Advances in the studies of Bio-inspiration and swarm intelligence

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Abstract:

In this study, we are interested in models that copy the social behaviours of animals that is collective intelligence or the swarm intelligence that can be observed more particularly in ants, which will be the main species studied in this state of the art. From one point theory, this chapter is situated within the general framework of the study of the systems of swarm intelligence and its characteristics in the computer field

1 Introduction:

Over the past decade, swarm intelligence has been addressed from several scientific angles: first of all, in biology since this field remains strongly bioinspired, then in computer science where it constitutes a branch of artificial intelligence, etc. The problems dealt within computer science are most of the time solved by simple mathematical methods. However, these methods are not always suitable for complex issues, which appear, for example, in the field of robotics, or operational research. It is then necessary to invent new methods of resolution, and a source of inspiration used in the artificial intelligence branch is modelling complex natural systems. Swarm intelligence is like a form of collective intelligence that is observed in a large number of animal species (insects, fish, birds, mammals). The advantage of these approaches compared to traditional techniques is their robustness and exibility. These properties present the success of swarm intelligence, which is a paradigm for designing algorithms for complex problems by analyzing individually the cognitive capacities of the entities, sometimes extremely limited.

The notion of collective intelligence was born in the 1960s, from the application, in robotics, analyzes of ethologists on the behaviour of societies insects. Today, social behaviour patterns of social insects provide computer scientists and roboticists with powerful methods for optimization algorithm design and distributed control. Intelligence in swarm aims to transform the collective problem-solving skills social insects in artificial problem-solving techniques scientists. In addition to the ability of methods based on swarm intelligence often ofier a certain degree of exibility and robustness in environments dynamics [1], [2] and [3]. According to Bonabeau [3], swarm intelligence is born from modelling mathematical and computer science of the biological phenomena encountered in ethology based on behavioural statistical studies in species Studied. These areas of applications are now numerous for computer science, in operational research, particularly in communications networks computer.

Bonabeau et al. [3] extends the definition of swarm intelligence beyond the original robotic context: Swarm intelligence includes any attempt to design an algorithm or a problem-solving device in a distributed manner, inspired by the collective behaviour of social insects or other animal societies ". Merkle et al. in the book [4] proposes a pragmatic definition intelligence in a swarm from the computer point of view: "Swarm intelligence is a discipline of modern artificial intelligence which deals with the design of multi-agent systems for applications such as optimization and robotics ". "Collective intelligence refers to the cognitive abilities of a community resulting from multiple interactions between members (or agents). The elements made known to members of the community they do not possess that a partial perception of the environment and are not aware of the totality elements that influence the group.

Agents with straightforward behaviour can accomplish very complex tasks through a mechanism fundamental called stigmergy ". The social insects are nevertheless masters in the art of building gigantic structures and solving problems at the level of their society whole [5], [6], [7], [3]. Their colonies present a very varied range of collective behaviours, which combine eficiency with exibility and robustness. Social insects performed complex tasks. Indeed, although not being individually qualified as intelligent, the members of these societies are collectively capable of realize sophisticated constructions, adapt
to changing environments, to find the shortest way to a food source. These animals with simple appearance are thus able to build transport networks and exchange [8], [3], [9] within which the traficking in individuals and equipment is regulated [10], [11].

They are also able to build huge buildings compared to their small size [12], they have systems of division of labour allowing to dynamically allocate the difierent tasks to be performed for the good the functioning of the colony [13]. The study of animal behaviour has exciting aspects. Crowds pedestrians also create amazing structures creating alternating lines of individuals moving in the same direction [13]. Among them are the extraordinary collective phenomena (see Figure 1.1) that can be observed within many animal societies [3]. Figure 1.1 shows examples of collective behaviour in animal and human societies.

A collective intelligence supposes, to appear, that certain conditions [3]:

- Each individual is autonomous: no individual directs all others and there is no strategy at the global level.
- The system consists of independent and relatively simple individuals whose behaviors are correlated. The overall behavior is then the result finalized individual behaviors.
- The system is able to adapt and solve generic tasks in an intelligent way. This behavior emerges from interactions between people.

2. Intelligence in swarm, self-organization and systems complex

The process of self-organization is at the origin of what is called the intelligence collective. Collective intelligence has collective cognitive abilities evolved that emerge from limited individual cognitive skills. The self organization concept is essential to understand these Hermann phenomena Haken [4] defines self-organization as follows:

"Self-organization is spontaneous training, often with an apparent purpose, spatio-temporal, temporal, spatial or functional structures in systems are consisting of few or many components. In physics and biology, self-organization appears in open systems far from thermodynamic equilibrium ". In [14], the authors give the following definition of self-organization : "Self-organization is any process in which structures emerge at the collective level (or more generally the appearance of a scale structure N + 1 from a dynamic defined at the N scale, from the multitude of interactions between individuals, without being explicitly coded at the individual level.

