

Hamelin:

A model for collective adaptation based on internal stimuli

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Abstract

Groups of rats confronted to an increasing difficulty to reach food organize themselves. The emergent organizational structure is characterized by a distribution of two different behavioral profiles among the rats. This specialization is stable, robust and presents adaptive properties.

Hamelin, the simulation system we propose is based on the coupling of two existing models: adaptive response thresholds and dominance relationships. It manages to reproduce the organization observed by biologists and presents some interesting adaptive properties. The originality of this model is that local internal needs (hunger) are distributed among the collectivity without an explicit global representation. The collectivity profits from individual adaptation abilities.

1. Introduction

Animal societies manage to organize themselves to face problems in their environment. The way they ensure a global coherence of the collectivity on the basis of individual decisions has attracted a lot of attention. A lot of studies have focused on collective behaviors (Bonabeau and Theraulaz, 1999) (Camazine et al., 2001) observed in several species: ant colonies (Deneubourg et al., 1990) (Corbara et al., 1993), social spiders (Dury et al., 2001) (Bourjot and Chevrier, 2001), fish schools (Reynolds, 1987) (Kunz and Hemelrijk, 2003), termites (Miramontes and DeSouza, 1996) or primates (Hemelrijk, 1996). Some principles at the root of some of those phenomena have been extracted, like for example the stigmergy principles (Grasse, 1959) which can explain various collective phenomena from the nest building of wasps or termites

(Bonabeau and Theraulaz, 1999) to the collective foraging behavior of ant colonies (Deneubourg et al., 1990).

An interesting collective phenomenon that can be observed in various species is the specialization behavior. Specialization is a way to assign different tasks to the animals belonging to a colony. These phenomena have been observed in various insects colonies like ants (Bonabeau and Theraulaz, 1999) or wasps (Theraulaz et al., 1990). Specialization have some specific assets. A specialized system in which tasks have already been assigned is supposed to be more efficient, because there is no need to reassign the tasks to agents, which can cost time and need a lot of communication. Moreover, specialized individuals can collect experience from the tasks they perform and thus, the overall performance of the system can be higher.

This paper focuses on task allocation and specialization observed in groups of rats when they have to face an increasing difficulty to reach food (Desor et al., 1991). Under certain conditions, a differentiation between individuals with same abilities can be observed and leads to a division of labor: some rats fetch food whereas other reach food by stealing it. The phenomenon of task allocation in insect societies has been modeled by a mechanism called response thresholds model (Bonabeau and Theraulaz, 1999) (Theraulaz et al., 1998). This model has been extended to explain the genesis of specialization and task allocation to a population of homogeneous individuals. However, it is based on an external stimulus which can be perceived by various individuals, whereas the phenomenon we have focused on is not characterized by external stimulus but by local internal stimuli: the hunger of the rats put in the system. We introduced in task allocation a second mechanism which can be observed in nature and which can explain how the differentiation can appear on the basis of these local stimuli.

This mechanism is a second model: self-organizing hierarchies. This kind of model which can be found in (Hemelrijk, 1996) (Hogeweg and Hesper, 1986) (Bonabeau et al., 1996) is wide-spread and has been used to explain some phenomena like coalition formation observed in primates group (Hemelrijk, 1996) which was at first attributed to high cognitive abilities.

The model we present in this paper consists in the coupling of response thresholds model with self-organizing hierarchies. It manages to reproduce the global phenomenon by organizing the society of rats according to a hierarchical structure. The task allocation is then made on the basis of this organization between individuals. A coupling of these two models has already been seen in literature (Theraulaz et al., 1990) but it relies on external stimuli. The originality of the coupling we propose is that its goal is to distribute internal stimuli among agents.

This paper presents in the first part the biological experiments that have been conducted in the behavioral neuroscience laboratory of Henri Poincare University of Nancy and explains why it can be described as an adaptive self-organized system. Then, it depicts the model we have developed and validates its conformity with respect to biological observations. The next part dwells on the properties such a complex system can exhibit and analyzes them. To conclude, we will propose an interpretation and few hints we are planning to follow in order to reuse mechanisms of this model for collective problems solving.

2. Biological phenomenon

2.1 Specialization experiment

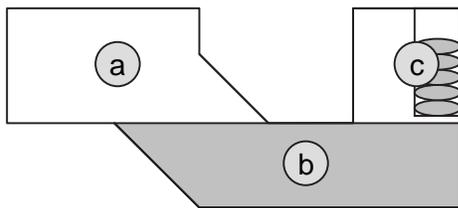


Figure 1: Environmental setup composed of a cage (a), an immersed corridor (b) and a feeder (c).

