Systèmes Multi-Agents Coopératifs

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A THEORY OF EMERGENT COMPUTATION BASED ON COOPERATIVE SELF-ORGANIZATION FOR ADAPTIVE ARTIFICIAL SYSTEMS

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Résumé : Ce papier propose une nouvelle approche théorique et pratique pour concevoir des logiciels adaptatifs artificiels immergés dans un environnement dynamique. Cette approche est basée sur une méthode d'auto-organisation indépendante de la fonction globale réalisée par le système. Elle est dérivée du théorème suivant : "à tout système fonctionnellement adéquat dans un environnement donné peut être associé un système ayant un milieu intérieur coopératif qui réalise une fonction équivalente". Cette méthodologie de conception est adaptée aux événements imprévisibles survenant dans l'environnement du système. Ceci est un avantage majeur par rapport à de nombreux modèles d'algorithmes adaptatifs modélisant des systèmes naturels (comme les réseaux neuronaux ou les algorithmes génétiques).
Nous expliquons ensuite pourquoi la méthodologie de conception proposée pour le développement d'applications multi-agents réduit grandement la complexité lors de la phase de conception. Le critère de coopération, sous-jacent à notre processus évolutif, est enfin défini formellement et analysé par rapport aux systèmes naturels tout particulièrement à partir de l'approche sélective darwinienne.

Abstract : In this paper, we propose a new theoretical and practical approach for designing artificial adaptive software plunged in a dynamic environment. It is based on a self-organization method without any evaluation of the global function realized by the system. It is derived on the following theorem : "For any functionally adequate system in a given environment there is a system having a cooperative internal medium, which realizes an equivalent function". This evolving method is appropriate when really unforeseeable events occur in the environment. This is a major advantage compared to many well-known models of adaptive algorithms mimicking natural systems (as neural networks or genetic algorithms).
We show then the method for developing multi-agent applications and why it reduces greatly the complexity at the conception phase. The cooperation criteria, underlying our evolution process, is then formally defined and analyzed in regard of natural systems, especially from the darwinian selection approach.

1 INTRODUCTION : DESIGNING COMPLEX ADAPTIVE SYSTEMS

Many systems in nature exhibit sophisticated collective information-processing abilities that emerge from the individual actions of simple components interacting via restricted communication pathways. Some often-cited examples include efficient foraging and intricate nest-building in insect societies, the spontaneous aggregation of a reproductive multicellular organism from individual amoebae in the life cycle of the Dictyostelium slime mold, the parallel and distributed processing of sensory information by assemblies of neurons in the brain, and the optimal pricing of goods in an economy arising from agents obeying local rules of commerce [Crutchfield,1994]. These coherent global activities are realized by entities having only local view of their environment. Erroneous behaviors or unexpected events are not controlled by an individual but must be recovered by its adaptation process. Adaptability is required to unexpected events, dealing with imperfect and conflicting information from many sources, and acting before all relevant information is available.

1.1 From complex systems to emergent computation

Computer scientists are nowadays confronted to the development of artificial systems not easily understandable, due to performance of concrete machines and their networks. Commonly speaking this refers to the broad use of complexity as an intuitive notion to speak about intractable systems. Many definitions are in the literature [Edmonds, 1995] :

- computational complexity is the amount of computational resource (usually time or memory) that it takes to solve a class of problem,
- the minimum length of a Turing machine program needed to generate a pattern,
- logical depth as the computational resources (chiefly time) taken to calculate the results of a program of minimal length.

But our purpose concerns only the usefulness application of this concept, and a good way to reduce complexity at the conception phase of artificial systems is to avoid programming at the higher global level. Thus, the result of the computation, could be built from microscopic level in a bottom-up fashion, and the macroscopic structure emerges from the microscopic computation [Forrest, 1991]. In this case, complex systems are notoriously difficult to study and there are many problems with predicting the emergent behavior of large numbers of interacting entities. This is why we show in this paper our theoretic approach, which explains how any set of local behaviors will collectively create the desired collective behavior.

2 WORKS ON ADAPTIVE AND COOPERATIVE ARTIFICIAL SYSTEMS

Salome [Salome,1994] has developed a self-structuring neural net classifier in which learning is not based on an error function but on the values of synaptic weights. A settled neuron presents a connection strength above a certain settling threshold fixed initially. A settled neuron will sharply truncate its input space and it is a candidate for duplication. A useless neuron has a connection strength below the uselessness threshold parameter, here again initially fixed. It will be suppressed of the network. This self-structuring process is guided by the utility of each neuron i.e. an implicit analysis of cooperative activity inside the network.