3. Mechanisms of biological self-organization

Swarm intelligence is a strongly bio-inspired field, this process of the biological inspiration passes naturally by the knowledge of the biological analysis mechanisms involved in a natural phenomenon. In animal biology, the aspects of self-organization are the most spectacular and easily observable (ant colonies, ocks of birds, schools of fish, etc.) Biologists agree on the definition of self-organization [3] next : "Biological self-organization has mechanisms that justify it: among the mechanisms responsible for biological self-organization, we find fundamental mechanisms highlighted in cybernetics, namely the mechanisms positive and negative feedbacks as modes of interaction between entities forming the biological system [3]. " The possibility of exchanging information, through changes to the environment, is called stigmergie [15]. She is a concept born of Grasse studies in 1959 on then construction of termite mounds [4]. Two main classes of stigmergy can be distinguished [3].

Qualitative stigmergy, for example the presence of a hole in a surface the plane will be filled to find the atness of the surface, atness (new stimulus) in turn triggers the construction of cells for rearing larvae of the colony. Pheromone-based stigmergy is considered quantitative : it does not change a priori any nature during stimulation and behaviour of the colony, is governed by the
concentration of pheromone present on the object of construction. These fundamental biological mechanisms being described, the main properties of natural phenomena of self-organization are the following [4]:

- Process dynamics, whose constituent elements interact to maintain the self-organization of the system. These processes dynamics are non-linear;

- Emerging new properties, not present in the elementary parts and not merely related to their primary properties (training clumps in some insect larvae, for example). Also, these processes can implement locally simple mechanisms but which produce complex results on a large scale;

- Presence of parameters: specific parameters related to biological functioning (the chemical composition of a pheromone for example) and other of a physical nature (for example the volatility of a pheromone, the temperature, evaporation) can have a substantial impact on selforganization processes.

This parametric dependence also reinforces the role and importance of the environment. Self-organization lends itself well to the study of social insects that show complex collective behaviours are resulting from simple individual actions. The processes of self-organization in social insects can be grouped in four groups as their diversity are essential:

- Recruitment and collective exploitation of food sources: foraging updates strategies that allow insects a great adaptation to their environment;

- The division of labor and the organization of social roles within a same society, we can observe difierent specialized castes in a certain number of spots (brood rearing, foraging, construction nest, etc.);

- The organization of the environment: the construction of the nest is a symbol of the distributed organization of insects. The nest is built without the insects are directed they respond to a number of stimuli coming from their environment;

Inter-individual recognition: each ant is able to identify its congeners while participating itself in the identity of its colony (the exchange of food between individuals of the same colony, the trophalaxis, is an example of an altruistic act that allows one to homogenize the identity of the colony, the colonial identity). Explanations of the recognition mechanism are not yet perfectly established. However, it turns out that there is both a genetic component and a component acquired by learning. For example, a neural network has been used to reproduce this mechanism of learning and difierentiation between chemical compounds, in the case of termites [3].

4 Self-organization in artificial intelligence

The first fields of computing to have exploited the phenomena of selforganization are the evolutionary algorithms [15], [16]. The interest of the computer approach is due to its extensive use of the concept of agent which it develops elsewhere and which is particularly adapted to the study of self-organization phenomena.

Selforganization is a phenomenon described in several disciplines, particularly in physics [17] and in biology [4].

A definition has been proposed by [4]: "Self-organization characterizes a process in which a structure globally only a large number of interactions between local level components of the system. In addition, the rules specifying the interactions between system components are tracked using only information local authorities, without reference to the overall structure. " Stephanie Forrest uses the notion of agent to define emerging computation [14] which consists of the following elements:

- A set of agents explicitly programmed: a local micro-program to the agent defines his behavior locally (typically automata cellular);

- interactions between these agents, regulated by their own program, which have for resultant the formation of a global pattern (pattern) at the macroscopic level ;

- The natural interpretation of these schemes as calculation.

