MAS and RATS :
Multi-agent simulation of social differentiation in rats' groups. Interest for the understanding of a complex biological phenomenon.

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Confronting groups of rats to a situation in which they have an increasing difficulty to reach food leads to the emergence of a social structure. Three profiles appear: supplier, non-carrier and autonomous rat. The regularity of this differentiation and the stability of the phenomenon let biologists assume that an underlying mechanism is responsible for the differentiation.

The problem remains of a possible involvement of social cognition among the members of the group. We developed a multi-agent model without social cognition but with a self-organizing mechanism and ran computer simulations. The results match the biological observations. Furthermore such a model can be helpful for the assessment of the influences of both individual parameters and the environmental constraints on the group behavior.

Biological experiments

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, the food accessibility is made difficult by the progressive immersion of the only path of access to the feeder. This experimental schedule leads in a few days to the emergence of a differentiation in each group of rats, in two main behavioral profiles: (a) the carrier rats, which dive and bring the food back to the cage, and (b) the non carrier animals, which never dive, but get food only by stealing it from the carriers. A more precise analysis leads to the conclusion that the Carrier group can be split into 2 subgroups: carrier rats which can defend the food they carried, (Autonomous carriers), and those which cannot, and consequently feed the non-carriers (Supplier carrier rats) [DES 91] [DES 92]. The social differentiation regularly happens with 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. This structuring can be considered as emerging from the interactions among the group members, and based upon certain individual initial characteristics. Among these characteristics, ethological and pharmacological investigations, which can be found in [SCH 98], stressed upon the importance of anxiety towards water, which would lead the less anxious rats to dive first, and consequently be attacked by their more anxious conspecifics.

One of the problems remains the possible involvement of social cognition in the process of differentiation. Multi-agent systems constitute a tool to simulate biological assumptions in order to determine whether these hypotheses are reasonable. The first aim of the model we present in this paper is to check whether it is possible to generate a similar social structure from perfectly identical individuals without explicit representation of others.

MAS modeling

The problem we are faced here is to make a link between individual behavioral characteristics and a global property (social differentiation emerging in groups). This issue is currently studied in the case of decentralized systems such as social phenomena simulation [EPS96] or experimentation of simple kinds of interactions [RES96]. In our case, biologists are interested by assessing some assumptions about the individual behaviors and the interactions that can lead to the social differentiation.

The problem is to study the possible apparition of some social pattern from a set of interacting individuals that do not have any explicit representation of the global pattern. Multi-agent models (also called individual based models) are suited to simulate such collective phenomena that emerge from multiple, interacting individuals, especially in the behavioral field. Such models emphasize the relationships between individual behaviors and collective observed phenomena.

Moreover, since simulations are built upon a computer model, “experimental” conditions can be perfectly controlled and thus undesired side-effects can be avoided. This is a reason why simulations have recently been undertaken in biology to capture the global effect as a consequence of the behavior and interaction of simple individuals. Such works have been undertaken with several social species [CAM 01]: social spiders to simulate collective decision [SAF99], collective weaving [BOU01] and coordination during prey capture [DUR01]; insect colonies: ants [DEN 89], [DEN 91], [COR93], honey-bee [SUM98], termites [MIR96], wasps [THE97]; or primates [HEM 96]. Various applications of such models on several collective phenomena can be found in [REY] and in [THE 99].

Multi agent model

In our approach, a multi-agent system is envisaged as a set of agents, an environment and the dynamics of the whole. The results of the activities and the interactions are observed and the system is expected to reproduce the desired phenomenon: the apparition with time of a social structure by the means of social differentiation through interactions.

Agents

Each agent is meant to be the computer model of a rat. Agents are reactive ones: they are characterized by an internal state; they don’t have any planning abilities, nor social representation. They behave according to stimulus-response rules which make them react to the partial perception of their surrounding environment.

The internal state is characterized by 4 internal variables, which, according to biological experiments, seem to be responsible for the differentiation :

- The strength of the rat ***f***, which stands for its ability to win when it is involved in a fight (to catch a food pellet or to defend itself).
- Its anxiety towards water $\boldsymbol{\theta}$ linked to the tendency to dive into water. The higher the value, the more reluctant is the rat to dive.
- Its hunger ***h***, which embodies the need for food and increases during simulation when the rat doesn't ingest food.
- The amount of food possessed ***Food.*** It is implemented as the size of the possessed pellet.