The diving-for-food situation can be considered as representative of an adaptive process for environmental exploitation by a group. It is a complex social task in which, for a group of 6 rats introduced in a specific environmental setup (Figure 1), the food accessibility is made difficult by the progressive immersion of the corridor, the only path of access to the feeder. This experimental schedule leads in a few days to the emergence of a differentiation characterized by two behavioral

profiles: (a) a carrier profile characterizing rats which dive into water and bring the food back to the cage, and (b) a non-carrier profile characterizing rats which never dive, but get food by stealing it from the carriers (Desor et al., 1991) (Desor and Toniolo, 1992). The social differentiation regularly occurs with the same respective proportions of carriers and non-carriers of about 50%. It remains stable for several months and has been observed in mice and rats, including Long-Evans, Wistar and Sprague-Dawley rat strains.

2.2 Other experiments

Other investigations have been undertaken to determine the characteristics of this process.

In these pharmacological experiments, a drug, the Diazepan, has been administered to 50% of the 6 rats introduced in the environmental setup (Schroeder et al., 1998). This drug has for direct consequence the decrease of the anxiety of drugged rats. Specialization still occurs in the system. The same profiles can be observed with qualitatively the same proportions. However, a more precise study highlights an over-representation of carrier rats in the drugged subgroup (80% of the rats), whereas at the same time, an over-representation of non-carrier rats (80%) in the non-drugged subgroup can be observed.

This lead biologists to two conclusions. The first one is that this experiment stressed upon the importance of anxiety toward water, which would lead the less anxious rats to dive first, and consequently be aggressed first by their more anxious conspecifics. The second one, is that it is the social environment of rats which determines the adopted profiles. It explains why, whereas the non-drugged rats have not suffered from any alteration, an over-representation of a specific profile (the non-carrier rat profile) is nevertheless present.

Finally, the introduction of rats that have already been specialized in previous experiments, lead to a re-differentiation. The social differentiation (profiles and sizes of groups) that occurs in this case is the same as the differentiation observed when the rats are undifferentiated at the beginning of the experiment.

2.3 Adaptive self-organized system

The profile adopted by a rat depends on its anxiety, its social environment and the interactions that occurred in the system. Other experiments have also shown that a single rat dropped in the environmental setup exhibits a carrier profile. It implies that each rat has the physical ability to cross the immersed corridor.

All these hints lead biologists to assume that the system is ruled by a robust underlying mechanism that allow the system to self-organize. This mechanism consists in two kinds of adaptation: the first one is an individual

adaptation: each rat of the system manage to sustain its needs in a specific way (by stealing or by diving). The second is a collective one: some rats don't dive and the system exhibits a distribution of roles among the individuals. This distribution has been interpreted by biologists as a limitation of the number of carrier rats appearing in the system. The next step we have followed to explain the social differentiation consisted in simulating this biological system.

3. The Hamelin Simulation

The problem we face is to study the apparition of a global pattern: the specialization between individuals who may have no explicit representation of the whole collectivity. To verify the connection between individual local behaviours and the observed collective phenomenon, an agent based model called Hamelin has been built. Hamelin has been designed following a parsimony principle that searches to reproduce the phenomenon with the simplest assumptions.

In this section, we will stress upon the different components of the agent-based model we have designed: the agents, the environment and the possible interactions in the system.

3.1 Agents

Each agent is the computer implementation of a rat. Agents are reactive agents: they have no planning abilities nor social representation and are ruled by stimulus-response rules which make them act according to their instantaneous partial perceptions.

The internal state of an agent is characterized by 4 variables which have been proven to have importance during biological experiments. These variables are:

- Its hunger h which represents the need for food and constitutes the motivation for the agent.
- The possessed amount of food $Food$ implemented as the size of the owned pellet.
- The strength of the agent s , which corresponds to its ability to win when it is involved in a fight (to catch a pellet or to defend itself).
- Its anxiety toward water θ corresponding to its reluctance to dive into water.

Due to the parsimony principle we have followed, these variables are not directly linked. For example, the strength of an agent is not directly related to the value of its food and hunger variables but such relationships between variables (which are not required to observe specialization) could be investigated in the future.

The activity of the agent is a combination of three behavioral items that will be depicted further in the paper:

- a diving item
- an attacking item
- an eating item

An agent perceives locally its environment. It knows if it owns a pellet and can detect if other rats in the cage possess pellets. Finally, it must be noticed that the perceptions of agents are still very simple: a rat cannot identify and thus can not recognize the other rats present in the system.

3.2 Environment

The environment represents the environmental setup. It is characterized by the length of the immersed corridor and by the size of the pellets in the feeder. The characteristics are implemented through two variables: τ the time needed to consume entirely a pellet and η the energy absorbed during a time step of eating a pellet. The energy contained in a new pellet is thus $\tau\eta$.

