COLLECTIVE BEHAVIOR FOR A MICRO-COLONY OF ROBOTS

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ABSTRACT

In this paper, we present a model of collective behavior for a micro-colony[1] of five[2] autonomous walking robots based on a very limited behavioral repertoire. For each of the individual robots, the behavior is determined by internal states, which can set off a synchronized mutation between the existing machine and another specialized in a different task. It is this qualification of the agent's behavior, as a machine relating to the environment via semi-synchronized states[3] which, through a change in scale, allows one to conceptualize the unity of a micro-colony of robots as an emerging phenomenon. We qualify this change of behavior as a possible phase transition.

INTRODUCTION

Robot engineers try to construct intelligent agents capable of adapting to an environment in perpetual change, while ethologists observe creatures who have already adapted to the real world. We think that the best technique is not to construct an isolated robot[4] which interacts independently and directly with the outside world. Rather, we suggest working with micro- colonies, which not only relate to the world according to their rules, but are composed of smaller agents, which, in turn, possess their own rules of interaction. Each agent is an autonomous entity, possessing its own capacity for evolution[5], and, at the same time, maintaining local resources, gathered through its interactions with its milieu and fellow robots. We have therefore chosen three actions that should take place between the micro-colony (through the intermediary[6] of each agent) and the milieu[7].

The first state allows the agent to gather information about the validity of the movement. This action can correspond with a geographical exploration of the milieu and can take into consideration different factors of the agent: its position, its orientation, or the extent of the movement that it can carry out at that moment. This action is determined by a response received from the milieu. In the case of a physical impossibility of surmounting an obstacle, for example, a hole, the milieu can send a negative response to an attempt at movement.

1. We define a micro-colony as a matrix of interactions among its members and the limited memory of the agents that compose it.

2. We have limited the number of robots to five so as to obtain complete behavioral coherence among the micro-colony. These robots are only efficient within the context of a group, and one is never absolutely certain as to how they will behave. Possessing a very limited memory and no internal structure of datum, it would be impossible to control them.

3. As the milieu was too complex to be accessible to our agents, we decided to adopt for a structure of semi-synchronized agents, in their relationship with the environment, in order to reduce the number of their reactions.

4. We think that the right level of simulation was not chosen. We prefer to simulate cognitive behavior of a simplified micro-colony, rather that of an autonomous animal. .

5. The meaning attributed to "evolution" here is limited to the change in state of each robot.

6. There exists an analogy between the behavior of a micro-colony and that of each agent.

7. We consider the milieu an outside agent that possesses both its own resources and its own capacity to evolve. We consider that physical impossibilities presented by the milieu correspond with a form of language that the robots generally can not interpret, and where the challenge for the robot engineers is to construct robots capable of adapting to these milieux.

The second interaction allows the agent to signal that the movement was really carried out. This interaction permits the agent to eventually deduct the consequences of the action by modifying its own behavior and allows it to control excessive behavior.

The third reaction is that the milieu[8] becomes a communal support of interaction; all the agents living in a milieu depend on the general equilibrium that is established in terms of individual and local interactions. In addition, as the milieu evolves, it can modify the conditions of life of its occupants, therefore favoring the development of new behavior. The milieu appears as an entity above and beyond its occupants, capable of influencing their outcome.

These interactions will allow each agent to pass from one state to another. For each of these states, an appeal can be communicated in a way in which to interact with the milieu; or a procedure of internal regulation can be activated. This type of internal functioning conforms to that of a finite state automata, where one of the possible transitions for a given state is validated through a signal emanating from a component outside of the micro-colony. This modelling, which starts with local characteristics in order to progress to general functionalities, possesses properties that are found in the parallelism of operations and at a local determination of cellular automatons' behavior (Greussay 1988). Our micro-colony is a super organism[9] made up of two types of agents that interact by releasing energy and regulating their actions according to the information that they received from others.

Our micro-colony is composed of:

A) Active robots (specialized agents)

The principal activities of these robots are:

1) the search for and collection of food, represented in the experiment by sources of light

2) the recruitment of passive agents.

