified overall intentions or strategies. Based on the above considerations, we have separated out [7, 8] the following reorganization aspects¹:

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, when they change between existing roles, 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 dimension of the reorganization problem, concerns the ways the reorganization decision is taken, i.e. who has the authority to take a decision to reorganize, and how the decision is conveyed and implemented. For example, in distributed decision-making situations it may be that all roles are collectively responsible for a change decision, whereas in other situations (for example those typified by military structures as C3 [23] (Command, Control and Communications) different roles may have authority to effect changes at different levels. Furthermore, reorganization decisions can be evaluated in terms of timing (reactive or proactive) and intention (defen-

¹ Elsewhere we will seek to make more precise these categorizations, but for now we leave them as informally presented.

sive or offensive) [12]. Together, these considerations form the 5 W's of reorganization, as follows:

What - the aspects of an organization that are to be reorganized.

- Behavior: change of the individual characteristics of the current population, as a response to environment changes
- Structure: change of the global characteristics of the organization, as a response to change of intent or strategy

Who - authority to take reorganization decisions, how decisions are taken:

- Directive, role-based decision making
- Collaborative, consensus-based decision making

When - the timing, when should the reorganization occur:

- Proactive, preparing in advance for an unpredictable future change
- Reactive, making adjustments after an event has occurred

Why - The strategic reasons for reorganization

- Offensive, aiming at gaining competitive advantage
- Defensive, aiming at organizational survival

Whether - the threshold for reorganization, when is the fit so bad that reorganization is likely to be beneficial

- High threshold, stability is seen as more desirable than flexibility
- Low threshold, flexibility is seen as more desirable than stability

4 Towards a Useful Simulation for Reorganization

In the previous sections we have outlined a number of aspects and ideas that play a role in the reorganization of MAS. In this section we wish to explain how we see the use of simulations to substantiate the theory. To motivate the discussion we draw on some recent research in the investigation of organizational restructuring in human organizations [5, 10] to assist in identifying aspects of organizational structuring that need to be made explicit in the design of organizational adaptation. Our interest in drawing on research in human organizations is twofold: first we look to draw on general organizational principles that may apply to artificial as well as human organizations; second, we are ultimately interested in being able to build hybrid human-agent networks, and so staying within the bounds of organizational properties that have some analogue in human behavior seems desirable.

In human settings, organizational performance has been demonstrated empirically to be associated with the degree of congruence (or 'fit') between organizational structure and properties of the task or environment [9]. Accordingly, it is to an organization's advantage to monitor the fit between its structure and mission, and to alter its structure when a misfit is identified. There is empirical evidence that high performing organizations can discern when environmental forces have changed the state of congruence (i.e., the goodness of fit), thus driving changes in the strategies (e.g., communication patterns, back-up behaviors) that they employ [11]. Rarely, however, do human organizations make changes to their organizational structures (i.e., asset allocation, team member roles and responsibilities) in order to facilitate congruence and some, at least, of the explanation for this relates to the characteristics of human be-

havior which is not necessarily replicated in artificial organizations. However, we believe there are aspects of human organizational adaptation from which lessons can be drawn for the design of mechanisms for the adaptability of artificial organizations. In particular we are interested to understand what can be identified from human organizational behavior about the triggers for reorganization, and strategies for implementation. Of special interest is being able to surface *explicitly* the kinds of knowledge that needs to be considered when making reorganization decisions.

Of note is the extensive empirical work of the Aptima group www.aptima.com on organizational adaptation in military settings. They have manipulated experimental conditions to explore degradation of organizational performance in a fine-grained way monitoring the nature and quantity of communication, and perceived workload of individuals, as well as measures of task performance [5, 10]. They were seeking to identify how organizations coped with incongruence, and in particular sought to identify the conditions that might be salient enough to cause organizations to alter not only their strategies, but also their structures. Their data pointed toward a set of indicators that have the potential to yield diagnostic information regarding congruence early in a mission scenario, including: performance measures (composite variables such as mission tasks processed, latency, and accuracy), team coordination processes (e.g., communication patterns), and workload levels (e.g., subjective assessments).

Now let us turn to consider the implications of these observations for the design of simulation settings in which (artificial) organizational redesign can be investigated. Here, we must 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 into 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. Importantly, 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 the elements of the organizational form that we consider. Without claiming completeness, we consider the following aspects to be the most important ones²:

- 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.