3.3 Behavioural items

Each of the behavioral items (diving, attacking and eating) is stochastically triggered or stochastically carried out. The associated probability is computed according to the internal state of the rat and biological observations. When the item is triggered, the associated action is effectively performed and a reinforcement alters the internal state of the agents allowing them to learn and modify their behaviors according to their past actions.

3.3.1 Diving

This action is considered by an agent when it does not possess a pellet.

Probability This behavioral item is computed according to adaptive response thresholds (Bonabeau and Theraulaz, 1999) based on the hunger of the agent and its anxiety toward water. The hunger of an agent and the probability for it to dive are positively correlated. On the contrary, the higher its anxiety toward water, the lower the same probability. These tendencies are computed according to the following formula:

$$P_{diving} = \frac{h^2}{h^2 + \theta^2}$$

Results of the action When decision is made, the action is automatically and instantaneously succeeded. The agent dives into water, manages to take a pellet from the feeder and comes back to the cage. The agent possesses then a new pellet

$$Food \leftarrow \tau$$

Reinforcement Moreover, when the action is performed, the anxiety of the rat is reduced according to adaptive response thresholds models.

$$\theta \leftarrow \theta \cdot \delta_\theta$$

$\delta_\theta \in [0, 1]$ is a global parameter. Thus, the agent learns to react more quickly to the same hunger. This reinforcement is responsible for the individual adaptation and the genesis of task allocation between agents. The more an agent has dived, the less reluctant it will be to dive. Finally, agents tend to forget their past experience and their anxiety increases gradually ($\delta_f \in [0, 1]$ also a global parameter of the system is responsible for the increase and 1000 the highest possible anxiety).

$$\theta \leftarrow \theta + (1000 - \theta) \cdot \delta_f$$

3.3.2 Attacking

This action is considered when a rat has no pellet in its paws and perceives pellets in the cage.

Probability This behavioral item is systematically triggered but the results are stochastically determined according to the relative strength of the two individuals involved in the fight. The probability for the aggressor (agent *A*) to steal the pellet from the victim (agent *B*) is computed according to dominance relationships.

$$P(\text{winning}_A) = \frac{s_A}{s_A + s_B}$$

Results When the action is successful, the aggressor *A* manages to steal the pellet from the victim *B*. The size of the received pellet depends thus on how much of the pellet the loser has already eaten.

$$Food_A \leftarrow Food_B, Food_B \leftarrow 0$$

Otherwise, nothing happens.

Reinforcement Whether the action is successful or not, the strength of the winner (*A* or *B*) is reinforced whereas the strength of the loser is decreased ("winner and loser effect"). Alterations of strength are computed according to dominance formula presented in (Hemelrijk, 1996):

$$s_A = s_A + \left(\text{Winning}_A - \frac{s_A}{s_A + s_B} \right) * \delta_s$$

$$s_B = s_B - \left(\text{Winning}_A - \frac{s_A}{s_A + s_B} \right) * \delta_s$$

δ_s is also a global parameter of the simulation and Winning_A is 1 if *A* won the fight, or 0 otherwise.

3.3.3 Eating

This action is automatically performed. If the agent owns a pellet, it has for results the decrease of its hunger and the decrease of the size of its pellet.

$$h \leftarrow h - \eta, Food \leftarrow Food - 1$$

Otherwise, the hunger of the agent increases.

$$h \leftarrow h + 1$$

4. Validation of adaptation

Computer experiments have been conducted to confront the results of the model with the results observed in biological experiments.

4.1 Individual adaptation

When a single agent is confronted to a difficulty of accessing food, there is no possibility of interacting with other agents and its behavior is only ruled by a response threshold model. The rat learns to dive and to reduce its hunger, according to adaptive response model properties. There is individual behavior reinforcement and individual adaptation to the situation.

The next part will focus on the adaptation of the system when some rats are put together in the environment.

4.2 Collective adaptation: Specialization

4.2.1 Parameters of conducted simulations

number of rats	δ_θ	δ_s	δ_f
6	0.95	0.15	0.00001
τ	η	$\theta_{initial}$	$s_{initial}$
10	2	600	10

Table 1: Parameters of conducted simulations

We have studied the model for some fixed initial parameters. These parameters are summed up in the Table 1. Some of these parameters are global parameters (δ_θ , δ_s and δ_f). They have been empirically tuned to effectively observe the specialization phenomenon among initially homogeneous agents. These parameters will stay unchanged in all conducted experiments. The other parameters (the number of rats, η , τ , $\theta_{initial}$ and $s_{initial}$) represent the conditions under which a specific kind of experiment has been undertaken. They will be altered in the next experiments presented in the paper.