In this definition come several areas of computer development : connectionist models, cellular automata, biological models, classifiers, artificial life models, and models of cooperation in social systems without centralized authority. Forrest [14] insists that emerging computation concerns computational processes nonlinear. Non-linearity is commonly considered characteristic in the mathematical formalism of description of complex systems

5 Complex systems for swarm intelligence

Swarm intelligence is now an integral part of intelligence artificial distributed. The issues it raises, however, aﬁect many other scientific fields. In particular the concept swarm finds its place in the so-called "complex systems". Several authors have variably defined complex systems, but we always find a standard definition: a complex system is consisting of a large number of mutually interacting entities, and possibly interaction with an environment, whose overall behaviour emerges nonlinear of the local level. For some authors, non-linearity is essential to express complexity, even if the number of entities is small. Swarm Intelligence aims to provide a quantfiable size of self-organization systems. Science has developed around this problem bearing the name of complex systems science which seeks to theorize the phenomena of self-organization. The crucial question is therefore understand how the components of a system emerge from each other to produce a complex structure. Rodolphe Charrier [3] presents the design, features and applications of an original model, the system Multi-Logistics Agent (SMAL), for the field of swarm intelligence. The SMAL finds its origin in modeling complex systems: it is indeed derived from the coupled logistics iteration networks which is adapted in the model of calculation in the "inuence-reaction" scheme of multi-agent systems. Nino Boccara in the preface of her book dedicated to complex systems [4] proposes the following agent-based definition: "Although there is no universally accepted definition for defining a complex system, most researchers would describe as complex a system linked agents
that exhibit global emergent behavior not imposed by a central controlled but resulting from interactions between agents. These agents may be insects, birds, people, or companies, and their number may vary from one hundred to one million ".

Complex systems present types of behavior that are in a large measure independent of the nature of the individual element, one can quote for example:

- The stars in a galaxy,
- The components of a planetary atmosphere,
- The inhabitants of a city,
- Cars in a trafic jam,

- Social insects in a colony,
- Currents in a moving liquid,
- Cells in a multicellular organism,
- The genes in a network,
- groups of molecules in a reactive medium,

6 Fields of swarm intelligence

The immune system is responsible for protecting the body against the "aggression" of outside organizations. The immune response is based on the principle of clonal selection, also called clonal choice theory [3]. The subject of immunology is the study of the immune system. This system, composed of organs, cells and molecules, ensures the maintenance of the integrity of the organization he defends. So, it can be defined as, the set of biological mechanisms that allow the organism to recognize and to tolerate what belongs to it (the self), and to recognize and reject what is foreign to it (the non self): foreign substances or infectious agents to which it is exposed, but also its own altered constituents (such as tumor cells). This intelligent recognition mechanism has been modeled to give birth to the artificial immune system AIS (Artificial Immune System) [14] and [13].

These systems have complex properties because they are able to generate solutions and select them according to their eficiency according to heuristics original [4]. A description of the theoretical foundations and many applications of artificial immune systems can be found in [5]. The principle of systems Immunity is applied to the classification problem. Other more complex models exist. So in [6] the system uses multiple levels of cells and interaction (antibodies, lymphocytes, cells memorization). In [7], this same system is generalized and improved using fuzzy membership functions rather than a distance Euclidean and a threshold.

7 Swarm robotics

Classical robotics, like classical artificial intelligence, has led the development of sophisticated processes and entities with similar capabilities of those of the man. More recently, as for Distributed Artificial Intelligence, the interest of developing groups of interacting robots has developed. One of the advantages of these decentralized systems lies in the fact that the control is decentralized into simple tasks on each cooperating robot rather than in one super-robot for which the very model of the control is sometimes dificult to conceive. Distributed control, on the other hand, combines activities at the local level, each robot having only a dynamism and a limited idea: it is collective robotics.

Swarm robotics is a relatively new field of research that is interested in the self-organized coordination of multi-robot systems, and especially to those that consist of a large number of units whose complexity is minimized. Originally inspired by natural examples, mainly due to social insects [3], the field of robotics in swarm applies the principles of collective intelligence to robotic systems, in the purpose of taking advantage of complex global behavior emerging from interactions between the agents and the environment, disturbed by noise and limited range their means of perception, communication and action. The robotics in swarm seeks indeed to stand out from distributed or collective robotics by his explicit bio-inspiration. A definition of the domain is given in [15], [16]: 'Swarm robotics is the study of how a large number of agents relatively simple physically embodied can be designed for wanted
to emerge from local interactions between agents and between agents and the environment ".

Swarm robotics considers robots generally identical, of design simple that have only local perceptions and interactions. These swarms robots are likely to ofier the following features that join those of collective robotics [17]:

Robustness: the inherent redundancy of the system, the decentralized coordination, the simplicity of design of each entity and the distribution of the perception, make swarms of robots robust systems to failures and changes in the environment;

Flexibility: concerns the capacity of different robots to treat different swarms types of problems;

Scalability: performance is not globally impacted by size of the swarm.