Hogg and Huberman [Hogg, 1992] showed that when agents cooperate in a distributed search problem, they can solve it faster than any agent working in isolation. A similar result was obtained by Mataric [Mataric, 1994] with a set of mobile robots foraging in order to bring back tiles to "home". She has observed that when the number of individualist robots increases, the global performance decreases due to the interfering activities. For her, the ideal result will be obtained with robots having altruistic behaviors.

Multi-agent learning relies on, or even requires, the presence of multiple agents and their interactions. Many authors in this domain [Goldman,1994], [Sekaran,1995], [Sen,1995], [Weiß,1993] have studied the role of social behavior of agents on the global performance. They found that cooperation between agents improves the results. If we consider each agent of the system as a piece of knowledge, these works mean that knowledge is well learnt when it is organized in a cooperative manner. This is a criterion independent of the meaning (the semantic needed for common knowledge), and thus could be a good approach for a general learning theory.

Steels [Steels, 1996] has taken an interest in self-organization in the case of two applications. The first concerns the foraging of a geographical zone by several robots. The self-organizing mechanism is similar to the one made by ants when they try to find food : a depositing of crumbs simulates the pheromone depositing, which guides other robots. The second application concerns the autonomous elaboration of a vocabulary by several agents present in a given environment. Each agent possesses for that its own set of associations word/meaning. So it can experiment associations used by other agents present in the system according to the following 3 manners : either by propagating the association it possesses, or by creating a new association or by self-organization (based on retroaction mechanism and allowing the agent to bring up to date the confidence it has in its association).

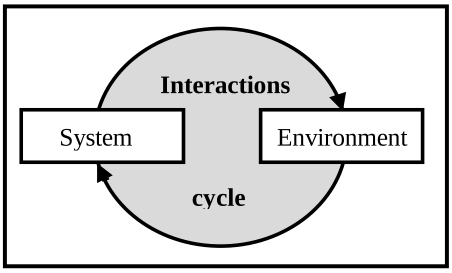
Bollen and Heyligen [Bollen, 1996] want to conceive an algorithm allowing distributed hypertext networks to self-organize themselves according the knowledge of their users in order to give the research more performing. The proposed method consists in applying 3 learning rules (frequency, symmetry, and transitivity) until reaching a stable state, which represents the knowledge, divided between participants. It has been applied to an associative network composed of nouns, which self-organizes itself until reflecting intuitive semantics between persons who used it.

Gasser [Gasser, 1991] and Guichard [Guichard, 1996] propose a self-organizing method based on two primitives called decomposition and composition which respectively consist in decomposing the knowledge of an agent or recomposing the knowledge of two agents (in order to form only one) in order to increase the parallelism and give the system better. The invocation of these primitives refers to a knowledge which is global in Gasser whereas it is local in Guichard (it uses introspection in this case).

The main theoretical question remains : can we design artificial systems without having an external evaluation function ? This question is associated with the ability to isolate universal characteristics of the learning process. The consequence of a positive answer is the ability to suppress any random process for learning strategy. Adami (Adami,1994) claims that "In almost all cases of learning in natural systems, the fitness of a certain configuration (or "hypothesis") is determined within the system.[...] We shall call systems that can perform this feat "auto-adaptive", to emphasise the fact that we do not provide a fitness -or error- function. For example, all adaptive natural systems are "auto-adaptive" in following the previous meaning and noise is outside of the learning algorithm : it cannot be avoided but these systems accommodate its presence. We think that cooperation could be a general learning criterion, which consequently avoids the disadvantage of attractors.

3 THE SYSTEM, THE ENVIRONMENT AND THE OBSERVER

A complex system designer is unable to know a priori all the events, which could occur in the future when he will be plunged in the real environment. Thus, the only way to adapt it, is autonomously without any predefined algorithm to follow. Adaptation occurs if the system is able to obtain benefits from past experiences and to react faced to an unexpected event : this implies that it must be situated in a concrete medium.



Generally speaking, the exchanges between a system and its environment lead to reciprocal influences allowing mutual adjustment. This process was observed for a long time and applied to artificial systems for example with the feedback control in cybernetics [Von Foerster, 1962].