This last operation consists of departing on exploration and returning to the base in order to warn the others of discoveries. The recruitment is a type of communication (Deneubourg et al 1987), which leads individuals of the same society to assemble in a given region of a territory, in order to accomplish a specific task: essentially the collection of food, but also work entailed in the construction and protection of the nest. For our experiment, the objects to be discovered will be represented by sources of light posed at different places in the laboratory. The robots are equipped with a behavioral repertory of four states (fig 1).

8. This organization echoes the principal of encapsulation belonging to object language (Krief 1992).

9. The idea of the fragmentation of a living entity into a structured organization of multiple interacting agents, has already been introduced by (Minsky 1965) in order to allow for the modelling of cognitive processes, proposed by (Moravec 1966) for the conception of autonomous robots, used by (Coderre 1989) and (Travers 1989) in order to describe the behavior of artificial animals.

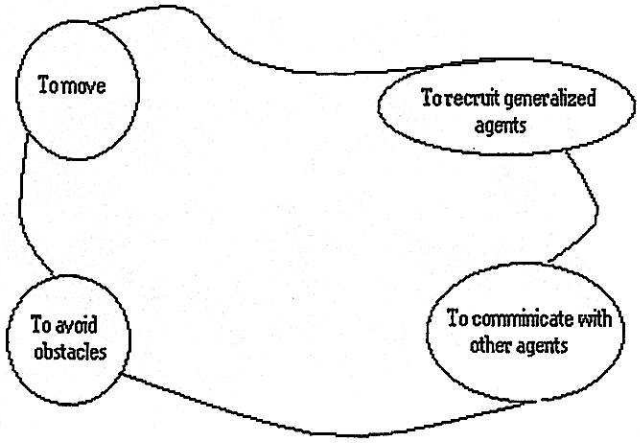

Fig 1 . The sum of the specialized agents' behavioral repertory of four states.

B) Passive robots (generalized agents)

A group of robots at the disposition of the rest of the colony provide a reservoir of manual labor. It is not directly the environment, but the interaction between the specialized and generalized robots, that will provoke the behavior. While waiting to be recruited, these agents move and stand guard in the local perimeter. The passive agents possess the following three states:

1) Capacity to move

2) Ability to avoid obstacles

3) Aptitude to respond to the specialized agents call for recruitment.

DESCRIPTION OF AN AGENT

Our agents are walking robots designed at University of Paris 8 (fig 2). Each agent is equipped with 12 electric monitors that move its feet. Supplied with three processors[10], our robots are capable of calculating, comparing results from their tactile sensors, controlling their speed, and determining the distance that separates them from an obstacle to the nearest centimeter. In the conception of each robot, we have tried to limit the amount of programming necessary to obtain a displacement. The local electronic part of each foot is such that it can move without intervention form the microprocessor, which simply selects possible trajectories for each foot. We use the principle of crossed inhibition as the basis of the synchronization of the feet's displacement. This crossed inhibition is used as the unit of temporary memorization. This information is immediately saved in the local memory and thereby enhances the history of the foot.

[10]. The local responsibility of each organ, the functional autonomy, the internal communication, and the memory distributed has lead us to conceive a multi-level architecture with three processors. Each functional part of our robots is controlled by a microprocessor that the responsibility of reading regional sensors and recording changes in its local memory.