4.2.2 Observation of specialization

The specialization observed with parameters from Table 1 divides the group of agents into two different sub-

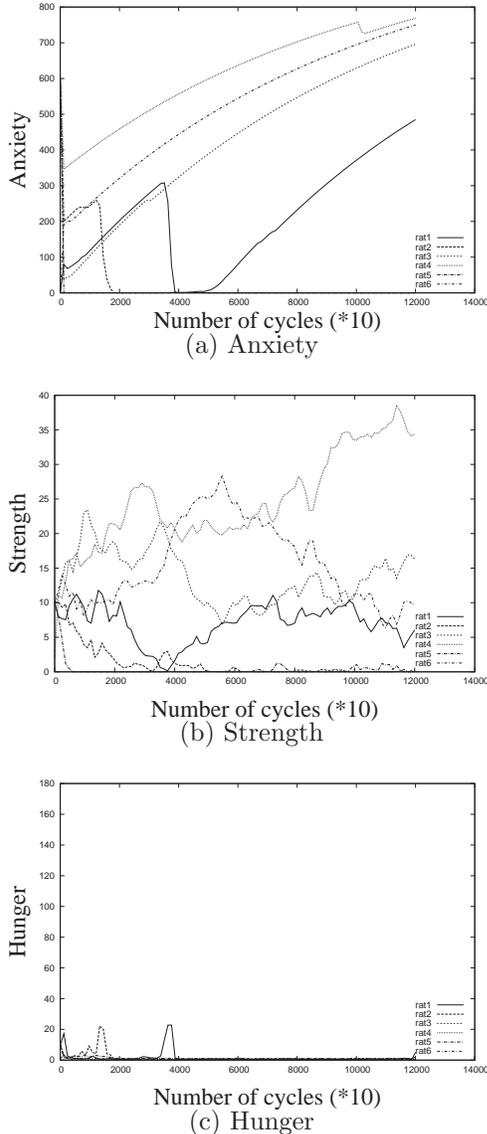


Figure 2: Computer-simulated specialization

groups. The first one contains agents with low anxiety and low strength. These agents are prone to dive, loose their stealing attempt against agents belonging to the second subgroup and correspond to the carrier rats. The second subgroup contains agents with high anxiety and high strength. These agents never dive, manage to fulfill their needs (hunger) by stealing the pellets from agents of the first subgroup and thus correspond to non-carrier rats.

The figure 2 shows results obtained by the execution of a single simulation. 4 agents (number 1, 3, 4 and 6) are non-carrier agents whose anxiety rises (Fig 2(a)) and who have a high rank in the hierarchical structure (Fig 2(b)). 2 agents are diving agents. The hungers of all the rats are controlled and are close to 0, except for some

events (profile inversions) we will discuss in the future.

For the initial values presented in table 1, the size of the subgroups of the various experiments are almost constant. We conducted 100 experiments and two global states have been observed: one state with 3 carrier agents and 3 non-carrier agents which occurs in about 60% of the experiments that have been made and a second state with 4 non-carrier agents and 2 carrier agents which appears in about 40% of conducted experiments. Moreover, in all the experiments, the hungers of the agents stay bounded and relatively low.

The system manages to reproduce collective adaptation: some agents manage to avoid facing water element, the whole need of the society is satisfied and self-maintenance of the system is reproduced.

4.2.3 Stability

During these experiments, it has been stated that the profiles associated to agents evolve. However, whenever a profile change occurs, it is compensated by another change of profile. It ensures the constant size of the profile subgroups. For the conducted experiments, we have observed an average number of profile inversions by experiment of 2.1 (standard deviation of 1.22). This behavior is the consequence of the function we have chosen at first to decide the results of a stealing attempt between agents.

This function equals to the ratio of the strength of the involved agents. This function leads to a unstable hierarchical organization. Dominance ranks (determined according to relative strength) evolve in this hierarchy. An agent whose rank was high and whose rank has decreased must now dive to fetch food and simultaneously, the agent whose rank has increased can now access pellets by stealing them from less strong agent. This change of profile is accompanied by a temporary increase of hunger because the rat whose rank has decreased need to re-adapt itself to this new situation.

Other experiments (consisting in computing the probability of succeeding in stealing attempt as the ratio of the square of strengths) have shown that it is possible to make these profile inversions disappear to obtain a system with stable organization.

4.3 Re-differentiation

Specialization still occurs if we alter the initial values of the agents introduced in the system, simulating the fact that agents have already been differentiated in previous experiments.

When the system contains initially only carrier agents (low initial anxiety $\theta_{initial} \leftarrow 50$ and low initial strength $s_{initial} \leftarrow 1$), specialization can still be observed. The same division in two groups, each one characterized by a profile, occurs and the sizes of these groups are globally

the same as the sizes observed in previous experiments. 3 global states have been detected: one constituted by 4 non-carrier and 2 carrier agents which appears in about 30% situations, another constituted by 3 non carrier and 3 carrier agents which appears in about 60% of situations and a last constituted by 2 non-carrier and 4 carrier agents which appears in about 10% of situations for 100 experiments. The number of inversion of profiles also rises (an average number of 4.8).