² As noted above, we do not consider yet the important interplay between organizational form, agent cognitive capability, and organizational performance, cf. [21].

- 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 organizations 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. 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: Exploration of organizational adaptation requires not only that we have an explicit representation Ω of the set of available organization types, ω , and some measure of organizational utility, but we also need to represent:

1. organizational performance (with respect to a goal, and measured over time);
2. a set Γ of change indicators γ , i.e. potential triggers for organizational restructure, these will relate to observable suboptimal or degraded organizational performance, and are likely highly context dependent, cf. [5];
3. a mapping $\mu: \omega \rightarrow \omega'$ between organization types that provides a recipe for reorganization; and
4. a cost function $f(\omega, \omega')$ that computes the cost of implementing the reorganization.

Then organizational adaptation should occur when the performance falls below some acceptable level, and/or some trigger condition is activated. The trigger condition likely takes into account a performance trajectory over time, as part of the context, and not just an instantaneous snapshot. The choice of structure for the new organization should take into account the expected increase in organizational utility, and discount for the cost of change.

Ultimately we would seek to encode such dynamism explicitly as part of organizational definition. For now, we seek to simulate various alternate conditions and understand the tradeoffs between structure and performance, given different environmental conditions. In the next section we discuss an initial attempt to develop a simulation tool that on the one hand is simple enough to be controllable and interpretable, and on the other hand is complex enough to allow rich parameter variation and the exhibition of interesting behaviors.

5 Discovering Conditions for Reorganization

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. In order to simulate real-life organizations it is first necessary to find out which are the most important parameters and measurements. For this purpose we have developed a simulation game, VILLA, representing a simple society. The VILLA environment is described in more detail in section 5.1.

5.1 The VILLA Simulation Environment

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: (1) be simple enough to enable empirical evaluation of the results, but (2) be complex enough to emulate situations where reorganization really matters. VILLA has been described in [8]. For the ease of understanding the remainder of this paper, we will describe here the main features of VILLA. VILLA simulates a society inhabited by number of Creatures, divided into three groups: the Gatherers, the Hunters, and the Others. The unique goal of the society is to survive. All creatures must eat in order to survive. When creatures don't eat, their health decreases. If the health reaches zero, 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. 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 VILLA environment is represented by a grid of cells with same size.

The definition of VILLA implements Ω , the explicit representation of organization types discussed in section 4 and assuming the role-based model described in section 2³. Formally, a VILLA society can be defined as follows:

$Villa = \{E; T; S; C; G; H; FS; F_0; m_E; M_E; R\}$, where:

- $E \subseteq \mathcal{N}$, $|E|$ is the number of runs.
- $T \subseteq \mathcal{N}$, $|T|$ is the number of ticks per run.
- $S \subseteq \mathcal{N} \times \mathcal{N}$, is the size of the grid.
- $O = \{(Ro_c, Ro_g, Ro_h)\}$ are the obligation rules of agent role.
- $C = \{c : c = (\{health; food\ intake\}; \{eat\}; \{Ro_c\})\}$, are the creatures (i.e. the set of agents fulfilling the creature role c).
- $G = \{g : g = (\{health, food\ intake, gather\ power, gather\ probability\}; \{eat, gather\}; \{Ro_g\})\}$, is the subset of Gatherers (i.e. the set of agents fulfilling the gatherer role g).
- $H = \{h : h = (\{health, food\ intake, hunt\ power, hunter\ probability, position\}, \{eat, gather, observe, move\}, \{Ro_h\})\}$, is the subset of Hunters (i.e. the set of agents fulfilling the hunter role h).
- $G \subseteq C, H \subseteq C, H \cap G = \emptyset$
- $Pt = \{P_1, P_2, \dots, P_n\}$ is a set of group of hunters.
- $Ps \in Pt = \{h_1, \dots, h_n\} \leftrightarrow \forall h_x, h_y \in Ps, adjacent\text{-}position(h_x, h_y)$. $|Ps| \in \mathcal{N}$, is the number of hunters of Ps .
- $FS = (\{food\}, \{\}, \{\})$ is the food stack role, describing the amount of food available at any moment.
- $F_0 \in \text{Int}$, is the value of the initial food stack.
- $m_E \in \mathcal{N}, m_E = \lfloor |C| \rfloor$, minimal number of creatures at a run E .