Currently, research is being conducted in the direction of the development of intelligent systems of robots inspired by the study of insect societies. Neural networks are an example of organizing small reactive units simple (artificial neurons) interaction of which can emerged a "intelligent" global behavior. The team of the Danish biologist Axel Michelsen designed Robobee in 1989 [9] as Figure 1.2 shows a ball of bronze and wax the size of an insect, animated by a metal rod and equipped, as a wing, with a razor blade operated by an electromagnet. Able to produce the dance of foraging bees indicating the location of feeding areas, Robobee managed to direct bees from a hive to goals predetermined. Elaborate "intelligent lures", able to recover from information in the community to interact with it and better handle it is precisely the aim of the European project Leurre.

Guy Thfieraulaz is the precursor in France of a new approach: Robotics collective is an alternative to the systematic use of a robot unique, ultrasophisticated, equipped with many sensors and very complex algorithms navigation and decision-making ". Craig W. Reynolds [9] was the first to design such systems in the field of Image Synthesis. Population management individuals (schools of fish, flight of birds, colonies of insects, ...) is no longer entrusted to a deterministic and sequential algorithm, but is the result of the many interactions between individuals, each with perceptive abilities local and limited, but whose overall behavior exhibits a complexity and apparent motivation that is found only in natural societies. The types of problems to be solved in swarm robotics are for many from phenomenologies identified in biological self-organization [8]:

Aggregation and dispersion are two sides of the same coin: the swarm must to be able to explore its environment (dispersion) and also toregroup to exploit (aggregation);

- Fourragement: inspired by ant behaviors, the swarm must be able optimize your search for resources;

- Self-assembly and coordinated movement: the swarm must be able to weld to constitute a structure responding to a constraint of the ground (ex: bridge formation in ants, towing prey, ...). In this configuration where robots are physically connected, the goal is to be able to continue to move collectively;

- Cooperative and collective transport: the metaphor here is that of ants carrying prey to several individuals;

- Shape generation and self-organization: this corresponds to the capacity of the swarm to produce specific or singular clustering schemes by self-organized process.

Self-organized collective robotics is based on a decentralized logic that uses disjoint units, simple and random, distributed in the environment without an exhaustive knowledge of it. These units interact with the environment and between them by means of signals of which only the intensity is significant. Each agent is able to anticipate an action by extrapolating his current situation in the neighborhood of which he has knowledge. In such systems, the solution to the problem posed is not programmed, but emerges from the many interactions. The Collective resolution of a task requires cooperation. Artificial Intelligence Distributed focused on multiagent systems whose elements integrated sophisticated behaviors, the Collective Robotics, inspired collective intelligence, only use simple agents (in the stimulus mode) having no representation of the system as a whole.

8 Distributed Artificial Intelligence and Multi-Agent Systems

The principle of the collective intelligence of several simple entities in interaction from which emerges on a collective level a complex structure (qualified of intelligent) is present in difierent disciplines: biology, physics, computer science, etc. In these areas, difierent models have emerged to describe and analyze such systems. In computer science, reactive multi-agent Systems provide a conceptual framework for the representation and simulation of such systems. One way to design such systems is to make a link between individual behavior and collective response is to draw inspiration from biology, particularly in the context of insect societies. A Such an approach provides solutions whose essential characteristics are:

- **Dynamic:** the system is organized according to its current context and it is able to continually adapt to variations of it;
- **Decentralized:** there is no need for a centralizing entity dictating what must do each agent, we get rid of bottleneck problems, construction and maintenance of a global representation as well as problems of dysfunction of this centralizing entity;
- **Simple:** the individual model is relatively simple and requires effort of lesser design.

As part of the multi-agent system organization, consider a collective then poses the problem of organizing the different activities of the agents so that overall this collective behaves as a coherent whole and meets the requirements which are fixed to it according to the capacities peculiar to each one, characteristics changing environment, etc. This organizational problem makes the subject of numerous studies in the context of multiagent systems.

For cognitive agents, these are equipped with means of representation, reasoning and communication elaborated. They can represent the task to solve, the skills of others, reasoning about the consequences their actions and interact in an elaborate way with others; In the reactive case the agents have no or little representation of others, they have stimulus-response-type decision mechanisms and interact via their environment with others. They only have information local. In this second case, the agents can not really be qualified as intelligent individually but the society they form can be. We then speak of reactive multi-agent systems or intelligence systems.

Conclusion:

This paper proposes state of the art on the topics we are are interested in our thesis work. We explain swarm intelligence and the main features as well as the properties that real ants possess for carrying out complex tasks. After a description of the sources of biological inspirations, we propose a state of places of what may exist in terms of mathematical modelling inspired by biology for several developments in computer science.

In artificial life, many researchers are interested in how and the emergence of collective intelligence and use computers and mathematical modeling as prospecting tools. In the case of ants algorithms, the link with the source of biological inspiration is more obvious still and the mechanism by pheromone deposition has become popularized in computer science networks, combinatorial optimization and data mining.

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