3.1 The observation of system-environment interactions

In the real world, a system perceives and acts locally in its environment. Its behavior modifies the state of the world that in turn reacts in exerting a pressure on the system. The designer of an artificial system is primarily interested by a "right" behavior of it in the desired environment. When a system has this "right" behavior -judged by an external observer knowing the environment- we say that it is **functionally adequate**. Functional adequacy represents something more than the function realized by the system. For example, the function of matrix inversion can be implemented in using many algorithms. Even the results are the same; software can be distinguished by criteria such as the memory space or the response time. These criteria could be crucial in specific environment such as real time for determining the "right" behavior of software. Thus, functional adequacy is always a situated notion. On the opposite, when the system is functionally inadequate, at least one unexpected response occurs for the environment viewpoint. The world state resulting from an external disturbance must lead the environment to an adaptation mechanism that opposes to it. If this adaptation could not occur, the environment will have at a later date a behavior, which disturbs the system.

Thus, system and environment are all the time in an interacting process where the resulting activity of one influences the other. From an ideal observer viewpoint knowing precisely the system and its environment, these influences can be classified into three categories :

- **Cooperative activity**. The system or its environment operates a world transformation favoring the further activity of the other. In this type of activity, a system and its environment are engaged in a mutually beneficial exchange. This can be partially observed in living symbiotic organisms or in ecosystems. In a cooperative activity, acts seem to be coordinated, even if they are not intentionally realized.
- **Antinomic activity**. The system or its environment operates a world transformation preventing the activity of the other. In the real world, the same critical resource (as food for example) is essential for many organisms. This is the resulting of a conflicting state of affairs, even not intentional.
- **Indifferent activity**. It is also an uncooperative activity, but in this case a particular world state resulting from the action of the system or its environment has no consequence for the other. This can be the case if an environment behavior is imperceptible in any way by the system. An indifferent activity could also occur for particulars reversible actions.

3.2 Systems typologies

We say that a given system S realizes the function f_S. We consider its physical support as the concrete mean by which the system S is able to realize f_S. As we have noted above, the physical support generally plays a role in the functional adequacy of the system. According to this analysis, the activity of the system in its environment is written as follows : $W\alpha \xrightarrow{fs} W\beta$.

In this paper we note W_α a state of the world produced by the environment and considered by the system S at a given time. W_β is the state of the world resulting from the action of S and now considered by the environment to produce something. According to the previous categories of interactions, a state of the world W_α can possess three components $W_{\alpha c}$ "cooperative", $W_{\alpha a}$ "antinomic", $W_{\alpha i}$ "indifferent" (from the system viewpoint). Conversely, W_β denotes the perception of an interaction from the environment viewpoint.

Property 1 : A functionally adequate system never produces an antinomic activity from the point of view of its environment

Intuitively a system, which realizes a «good» function, cannot prevents the activity of the environment in which it is plunged. We consider this as a thesis because it will be never proved; even we have many considerations, which leads to it in observing natural system. Furthermore, the set of its components is by evidence sufficient to realize this right function.

From the point of view of the following formal demonstration we consider this property as the only necessary axiom.

Definition 1 : A cooperative system is a system having always cooperative interactions with its environment.

We assume that a cooperative system has always cooperative exchanges with its environment. This is immediately derived from the previous notion of cooperative activity.

Definition 2 : A cooperative internal medium system, is a system composed of parts which are always in an interactive way with its own environment.

This is simply the definition 2 reported to all the parts of the system. Each part interacts cooperatively with the environment of the system and also with all (if the case occurs) the other parts of the system.

4 THE THEORETICAL RESULTS OF SELF-ORGANIZING COOPERATIVE SYSTEMS

The theory presented in this part gives a theoretical reason -the functional adequacy- to design artificial systems having components in cooperative interaction. Some points was previously developed in others papers such as [Piquemal,1996] and [Camps, 1998].

4.1 Lemma 1

The set of cooperative systems is included in the set of functionally adequate systems.

The definition given above for a cooperative system includes the definition of a functionally adequate system. Thus any cooperative system is also functionally adequate.

The lemma 1 is very useful to evaluate the functional adequacy of a system : when it is all the time in cooperative interaction, we can deduce that it is functionally adequate. But, an important problem remains : perhaps the subset cardinality is very small in regards of the set cardinality. In other words, perhaps we have possibly a very little chance to find a cooperative system for a given environment. If this would be the reality, this method for finding artificial adaptive system would be illusive. The lemma 2 gives an answer to this central question.

4.2 Lemma 2

For any functionally adequate system, there is at least one cooperative system functionally adequate in the same environment.