This experiment shows that the collective adaptation leads almost to the same global states independently of the history of the agents introduced in the system.

4.4 Hamelin for the biology

The simulation managed to reproduce the specialization that has been observed in real experiments. The reproduced computer specialization is characterized by the same profiles, the same global proportions of profiles, the ability to re-differentiate a system composed of agents that have already been differentiated. Finally, because the hungers of the agents are close to 0, the system is assumed to reproduce the self-maintenance of the biological system.

Hamelin has shown that no social cognition nor individual recognition is necessary to explain specialization observed in groups of rats confronting environmental difficulties to reach food. Hamelin shows also that reinforcement rules that have already been observed in other animal collectivities can explain such a phenomenon. Furthermore, Hamelin manages to reproduce the two kinds of adaptation observed: individual adaptation when a single rat is put in the environmental setup and collective adaptation leading to specialized agents.

Hamelin constitutes a first step to apprehend the biological mechanisms responsible of social differentiation in these diving-for-food situations.

5. Analysis of the system

Hamelin system can also be seen as a multi-agent system which generates global pattern (specialization) on the basis of individual local rules (the behavioral items of the agents). In order to have a better assessment of the adaptation abilities of the computer system and to have a better understanding of the principles involved, other experiments that have not been conducted with real rats have been undertaken with the Hamelin system. These experiments are presented in the following.

5.1 Adaptation to the number of agents

We have focused on the influence of the number of agents in the differentiation. We have conducted experiments with 20 agents (see Figure 3) and parameters from Table 1. The agents have still no social cognition and can-

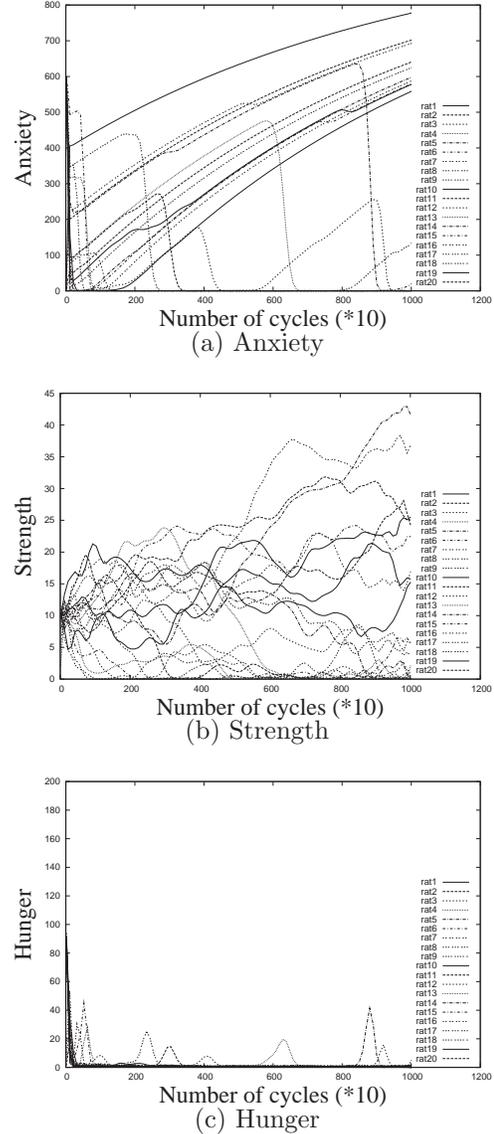


Figure 3: Adaptation to the number of agents

not recognize other individuals. Nevertheless, differentiation is still observed and the global hunger of the system is still very low except for profile inversions which are more frequent than with less agents.

The global state depends on the conducted experiment, but the number of carrier agents is comprised between 12 and 14. It shows that the system manages to adapt itself to social environment of the rats without needing any representation of the agents of the system.

Moreover, adding or taking out an agent during execution don't hinder the system which manages to re-adapt itself to the new situations.