Ultimately, the agent activity is implemented through three behavioural items that will be further described:
- a diving behavioural item,
- an attacking behavioural item,
- an eating behavioural item.

Decision processes are stochastic: each decision is made according to a probability based on the internal state of agents and is triggered by the presence or absence of a pellet in the paws of the active rat.

Environment

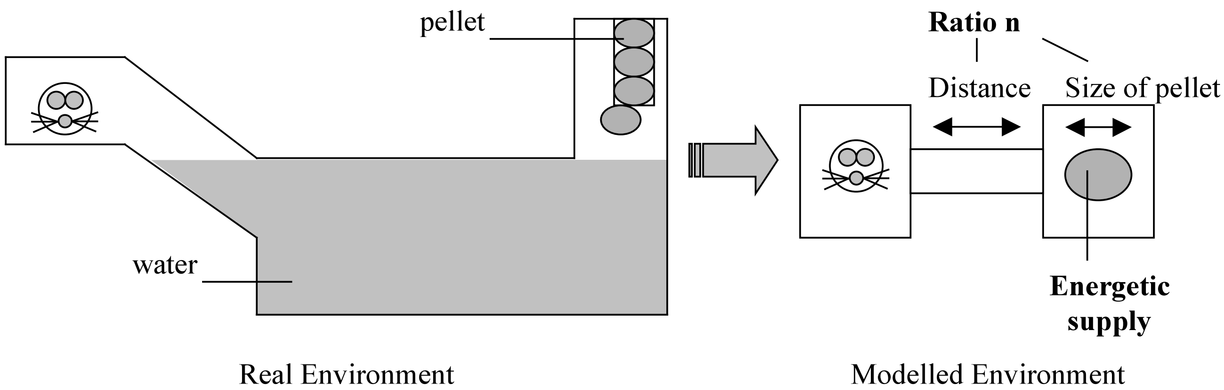

Figure 1: Modelled environment

The environment (*fig 1*) is defined by the elements that are exterior to all agents. The level of modelling of the environment must allow the apparition of specialization but the environment is also wanted to be as simple as possible. It is thus an abstract environment without any topology, only defined by the pellets it contains and by the characteristics of the swimming pool. It is defined by two parameters:
- The first parameter concerns the pellets by the mean of an *Energetic supply* coefficient. It corresponds to the energy gained by the rat after eating a part of the pellet in one cycle, leading to a diminution of the value of hunger.
- The second parameter expresses the constraints of the environment (swimming pool) through the ratio ***n***: duration of eating a full pellet / time necessary to carry it. It is implemented as the number of cycles needed to eat an entire croquette (carrying a pellet needs one cycle).

Dynamics

Ultimately, the system is ruled by its dynamics. This dynamics is linked with the control of the system and corresponds to the way the internal states evolve with time. It is defined by a few parameters: the *delta hunger*: the increase of hunger in one cycle when a rat doesn't eat, the reinforcement coefficients of behavioural items : the *reinforcement coefficient of strength* and the *reinforcement coefficient of water anxiety*. The use of these coefficients will be depicted in the next chapter.

Behavioural items

In this chapter, we will dwell on the different behavioural items. They will be depicted by the stimuli triggering action, by the way the probability to carry out an action is computed and by the result of the possible performance of the action.

Diving

This behaviour is activated when a rat doesn't have any pellet. It is then enticed to dive in order to fetch food.

The decision is made according to a probability, which depends on the hunger of the rat and its anxiety towards water. On the one hand, the higher the hunger, the higher the probability to dive. On the other hand, the higher its anxiety towards water, the lower the same probability. These relations are accordingly computed by the following formula inspired by the works of Theraulaz, Bonabeau and Deneubourg on division of labour in insect societies [THE 98]:

$$P(dive)=\frac{h^2}{h^2+\theta^2}$$

When diving decision is made, the action is automatically and instantaneously performed. The agent is, after carrying out the action, in possession of a full pellet and the action performed has for consequence a decrease of its anxiety towards water.

$$\theta \leftarrow \theta . R_{diving}$$

R_{diving} is the reinforcement coefficient of diving (belongs to [0,1])

The decrease of the anxiety towards water makes the rat more eager to dive (*Fig 2*). It must be noticed that the anxiety towards water cannot increase during simulation.