$R = \{r1; r2; r3, \dots; r11\}$ are the society rules, defined as follows:

R1: $\forall c \in C, i \in E, t \in T \text{ eat}(c, t) \rightarrow food(i) = food(i) - foodintake(c)$

R2: $\forall g \in G, i \in E, t \in T, gather(g, t) \rightarrow food(i) = food(i) + gatherpower(g, t) \times gatherprobability(g, t)$

R3: $\forall h \in H, \exists P \in Pt, h \in P, i \in E, t \in T, hunt(h, t) \rightarrow food(i) = food(i) + |P| * (\sum(huntpower(h, t) \times huntprobability(h, t)) \text{ (or a similar function on the number of hunters in group)})$

R4: $\forall c \in C, i \in E, t \in T, (food(i) \neq 0) \rightarrow eat(c, t)$

R5: $\forall c \in C, i \in E, t \in T, \neg eat(c, t) \rightarrow health(c, i) = health(c, i) - 1$

R6: $\forall c \in C, i \in E, (health(c, i) = 0) \rightarrow dead(c)$

R7: $\forall g \in G, i \in E, gatherpower(g, i) = f(health(g, i))$ i.e. *gatherpower is a function of health*

R8: $\forall h \in H, i \in E, hunt\text{-}power(h, i) = f(health(h, i))$ i.e. *huntpower is a function of health*

R9: $\forall h \in H, i \in E, t \in T, t > 0, move(h, t) \rightarrow position(h, t) \neq position(h, t-1)$

³ In VILLA roles are defined as $Role = \{Properties; Objectives; Norms\}$

R10: $\forall c \in C \text{ dead}(c) \rightarrow |C| = |C| - 1$

R11: $i = |E|$, $\text{success}(\text{village}, i) \leftrightarrow |C| \geq m_i$

The following rules are obligations of the agents:

Ro_c: $\forall c \in C, t \in T, i \in E, t < |T|, \text{food}(i) \neq 0 \rightarrow \text{eat}(c, t)$; creatures must eat in each tick.

Ro_g: $\forall g \in G, t \in T, i \in E, t < |T|, \text{food}(i) \neq 0 \rightarrow \text{gather}(g, t)$; gathers must gather food in each tick.

Ro_h: $\forall h \in H, t \in T, i \in E, t < |T|, \text{food}(i) \neq 0 \rightarrow \text{hunt}(h, t) \vee \text{move}(h, t)$; hunters are obliged to hunt or move in each tick.

Informally, the goal of VILLA can be described as to have as many as possible creatures surviving at as low possible cost. In each run, all Creatures eat, as long as there is enough food; 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 get together with other hunters and therefore be able to hunt. All other agents (Gatherers and Others) either gather food and/or eat in their own block. Rule R11 describes the success factors of VILLA. At this stage, we only consider *goal success* (cf. section 2.1) as a measure of success, which in VILLA is strongly related to *role success*. Due to the simplicity of interactions in VILLA, we do not consider yet *interaction success*. *Structure success* will be the object of the extension of VILLA discussed in section 6, where we will look at the appropriateness of different reorganization strategies. We have implemented the VILLA simulation game using the RePast simulation environment [4]. VILLA is a very simple organization, and can hardly be taken as a representation of realistic situation. However, we have found it useful to start with a simple artificial organization in order to keep the complexity in hand and as such be able to identify conditions for reorganization, as described in the next section 5.2. In the next steps of this project, we will move into more realistic situations.

5.2 Using simulation in the identification of reorganization conditions

As discussed before, the first step in the exploration of the reorganization process is to find out 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 elements of the organizational form we need to consider. The representation in VILLA of the aspects presented in section 4:

- Organizational Goal: survival.
- Organizational Roles: Gatherers, Hunters and Others.
- Agents: in each simulation, different numbers of agents can play VILLA roles. At this stage of development, agents are not cognitive entities, but are limited to reproduce the behavior described in the role specification
- Interaction: Interaction occurs through sharing of resources (the food stack and the area of movement)

We have simulated different organizational settings (varying the amount of initial food, food collection probabilities, the number of agents per role, and the capabilities of roles) in order to find out which of the organizations performs "best" in that environment. Assuming the amount of initial food and the food collection probabilities as

a representation of the 'hardship' of a certain environment, the aim of the simulation is to find out which type of population is the most appropriate for each environment. The availability of such a match between environment characteristics and successful organizational types, makes dynamic adaptation possible by giving agents the heuristics to determine which is the best structure for given environment conditions. For this effect, VILLA was run using the version without reorganization. Basically the experiment consisted of running simulations, each with the same initial environment setup, and variable organization setups: role combinations (only one type, different types,...), number of agents per role, and role capabilities (catch power, eating power,...).