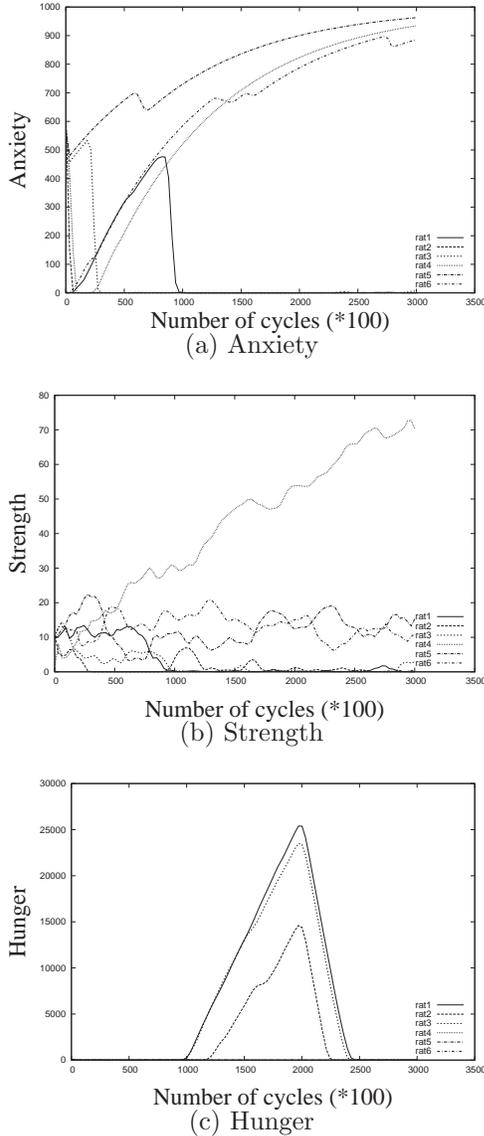


Figure 4: Adaptation to external condition during runtime (At 100000 step, τ is set to 2, and at 200000 step, it is reset to 10)

5.2 Adaptation to external conditions

We have also studied the way the system reacts when data describing the environment change during runtime. Simulations based on the parameters of the table 1 have been conducted. The first 100000 time steps, these parameters stay unchanged. After the 100000 step, the τ value is modified from 10 to 2. This new value corresponds to a strong constraint on the system. When an agent reaches the feeder and takes a pellet, the pellet is small from now on and contains less energy. In consequence, to fulfill the need of the collectivity, more agents have to adopt a carrier profile.

In the conducted computer experiments, we have ob-

served a re-differentiation as shown in the figure 4. An agent (the first rat) which was a non-carrier agent become a carrier agent. Its anxiety drops, meaning that he dives into water and learns to do so. Moreover, this change of profile is not compensated by the appearance of a new non-carrier agent in the system, the global state of the system has thus changed to response to the increase of difficulty presented by the environment. However, this re-differentiation is not sufficient to provide enough food to the collectivity because of the harshness of the new situation: the hunger of agents increases linearly. After 200000 steps, the τ is re-affected to its initial value 10, agents manage to fulfill the needs and hungers decrease to 0.

The system manage to readapt itself to changing environmental conditions, but if the constraints are too important, some agents still don't manage to eat.

5.3 Modification of organization process

In some cases, the hunger of agents increases linearly and questions the viability of the collectivity. This is due to the absence of transmission of information on the system. In these cases, carrier agents manage to fetch enough food for reducing the hunger of the non-carrier agents but not enough for them. Because of the partial perceptions of the agents, this kind of situation cannot be detected by the non-carrier agents which are not incited to change their behavior. One way to transmit this information is to introduce a feedback by making the stealing attempts dependent on the hunger of the aggressed rats.

To do so, we have modified the probability of winning a fight according to the hunger of the potential victim. If this hunger is above a specific threshold, the stealing attempt is always a failure.

When this alteration of interaction is implemented in the system (with a threshold of 100), the problem of hungers increase disappears and the system readapts itself in a more efficient way. The figure 5 presents the graphics for the same scenario as the one of the figure 4. It can be noticed, that the system readapts itself at the 100000 step. At this moment, the difficulty to fetch food is very important, and all the rats except one become carrier rats. The number of rats is then sufficient for the fulfillment of the needs of the group. When, after 200000 steps, the difficulty is decreased the system readapts itself to a state close to its former global state.

5.4 Hamelin properties

The Hamelin simulation can be considered as a complex system inspired by biological observations. This system manages to organize behaviors of agents during runtime according to interactions occurring in the system. This organization appearing in the system is the consequence