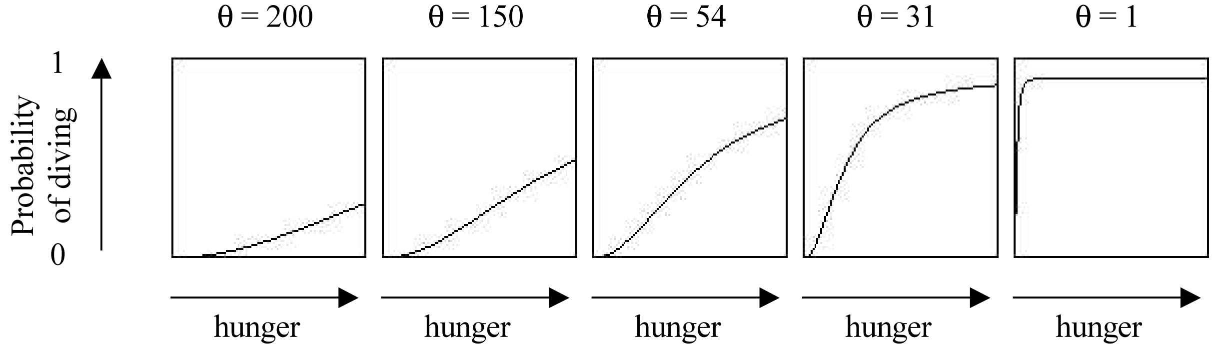

Figure 2: consequence of reinforcement

Stealing

This action is systematically triggered when a rat, which has no food pellet is in presence of a rat which is possessing one.

The result of the action depends on the relative value of the strengths of the two rats involved in the fight.

$$P(winning)=\frac{F}{F+f}$$

With F the strength of aggressor and f the strength of the potential victim.

When the action is performed, the aggressor manages to steal the pellet of the victim, the strength of the aggressor is reinforced and the strength of the victim is reduced. Otherwise, the strength of the aggressor is reduced and the strength of the victim reinforced.

Increasing and decreasing of strength are computed according to the dominance formula presented in Hemelrijk [HEM 96]:

$$F \leftarrow F+\left(win-\frac{F}{F+f}\right)*R_{fight}$$

$$f \leftarrow f-\left(win-\frac{F}{F+f}\right)*R_{fight}$$

with "win" the boolean (0 or 1) "the aggressor has won the fight"

Eating

Every cycle, the hunger of the agent increases by delta-hunger :

$$Hunger \leftarrow hunger+delta\_hunger$$

Ultimately, if the considered agent owns a pellet, it eats a part of it. This leads to a reduction of its hunger by the *Energetic supply* coefficient.

$$Hunger \leftarrow hunger\ -Energetic\ supply$$

The simulation system

The simulation consists in making the system evolving from cycle to cycle (the duration unit of a cycle corresponds to the duration of carrying a food pellet from the feeder to the cage). A basic cycle of the simulation can be depicted in 3 steps, each one focusing on a specific behavioural item.

1. Start of simulation
2. Diving: Consider successively all rats and test their diving behavioural item. If the decision is made, perform the action.
3. Creation of sets: Create two sets. The first one contains the agents that own a pellet, the second contains the agents that haven't got anything.
4. Fight : Randomly select an agent from the non-possessor set and remove it from set. Randomly select an agent from the possessor set. Test if the attack of the first rat against the

second one is performed and possibly perform the action. Repeat until the possessor set is empty.
5. Eating: Test the eating behavioural item of each rat.
6. Next cycle: Go to step 2