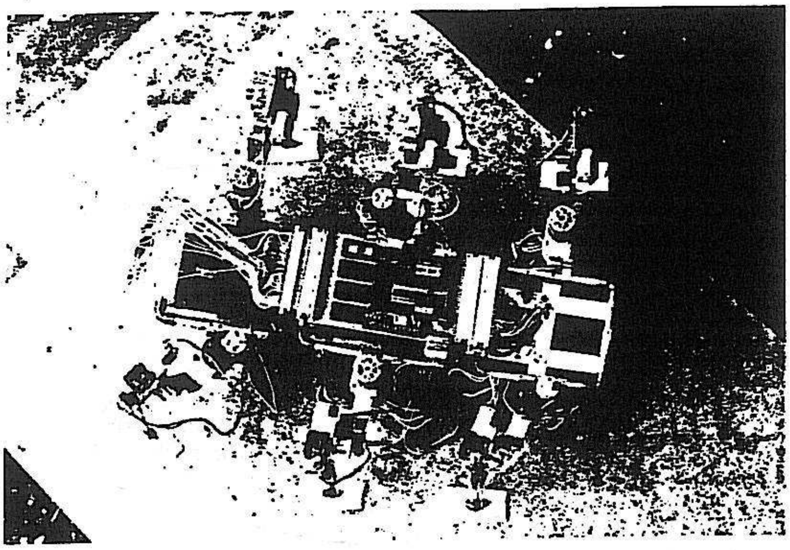

Fig 2. Presentation of an agent (Ali cherif 1991).

SYSTEM OF TOPOGRAPHIC NAVIGATION

To provide our agents with a system of vision, we were inspired by the topographic orientation of the ants Mymecopcystus of North Africa (Ataya 1980, Dartigues 1978). These hymenopterans are capable of using terrestrial references in order to determine the direction of the nest. We do not know if ants are capable of long term memorizing, or if they are limited to temporary conditioning using the pheromones that are still active. In any case, it is certain that they possess a precise memory of visited terrain. Each agent's vision is entirely secured by a telemetric[11] radar connected to the command card with a conductor. The role of the sonar is to detect and to locally take into account obstacles that could restrict displacement. The waves travel in a fluid at the speed given by the following expression:

$$C = \sqrt{OP/R}$$

- O Is the relationship between specific heats
- P The average pressure
- R The volume of the fluid

In the case of an acoustical emission in air, the speed of the propagation is the following:

$$V = 331.4\sqrt{T/273}$$

- T is the temperature in degrees Kelvin[12]

The navigation of each of our agents depends upon a dynamic system of environmental representation in a way that confronts all possible modifications. We consider that our agents discover their universe through trial and error, as they progress with the help of tactile and visual captors. In each position, the robot must be able of combining primitive and simple[13] geometrics in order to construct more

11. We have created a multi-frequenced sonar by modifying a mechanism of focussing a photographic diaphragm, commercialized by polaroid film. We have interfaced this sonar with a micro-controller Intel 8051.

12. Kelvin = Celsius + 273.

13. By simple, We mean local detections made without aid of movement.

robot must be able of combining primitive and simple[13] geometrics in order to construct more comprehensive ones. When the robot moves, it must model its displacement and associated uncertainty[14]. Using calculated maps in various neighboring positions, it must detect the multiple occurrences of these primitive geometrics. Fig 3 shows the location of a point calculated from two different positions. The matrix of an estimation of the displacement and the agent's uncertainty should place the two descriptions in the same reference and decide that the two measures correspond to the same physical point.

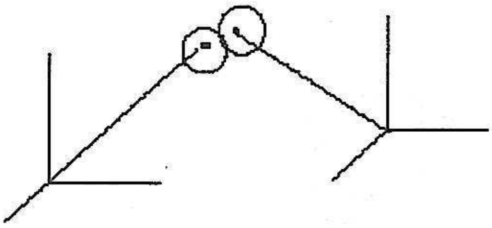

Fig 3. The same obstacle is detected from two different points of reference.

This decision must allow for the calculation of a more precise position of the displacement, as show in fig 4. In this way, a comprehensive visual map of the environment can be created by using a local map.

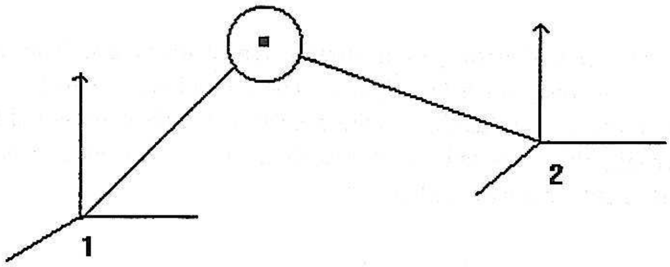

Fig 4. Two measurements are fused so as to reduce the uncertainty of the point and to correct the estimation of displacement between two points of reference.