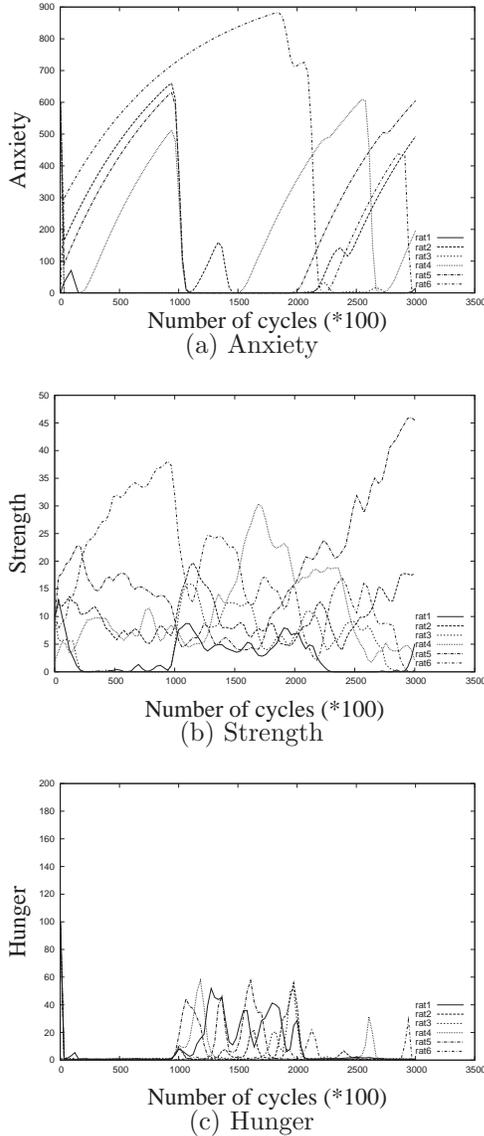


Figure 5: Specialization observed after adding a feedback in fighting interactions

of the partial observations of agents and of simple reinforcement rules. This allows the system to readapt itself to various conditions without needing an explicit representation of these changes.

The system presents interesting adaptive properties: it manages to readapt itself to external conditions, to the number of agents put in the system and to different initial conditions as it has been presented in re-differentiation experiments.

6. Discussion

The last part of the paper is a discussion about this system and the underlying mechanisms. The main goal of this part is to have a better point of view of the system

in order to generalize the interesting principle involved.

6.1 Interpretation of Hamelin

The system is characterized locally by a need to fulfill (the hunger of each rat) and by a difficulty to reach the resource needed to fulfill it. Each agent has its own need and can accede to the resource by two different ways: it can steal the pellet from other agents or dive and take a pellet from the feeder.

Initially individuals are undifferentiated, they have no preferred way of acquiring the resource. The collective dynamics of the system leads to an organization of these agents where specialization concerning the way of acquiring the resource emerges: some agents prefer to accede directly to the resource by diving into water, other prefer to obtain it indirectly by interacting with agents.

This differentiation process is the consequence of a coupling of two reinforcement based models: the first model, adaptive response thresholds, rules the direct acquiring way and reinforces the diving decision each time an agent reaches food directly. The second, dominance relationships rules the indirect acquiring way and the associated behavioral item is reinforced each time an agent manages to possess food by stealing it. The coupling of these two mechanisms is responsible for the dynamics of the system and the appearance of specialized profiles.

A more detailed analysis of the first profile inversions of figure 2 shows that those two models have not the same functionality.

Dominance relationships allow the distribution of pellets in the system. Agents manage to steal pellets according to their dominance value. Dominance relationship is then a way to transfer the pellets among agents (from the weakest agents to the strongest). Because the pellet is the resource needed by individuals, the transfer of pellets can be interpreted as a transfer of needs among the agents from the strongest to the weakest.

Response thresholds model allows the weakest agents (which concentrate the need of the collectivity) to adapt themselves to their hunger due to the environmental constraints and to the social pressure generated by hierarchical organization. This adaptation is an individual one: agents learn to dive more early in order to reduce their own hunger.

Hamelin can thus be seen as a coupling between an organizational process responsible for the transfer of internal stimuli through the system and a local individual adaptation process enable the fulfillment of individual needs. The transfer of local information and the possibility to solve locally a part of the problem by the more experienced agent (the one whose anxiety is the lowest) lead to the adaptation of the collectivity without an explicit representation of the global needs of the system.

6.2 Hamelin as a problem solving process

It must be noticed that the Hamelin model is close to the satisfaction-altruism model of (Simonin and Ferber, 2000). In this model, agents have to explore an environment. The method proposed to achieve cooperation is to couple a model of selection of actions and a model of interaction between agents. The interaction model is based on satisfaction signals and social pressure: if the satisfaction of an agent is very low, it can make the other agents move to free the path.

The interaction model and the social pressure of satisfaction-altruism model can be compared with the dominance relationship model of Hamelin and the action selection model with the response threshold model. The satisfaction-altruism and Hamelin model are based on the same abstract principle of coupling an interaction model to transfer local information through collectivity and a model of selection of action. This comparison let us think that this general principle can be a general mean to achieve cooperation between agents for collective problem solving.

7. Conclusion

In this paper, we have presented a simulation of a phenomenon of specialization observed in groups of rats when they face a diving-for-food situation. This simulation, Hamelin, is a self-organized process based on local interactions between agents.

It manages to reproduce the differentiation phenomenon and the collective adaptation of the group characterized by the viability of the collectivity while limiting the number of diving agents. The computer simulated specialization leads to the same profiles as those observed in biological experiments and reproduces the re-differentiation of individuals. It is based on reactive agents without any social abilities and proves thus that developed cognitive abilities are not required to explain the specialization occurring in this situation.