The following pseudo algorithm describes more precisely the implementation of the simulation.

```
Start
For all rats
        Test if considered rat dives and possibly perform the action
Initialise Possessors set (PS) and Non-Possessors set (NPS)
While (PS is not empty) and (NPS is not empty)
        Randomly select rat R_aggr in NPS and remove R_aggr from NPS
        Randomly select rat R_vict in PS
        If R_aggr manages to attack R_vict, perform action and remove R_vict from PS
                Else perform the failure of the attack (Reinforcement only)
For all rats
        Considered rat tries to eat, which leads to the increase or the decrease of its hunger
Go to start
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It must be highlighted that no social cognition is explicitly coded in this simulation. An agent has no hint about the strength of an adversary and doesn't select the rat it is willing to attack: the two protagonists of a fight are randomly selected.

Empirical assessment of the model

This part will present results obtained with this simulation model and compare them with the biological observations in order to determine if such a model manages to emulate the rats social differentiation.

In simulation experiments, we focused on systems containing 6 agents corresponding to the biological experiments that have been performed (more agents might be considered in the future). Simulations run according to the previously described model during a fixed number of cycles (3000). Initially, all rats have exactly the same characteristics: $\boldsymbol{h}$ is null, $\boldsymbol{\theta}$ is set to 600, strength $\boldsymbol{f}$ equals 1 and they don't possess any pellet. At the beginning, rats are thus totally identical and very anxious. Global parameters of simulation are ***delta_hunger*** =1, ***Energetic supply*** = 2, $\boldsymbol{R_{diving}}$ = 0.8, $\boldsymbol{R_{fight}}$ = 0.5 and the ratio $\boldsymbol{n}$ = 30. The values of these parameters have been empirically tuned.

Raw results

Before presenting statistically analysed results, we will focus on some exemplary graphs obtained by the simulation.

The first plot displayed in *Fig 3* shows the cumulated number of dives performed and the second one (*Fig 4*) shows the cumulated number of successful thieves. Each letter corresponds to a rat.

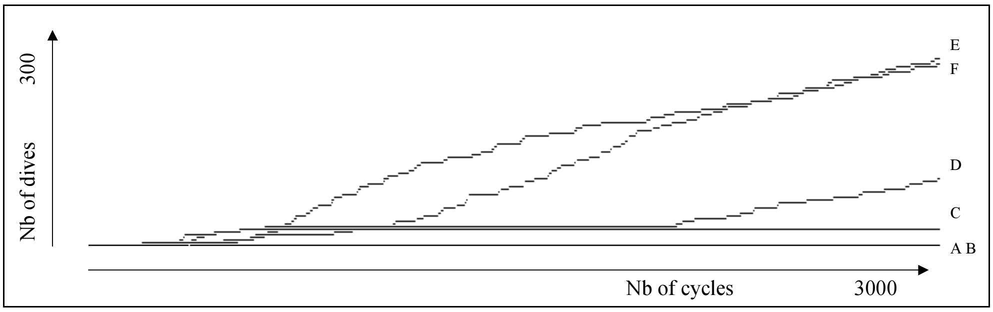

Figure 3: Cumulated number of dives

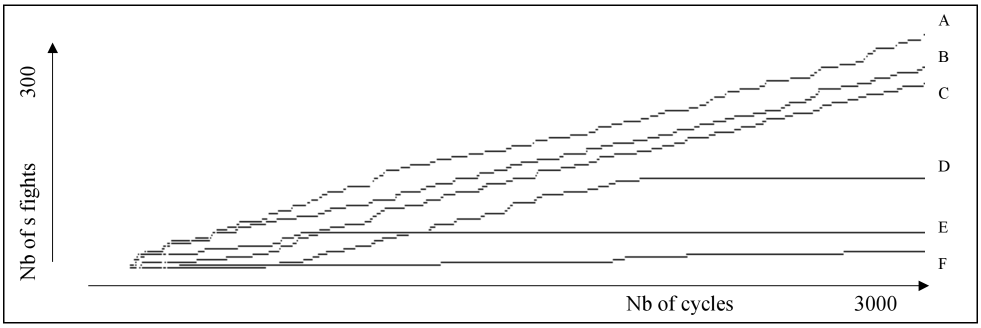

Figure 4: Cumulated number of successful fights

A specialisation can be observed. Plots bring to light that some rats are specialized in diving (E and F) and correspond to supplier rats and that others are specialized in fights (A, B and C) and correspond to Non-carrier rats.

Thus, such results bring to the fore the ability of the model to reproduce differentiation in some runs. To better assess our proposal, we need to analyse statistically the agents' behaviour.

Statistical results

Method

Originately, in biological experiments ([DES 91]), 13 variables were computed for each rat, in order to describe its behaviour in the group. These variables were treated by a factor analysis (Principal Components Analysis) followed by a cluster analysis on the individual coordinates in the first factorial plan. We performed exactly the same analysis upon the equivalent data obtained by the *in silico* model in order to confront it with the *in vivo* observations.

Results

The first two axes of the PCA explain 89% of the global variance. The first axis is mainly correlated with the *number of carrying*s (-0.99) and the *Ingest ending rate* (0.99) and explains 79 % of total variance. The second axis is mainly correlated with the *number of food acquisitions* (0.95) and the *supplying index* (-0.51).

A cluster analysis has been performed upon the coordinates in the first factorial plan. Eta^2 coefficient indicated that the 3 clusters solution is better than the solution with 2 clusters. Anova Analyses based on the clusters indicated that the two clusters solution discriminates carrier from non-carrier rats. The solution with 3 clusters (*Fig 5*) splits the previous carrier rats group into a supplier and an autonomous rats subgroup.

	Nb of carryings	Transport rate	Supplying index	Thief rate	Ingest ending rate	Loss ending rate
Non-carriers (A)	0,3952	1,15E-03	1,96E-02	0,9989	0,7478	0,2521
Autonomous (B)	153,625	0,5135	6,54E+01	0,4865	0,4266	0,5732
Suppliers (C)	299,0781	0,8784	1,08E+02	0,1216	0,1675	0,8325