The type of displacement made by each agent does not require a map of high precision. The measurements are not treated in isolation, rather the system tries to regroup them with a straight line. The environment is therefore symbolized by a series of segments, overlooking the different makeup of the obstacles. From a cycle of measurements, we obtain a visible horizon[15]. This vision of the domain, while still very far from the final map, determines a space in which the robot can evolve. From this visible horizon our mechanism extracts the straight lines representing the measurements taken of the walls, which form a sensorial model[16]. However, the mechanism is not free from false aligned measurements, which would be treated like the image of a wall. In this case, the readings must be erased during the following measurements. Its through its movement in a visible domain and through the repetition of cycles of measurements that the system confirms or refutes the validity of lines (fig 5).

13. By simple, We mean local detections made without aid of movement.

14. Each agent can and must detect the same obstacle from different positions.

15. A polygon determines the visible space of the robot. The vertexes are obtained by telemetrical measurements in an absolute cartesian system using the position of the robot.

16. We were able to extract the ensemble of straight lines from the visible horizon.

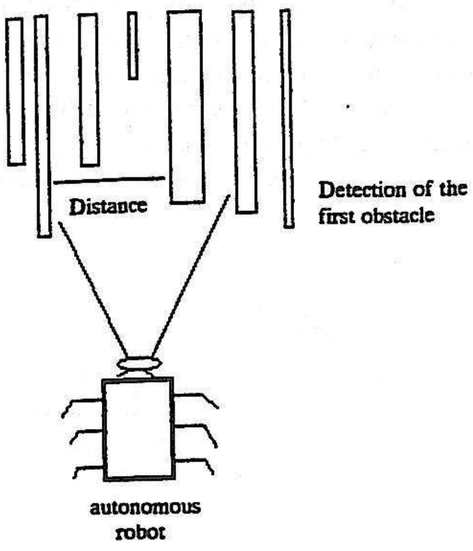

Fig 5. List and position of detected obstacles. We esteem that every robot must have a minimal and local representation of the surface of action. This represents a form of intelligent interaction with its environment

OUR PROBLEMS RELATED TO ULTRA-SONIC MEASUREMENTS

We have encountered two types of errors in our ultrasonic measurements. The first error is due to the encounter with sound wave absorbing obstacles (fig 6a). The second error, which is much more common, is the detection by sound wave of a reflecting inclined surface which does not diffuse the echo in the direction of the transducer (fig 6b). It is evident that such situations can have catastrophic consequences for the reliability of displacements in hostile milieux.

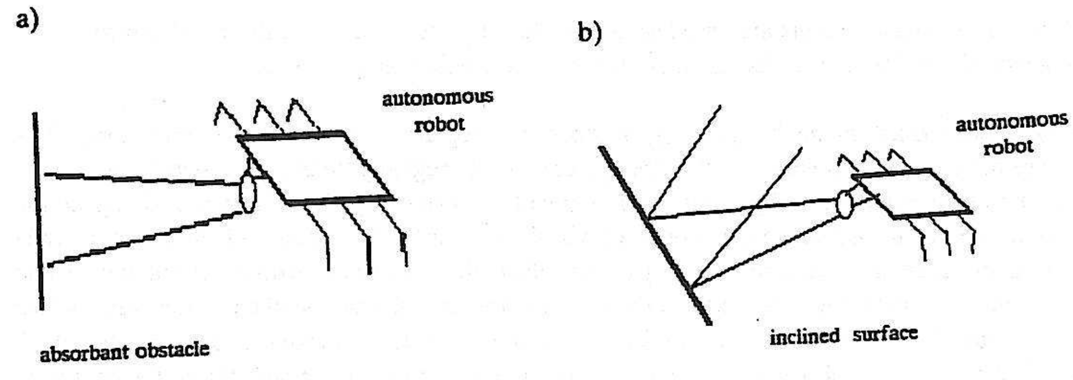

Fig 6. Case of non detection of echoes.

This creates a selection in which the least capable individuals are eliminated. If our robots are not in measure to detect the presence of salient or absorbing obstacles in their path and if the obstacles are not mobile, there is a high chance that the robots will be destroyed. Thanks to this mini theory of selection, it is possible to understand how correct behavior can develop in a way that becomes quasi automatic. All is possible to understand how correct behavior can develop in a way that becomes quasi automatic. All depends on the variation, or small modifications that appear in large numbers, as the animal populations reproduce.