Society Typologies Society typology (types of roles and numbers of agents per role) can be seen as a simple way to describe an organization structure, abstracting from interaction forms and role dependencies. Our first study was to analyze the influence of agent distribution to the success of a society. For this effect, we simulated several societies where reorganization was not available, fixing the all society parameters except for the number of agents per role, which was different for each simulation. Figure 1 gives an overview of the results of simulations with different configurations, for simulations with a length of 500 runs and a total of 117 agents.

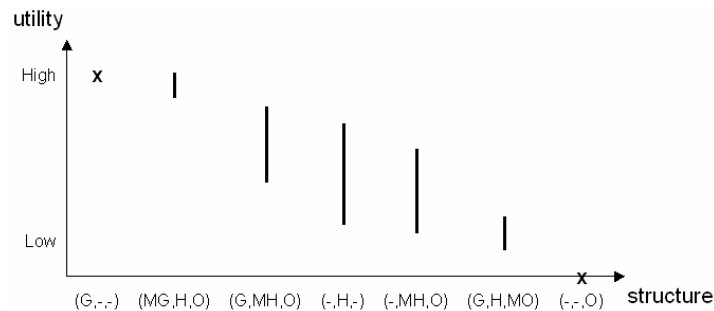


Fig. 1. Success of different society typologies. Legend: typologies are given as (Gatherer,Hunter, Other). A M before the role indicates a majority of that type

The large difference in utility of the different settings involving Hunters, can be attributed to the fact that Hunters must hunt in groups and are therefore dependent on the chance of finding other Hunters. Gatherers are the stable factor on collecting food, even if by design their catch power is lower than that of Gatherers. Actually, the simulation tool demonstrates that in societies with only Gatherers the chances of survival depend on the initial food stack and on the gather probability. More realistic settings, with still a higher chance of survival, are those where there is a majority of Gatherers. It can also be seen that Others are mainly a burden for the society since they only eat. Their function is their capability to assume other roles, during society reorganization, as will be discussed in the next section. The simulations showed that a society could reach equilibrium with the existence of all three roles.

Environment conditions Besides its typology, the success of a society depends on the conditions of the environment. In VILLA, the hardship of an environment is represented by a low probability of collecting food. Easy, friendly environments have

high food collection probabilities. Furthermore, large environments make it more difficult for Hunters to find each other and as such, the ratio between number of Hunters and grid size can be also interpreted as an indication of the difficulty of an environment. We have performed a large number of simulations, varying on the size of the grid, the number of agents and the food collection probabilities. In these simulations the society typology was fixed (7 Gatherers, 6 Hunters and 4 Others). Due to lack of space, we will not describe these simulations in detail. In general, given these setting, environments where Gather probability is higher than 15% result in healthier societies, independently of the capabilities of the Hunters and the size of the grid. It should be evident that given a fixed society typology, a larger grid will make it more difficult for Hunters to contribute to food collection, as it will be more difficult for them to form groups. Figure 2 shows an example of a healthy society on a grid of 60x60 that becomes bad on a grid of 120x120.

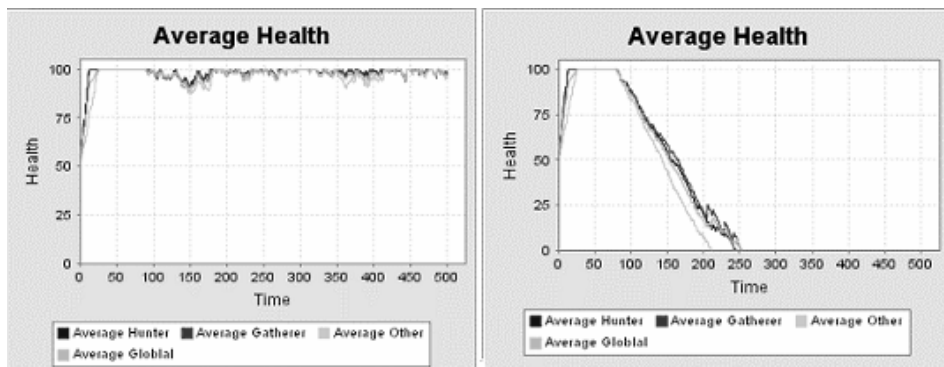


Fig. 2. Average health of typology (10,6,4). Left: 60x60 grid. Right: 120x120 grid