Nb of carryings : Number of carryings
Transport rate : % of possessions beginning by food carrying
Supplying index : Amount of food transported and left to the group
Thief rate : % of possessions beginning by stealing food
Ingest ending rate : % of food possession periods ending by a complete ingestion of the pellet.
Loss ending rate : % of food possession periods ending by the loss of the pellet.

Figure 5: Means of the different clusters

The cluster A is characterised by the absence of carryings and a high thief rate: rats from cluster A manage to get food by stealing it from others. Moreover, their low loss ending rate indicates that they manage to defend their food. Thus, cluster A corresponds to non-carrier rats. Cluster C is characterised by a high nb of carryings and a high supplying index. Furthermore, rats of this cluster are prone to get their food stolen. Cluster C corresponds to supplier rats. Ultimately, cluster B contains autonomous rats.

The results of the *in silico* model are qualitatively similar to the *in vivo* observations : behavioural profiles are quite identical. From a quantitative point a view, it is also possible to obtain same relative sizes of clusters (124 non-carrier rats, 48 autonomous rats and 128 carrier rats for a set of 300 rats) when parameters of the simulation are correctly empirically tuned.

Conclusion

In conclusion, the preliminary results indicate that the *in silico* model fits with the *in vivo* observations on several basic points, mainly the occurrence of behavioural differentiation into similar profiles in similar proportions. An important point is that these results were obtained by the use of a model in which there is no explicit individual representation of others, consequently without any social cognition.

Computer model as a heuristic model

The next step consisted in the use of the simulation model as a heuristic model to help the formation of biological assumptions. We used it in two cases:

First, the basic assumption underlying the interpretation of the observed social differentiation occurring in a group is that environmental constraints impose this evolution. The social differentiation can be considered as a response of the group in order to adapt itself to the environment following economical rules:

- A daily food income is needed.
- The amount of energy brought by food is greater than the amount of energy spent in getting it.
- The supplier rats must eat minimal amount of food in order to survive.

In the computer model, the strength of the constraints is simulated by the ratio ***n*** = duration of eating / time necessary to carry it. So it becomes possible to analyse the link between the strength of the constraints and the emerging social structure of the group.

Corresponding biological experiments have not yet been conducted. An increase of the environmental constraints can be obtained by reducing the size of the pellets. But in this case, a side-effect would probably appear: small pellets are more defensible than big ones. However, such experiments have been simulated by changing the ratio **n** from 30 to 4. From now on, the strength of the environment is important and will alter the emerging social structure.

After the same analyses as presented on the previous chapter, the relative sizes of the clusters obtained turn out to be different: from a set of 300 rats, only 49 have specialised in non-carrier rats, 100 in autonomous rats and 151 in supplier rats. Indeed, if the proportion of carrier rats has stayed the same, they could not have brought enough food for the whole group. Thus, previously non carrier rats have been too hungry and were enticed to dive and fetch food by themselves. The computer model presented here seems, according to biological assumptions, to solve an economical issue.

Second, in a special case, we found a discrepancy between biological facts and simulation, namely: when biological rats that have already adopted the same specific profile in various groups are put together in a same cage, new specializations can be observed. Our computer model cannot explain it: as it has been highlighted in this paper, the anxiety towards water can only decrease. Thus, if we put together virtual supplier rats, all will dive at once and no fight will occur. This is not observed in reality: non-carrier rats rapidly appear in this group. This raises the questions of a biological process that could explain this discrepancy between the biological observations and the multi-agent model. Does the modification of the social environment results in an increase of the anxiety of the rat ? More accurate computer models could give few hints, but only additional biological experiments could validate the submitted hypotheses.