Furthermore, the simulation can be analyzed independently of biological considerations and turns out to have broader adaptive properties: it can adapt and readapt itself to changes of external conditions and to the number of agents. The core of the model is a coupling between an organization process which is in charge of distributing needs in the collectivity and an individual adaptation process.

Two perspectives are considered for this work. One consists in associating costs to the performed actions in order to assess the collective efficiency of the process we have described and to reuse the same dynamics to solve collectively problems of accessing resources.

The second consists in keeping in mind the main principle of the Hamelin system: the use of an organizational

process to profit from individual adaptation abilities for collective task solving. It requires to express this organization process in a formal framework (Decentralized Markov Decision Processes for example) where a collective problem can be described and where a local evaluation of the associated costs can guide the organizational process. Future works consist in expressing an organization principle similar to dominance relationship that can be guided by the task to be achieved.

References

- Bonabeau, E. and Theraulaz, G. (1999). *Swarm intelligence*. Oxford university press.
- Bonabeau, E., Theraulaz, G., and Deneubourg, J. (1996). Mathematical models of self-organizing hierarchies in animal societies. *Bulletin of Mathematical Biology*, pages 661–717.
- Bourjot, C. and Chevrier, V. (2001). Multi-agent simulation in biology: application to social spiders case. In *Agent Based Simulation, Passau, Germany*, pages 18–23.
- Camazine, C., Deneubourg, J., Franks, N., Sneyd, J., Theraulaz, G., and Bonabeau, E. (2001). *Self-Organization in Biological Systems*. Princetown university press.
- Corbara, B., Drogoul, A., Fresneau, D., and Lalande, S. (1993). Simulating the sociogenesis process in ant colonies with manta. In *Toward A Practice of Autonomous Systems: Proceedings of the First European Conference on Artificial Life*, pages 224–235.
- Deneubourg, J., Aron, S., Goss, S., and Pasteels, J. (1990). The self-organizing exploratory pattern of the argentine ant. *insect behavior*, pages 159–168.
- Desor, D., Krafft, B., Toniolo, A., and Dickes, P. (1991). Social cognition in rats : incentive behaviour related to food supply. In *Proc XXIIInd Int. Ethologica conference*.
- Desor, D. and Toniolo, A. (1992). Incentive behaviour in structure groups of rats : about the possible occurrence of socio-cognitive processes. In *Comparative approach in sciences cognitives, Aix en Provence*.
- Dury, A., Vakanas, G., Bourjot, C., Chevrier, V., and Krafft, B. (2001). Multi-Agent Simulation to Test a Coordination Model of the Prey Capture in Social Spiders. In *13th European Simulation Symposium - ESS'01, Marseille, France*, pages 831–833.
- Grasse, P. P. (1959). La reconstruction du nid et les coordinations interindividuelles chez bellicositermes

natalensis et cubitermes sp., la théorie de la stigmérgie : essais d'interprétation du comportement des termites constructeurs. *Ins. Soc.*, 6:41–84.

- Hemelrijk, C. K. (1996). Dominance interactions, spatial dynamics and emergent reciprocity in a virtual world. In Press, M. T. M., (Ed.), *Proceedings of the fourth international conference on simulation of adaptive behavior*, volume vol. 4, pages pp. 545–552, Cambridge.
- Hogeweg, P. and Hesper, B. (1986). Knowledge seeking in variable structure models. *Modelling and Simulation Methodology in the Artificial Intelligence Era*.
- Kunz, H. and Hemelrijk, C. (2003). Artificial fish schools: collective effects of school size, body size, and body form. *Artificial Life*, pages 237–253.
- Miramontes, O. and DeSouza, O. (1996). The nonlinear dynamics of survival and social facilitation in termites. In *Journal of Theoretical Biology*, pages 373–380.
- Reynolds, C. W. (1987). Flocks, herds, and schools: A distributed behavioral model. *Computer Graphics*, 21(4):25–34.
- Schroeder, H., Toniolo, A., Nehlig, A., and Desor, D. (1998). Long-term effects of early diazepam exposure on social differentiation in adult male rats subjected to the diving-for-food situation. *Behavioural Neuroscience*, pages 1209–1217.
- Simonin, O. and Ferber, J. (2000). Modeling self satisfaction and altruism to handle action selection and reactive cooperation. In *6th conference of simulation and adaptive behaviour*, pages 314–323.
- Theraulaz, G., Bonabeau, E., and Deneubourg, J. (1998). Response threshold reinforcement and division of labour in insect societies. *Proc. Roy. Soc. London B 265*, pages 327–332.
- Theraulaz, G., Goss, S., Gervet, J., and Deneubourg, J.-L. (1990). Task differentiation in polistes wasp colonies: a model for self-organizing groups of robots. In *First International Conference on Simulation of Adaptive Behavior*, pages 346–355.