5.3 Discussion

The success of societies where no reorganization can occur is, as can be expected, highly dependent on the initial settings (environment conditions and typology).

An important factor for mixed societies (containing all different roles) to survive is the likelihood that Hunters will effectively be able to contribute to the food collection effort, which is dependent on their chances of forming groups. In the current version of VILLA, initial position of the agents and the movements of Hunters are randomly determined. A more realistic version should include the possibility for Hunters to actively search for partners, and possibly to learn from their earlier efforts.

The above experiments have enabled us to start to understand the conditions that indicate the need for reorganization of a society. By studying the results of many different simulations, several aspects have been identified that can be taken as candidate conditions for reorganization. In particular, we have studied food stack value, average food in a certain period of time, health of Others, and average health. In general, the food stack decreases drastically at the beginning of the simulation. To define it as a trigger for reorganization is useful because the reorganization process will be done early and the society will have time to adapt to the change. The same can be said

from the use of the average of food stack as a parameter for reorganization. Food stack average also decreases strongly, even if less drastically. In addition, we have used the overall average health and the average health of Others as possible triggers for reorganization. Finally, we have observed that measures for utility, or success, of an organization should not consider only one point in time, but look at the situation during a time interval. That is why average health seems to be more relevant as trigger for reorganization than the current value of the food stack.

As a side effect, the analysis of reorganization conditions leads us to understand that the status of the society should not be evaluated too soon after a reorganization trial. That is, it is necessary to allow for the reorganization to make effect before another trial is performed. This has been achieved by introducing a new parameter defining the delay of reorganization, which specifies a time interval that the simulator will wait to apply the reorganization rule again.

6 Simulating Reorganization

Our objective is to use the VILLA environment to implement different reorganization strategies. Based on the experiments described in the previous section, we have come up with a set of *change indicators* (cf. section 4) to be used as triggers for reorganization: amount of food in the stack, average food stack, average overall health, average Hunter health, average Gatherer health, and average Other health. So far, we have only considered the role-based decision making case (cf. section 3), in which one role has the capabilities to evaluate the current situation, and the power to order others to effectuate changes deemed necessary. To this effect, a new role is introduced, the society Head, that evaluates the overall state of the society, and decides on possible changes for the next run. VILLA implements the reorganization strategies discussed before as follows:

- **Behavioral change:** the Head can change the food intake and food collection power of creatures. Society typology remains fixed.
- **Structural change:** the village Head can order Others to enact the role of either Gatherer or Hunter, and as such change the society typology.

The simulation environment enables the user to indicate which reorganization strategy to be chosen, which condition the Head should use to determine the utility of the society at a given moment, and the reorganization action that the Head must take. The user can also indicate the length of the simulation.

6.1 Using VILLA to determine congruence

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. Initial statistical results are available, but lack of time has prevented us to present here the complete experiment¹⁰. The current experiment concerns the comparison of different reorganization strategies, given a fixed initial setting. We have performed 30 simulations (10 without reorganization, 10 following a behavioral adaptation strategy and 10 following a

structural adaptation strategy). Initial environment conditions and society typology were the same in all 30 simulations, as follows:

$Villa = \{C, G, H, FS, 200, 200, 1, 0, \alpha, 60 \times 60; Rules\}$, where:

- $C = \{c_1, \dots, c_{25} : c = (\{100, 2.0\}, \{eat\}, \dots)\}$
- $G = \{g_1, \dots, g_{10} : g = (\{100, 4.0, 20, 9\% \}, \{eat; gather\}, \dots)\}$
- $H = \{h_1, \dots, h_8, h = (\{100, 4.0, 30, 15\% \}, \{eat, gather, observe, move\}, \dots)\}$

The change indicator that triggers reorganization (both in the structural as in the behavioral case) is: $\gamma = (AverageHealth \leq 75)$. Reorganization attempts have a delay of 4 runs (that is, during 4 runs after a change no other reorganization attempt will happen). The mapping μ between organizations types, that provides the recipe for reorganization (cf. section 4) is for the behavioral case: γ then $g \in G$: $gatherpower(g) = gatherpower(g) + 3$; and, for the structural case: if γ then $\exists c \in C : c \notin G \wedge c \notin H \rightarrow G = G \cup \{c\}$

The comparison of the simulations is depicted in figure 3.