Conclusion

The presented model manages to some extent to generate the same observations as the biological ones. Thus, it seems possible to obtain a robust social differentiation without the help of an explicit individual representation of others. Furthermore, the use of this model can help the formation of biological hypotheses.

Up to now, we have managed to produce adequate model by the use of formulas found in literature [HEM 96] [THE 98]. A question remains: could other forms of formulas give results which better fit biological observations ? New experiments will be carried out in the future in order to do so. We will then focus on the dynamics of the system in terms of stability and robustness to varying conditions in order to highlight the impact of formulas on the specialization process.

References

[BOU 01] C Bourjot, V Chevrier, "Multi-agent simulation in biology: application to social spiders case", *In Proc. Of Agent Based Simulation Workshop II*, Passau, pp18-23, April 2001

[CAM 01] Camazine S., Deneubourg J.L., Franks N.R., Sneyd J., Theraulaz G., and Bonabeau E., *Self-Organization in Biological Systems* Princetown university press, 2001.

[COR 93] Corbara B., Drogoul A., Fresneau D., Lalande S. "Simulating the Sociogenesis Process in Ant Colonies with MANTA" *in Towards a Practice of Autonomous Systems II*, MIT Press, Cambridge, 1993.

[DEN 89] Deneubourg J.L., Goss S., “Collective patterns and decision making”, *Ethol. Ecol. Evol.*, 1: 295-311, 1989.
[DEN 91] Deneubourg J.L, Goss S., Beckers R., Sandini G., “Collectively self-solving problems, in Self organization, emergent properties and learning”, ed. A. Babloyantz, Plenum, 1991.
[DES 91] Desor D., Krafft B., Toniolo A.M., Dickes P., “Social cognition in rats : incentive behaviour related to food supply” *Proc XXIInd Int. Ethologica conference*; Kyoto University Press 1991.
[DES 92] Desor D., Toniolo A.M.: “Incentive behaviour in structure groups of rats : about the possible occurence of socio-cognitive processes” *Comparative approach in sciences cognitives*. Aix en Provence, 1992.
[DUR 01] A Dury, G Vakanas, C. Bourjot, V. Chevrier, B. Krafft “Using multi-agent system to model prey capture in social spiders”. *In ESS01 13th European Simulation Symposium*, N. Giambiasi and C. Frydman (eds). Erlangen, SCS European Publishing House, pp831-833, Marseille, France, 2001.
[EPS 96] Epstein J.M, Axtell R., *Growing artificial societies*, MIT Press, 1996.
[HEM 96] Hemelrijk, C. K. “Dominance interactions, spatial dynamics and emergent reciprocity in a virtual world”. *Proceedings of the fourth international conference on simulation of adaptive behavior*, vol. 4, pp. 545-552. Cambridge, MA: The MIT Press, 1996.
[MIR 96] Miramontes O., DeSouza O. “The Nonlinear Dynamics of Survival and Social Facilitation in Termites”. *Journal of Theoretical Biology*, Vol. 181, No. 4, Aug, pp. 373-380, 1996.
[REY] Reynolds C. “Individual-Based Models, an annotated list of links”. http://www.red3d.com/cwr/ibm.html.
[RES96] Resnick, M. “Beyond the Centralized Mindset”. *Journal of the Learning Sciences*, vol. 5, no. 1, pp. 1-22., 1996.
[SAF 99] Saffre F., Furey R., Krafft B. and Deneubourg J.L. “Collective Decision-making in Social Spiders : Dragline-mediated Amplification Process Acts as a Recruitment Mechanism”. *J. Theoretical Biol.*, 198, pp 507-517. 1999
[SCH 98] Schroeder H, Toniolo AM, Nehlig A, Desor D. “Long-term effects of early diazepam exposure on social differentiation in adult male rats subjected to the diving-for-food situation” *in Behav Neurosci* 1998 Oct;112(5):1209-17, 1998.
[SUM 98] Sumpter D., Broomhead D. “Formalising the link between worker and society in honey bee colonies”, *First International Workshop*, MABS ’98 LNAI N°1534, pp95-110, 1998.
[THE 97] Theraulaz G., Bonabeau E., “La modélisation du comportement bâtisseur des insectes sociaux”, *Auto-organisation et comportement*, Hermès, 1997.
[THE 98] Theraulaz G., Bonabeau E., Deneubourg J.L. “Response threshold reinforcement and division of labour in insect societies”, *Proc. Roy. Soc. London* B 265, pp327-332, 1998.
[THE 99] G. Theraulaz E. Bonabeau, M. Dorigo. 1999. *Swarm intelligence*. Oxford university presses,1999.