CONCLUSION

Contrary to (Flynn 1988), we think that communication among robots is not limited uniquely to a direct interaction[17] with the environment that creates a reaction on the part of the robots. This idea precludes all decisional cooperation among different agents composing a group. We construct artificial insects (Ali cherif 1991) in which a portion of the behavior is generated by their interactions with other robots of the same type and not by direct programming, which limits all parallelization of tasks.

The emission of a message intervenes when its initiator judges the moment to be opportune. In other words, in function of an internal dynamic, an agent decides to formulate an interaction with one of its fellow robots. This second robot also finds itself in a cycle that allows it to establish its own behavior. Taking into account the interaction provokes a behavior that depends on:

1) the nature of the interaction

2) the general state of internal functioning

3) the internal value of certain parameters

By taking into account this interaction, in function of the parameters exposed here, further interactions can be incited. This schema of general functioning recalls the image of an organization of systems, each possessing their own dynamic, but dependent on their mutual interactions. This manner of interacting mutually according to local schemes of behavior can be presented in terms of finite state automata, for which the rules of transition are validated by outside stimuli, that can themselves be produced by a change in state of another automata. Our model is characterized by:

1) states and rules of transitions

2) change of state that is at the center of the dynamic of the system

3) Lack of capacity to memorize a state

All the relations that unite the members of a society with the environmental milieu are the objects of communication, which is transmitted along different sensorial canals : acoustic, tactile, visual, and chemical. We have provided our agents with a radio system. All the exchanges among agents are transmitted in the same frequency. This organization offers the advantage of being able to support the increase in the number of agents composing the micro-colony. We have chosen to transport information along the modulation of frequency because of its minimal sensitivity to radio perturbations, but especially for its better distinction between logical states 0 and 1. To recruit generalized agents, the specialized agents emit a frame according to the following form:

17. For a robot, interaction with the outside world consists of surviving and gathering information about the configuration of the milieu and eventually communicating this information to other agents. These interactions are reduced and dependent on the characteristics of each agent.

beginning frame	state to activate	end frame

This frame is directed at all generalized agents. At the reception of this frame, if an agent is available it must put itself at the disposal of the specialized robot in order to carry out a useful task.

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REFERENCES

Ali cherif. A. "AWA" The Artificial Walking Ant. Rapport technique, Département d'Informatique Université Paris 8, Octobre 1991.

Ali cherif. A. Le robot fourmi marcheuse, étude réalisation et programmation, Mémoire de DEA, Laboratoire d'Intelligence Artificielle, Universit Paris 8, 1991.

Ataya, H. Le comportement nécrophorique et la division du travail chez les fourmis Lasius Niger. Thése de troisiéme cycle, Université Francois Rabelais, Tours, 1980.

Coderre, B. "Modeling Behavior in Petworld", Artificial Life I, edited by C. Longton, Addison Wesley, 1989.

Dartigues, D. Etude de polymorphisme chez componotus aethiops lat. Aspect biométrique et biologique. Thése de troisiéme cycle, Université Paul Sabatier Toulouse, 1978.

Dawkins, R. The Blind Watchmaker. Penguin Books, 1988.

Deneubourg. JL. Goss, S. Gervet, J Theraulaz, G. Task Differentiation in Polistes wasp colonies: a model for self organizing groups of robots. From animals to animats, MIT Press, pp 346-355, 1990.

Flynn. A. Gnat Robots: A Low Intelligence, Low Cost Approch, IEEE Solid-state Sensor and Actuator Workshop, Hilton head, SC, juin 1988.

Greussay, P. L'ordinateur cellulaire, La Recherche Nø 204, pp 1320-1330, 1988.

Krief. P. Utilisation des langages objets pour le prototypage, 1992.

Minsky, M. The society of mind, Simon et Schuster, 1989.

Moravec. H. Mind children, The future of robot and human intelligence, Harvard University press, 1988.

Travers, M. "Animal Construction Kit". Artificial Life I, edited by C. Longton, Addison Wesley, 1989.