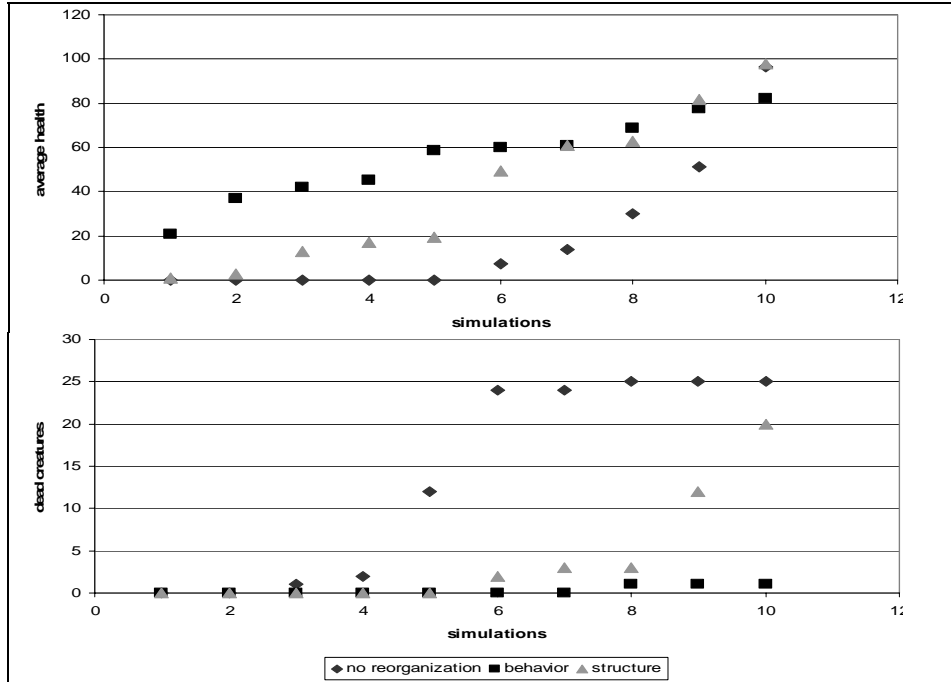


Fig. 3. Comparison of reorganization strategies

Both reorganization strategies are, as expected, better than no reorganization. This has to do with the initial setting. In this setting, Gatherers alone are not able to collect enough food to feed the whole group, a society without reorganization can only survive if Hunters manage to form groups and thus contribute to the food stack. This was also the case in the four best simulations without reorganization. From the results, it also appears that behavioral reorganization performs better than structural reorganization. However, this is for some part the consequence of the fact that no limit was set

to how much food a Gatherer can collect and thus *gatherpower* can increase for ever, which is of course a not very realistic situation. In the case of a structural reorganization, the number of new Gatherers is fixed by the number of available Others, and thus finite. Our next step is to introduce a limit to the amount of food that can be collected by a Gatherer. A final remark concerns the cost of reorganization. As discussed in section 4, the exploration of organizational adaptation, requires the definition of a function $f(\omega, \omega')$ that computes the cost of implementing the reorganization. So far, our experiments have not considered the cost of reorganization. This is again a reason for the less realistic results obtained and is an issue we are now implementing.

7 CONCLUSIONS

Reorganization 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 can help to determine whether and how reorganization should take place. We presented current work on the development of a simulation tool, VILLA that is used to evaluate the different reorganization forms. The aim of VILLA is to understand triggers for reorganization and evaluate different strategies and not to enable the dynamic adaptation of organization. As such, triggers and strategies are setup by the user. 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. 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. Furthermore, we also plan to simulate decentralized decision-making reorganization strategies.

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