The demonstration of this lemma is obtained by construction. We suppose that we are an omniscient observer able to know perfectly if a given action of a functionally adequate system is cooperative in the environment. When it is not cooperative, we transform the activity of the system without any consequence from the environment viewpoint. Thus the resulting system is also functionally adequate.

The fact that there is always a cooperative system equivalent to a functionally adequate system gives an interesting set of particular systems. Unfortunately, neither the lemma 1 nor the lemma 2 gives yet directions to know how to learn in order to obtain a functionally adequate system. In order to do that, we study now a particular subclass of cooperative systems : systems having a cooperative internal medium. If we find right properties for these systems, the basic idea will consist in reorganizing the components (given at the beginning of the system) to find cooperative interactions.

4.3 Lemma 3

The set of systems having a cooperative internal medium is included in the set of cooperative systems.

The outside of a part of the system (i.e. its environment) is composed of the environment of the system and all the other parts of the system. Deriving from this, we can assert that the set of interactions between the system and its environment is included in the union of the sets of the interactions of all these parts. Because the second set of interactions is cooperative, the first set (a subset) is thus cooperative

Now, we know that systems having internal cooperative medium are functionally adequate. But for a given environment we could not yet guarantee that if a cooperative system exists, a system having an internal cooperative medium is also available. This is the subject of the lemma 4.

4.4 Lemma 4

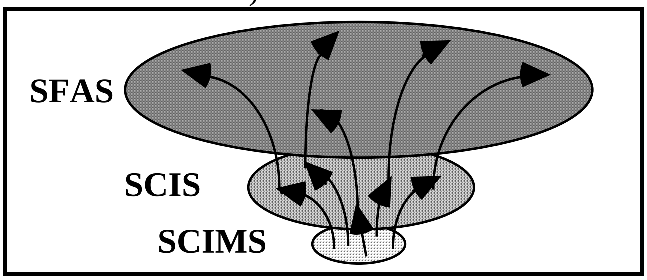
For any cooperative system, there is at least one system having a cooperative internal medium which realizes an equivalent function in the same environment.

The proof is similar to those given in the lemma 2. In observing all the parts of the system, we can find for each of them a new function f* allowing to give the same result as the previous function from the same environment point of view. Thus the new system is similar to the first one because it possesses all equivalent parts organized in the same fashion.

4.5 Theorem

For any functionally adequate system in a given environment there is a system having a cooperative internal medium which realizes an equivalent function.

The above theorem derives simply from the previous lemmas. Firstly, this is an evidence that a system having a cooperative internal medium is functionally adequate because it is a member of a set of system themselves functionally adequate (the cooperative systems). Secondly, for each functionally adequate system corresponds at least a cooperative internal medium system by the way of a surjection operation (having the property of “ functional adequacy equivalence in the same world”).



Surjective function between the set and subsets of functionally adequate systems

5 RESULTS ANALYSIS

The notions of emergence and self-organization are strongly linked in our works. Self-organization introduces behaviors, structures or forms in the collective level which are new relatively to behaviors, structures or forms which compose it : it’s the emergence [Forrest, 1991]. Self-organization, such that we consider it, doesn’t make a presupposition on the finality of the system. Entities that compose the system must only pursue an individual goal (being cooperative with others) while adapting themselves to possible external perturbations and learning during the functioning. Although no finality is explicitly programmed in the behavior of the system components, the self-organizing system reaches to provide a result : that is the emergence.

5.1 Designing multi-agent for self-organized adaptive complex systems

Multi-agent systems consist of several agents capable of mutual and environmental interactions. Each agent has a local view of the environment, has generally specific goals and is unable to solve alone the global task devoted to the system. This class of complex systems, composed of many active elements with mutual interactions, is a typical example in which global characteristics of the system arise from the cooperation of the elements. And this phenomena, in turn, acts on the interactions and modifies the properties in an intricate manner. This kind of problems resulting from the complexity of multi-agent systems can be avoided or at least reduced by endowing the agents with the ability to adapt and to learn, that is, with the ability to improve the future performance of the total system, of a part of it, or of a single agent [Weiß, 1996]. Obviously, if we consider a multi-agent system as the whole system described in the above theory and agents as the parts which composed it, we see that this field of computer science is very relevant to implement our theory of complex adaptive systems.

In our approach, the goal of each autonomous agent is to find the right place inside the organization in order to interact cooperatively with others. The behavior of an agent is determined at a time by its current skills and beliefs in order to obtain only cooperative interactions from its own viewpoint. The behavior of a cooperative agent leads the global multi-agent system to become a member of the set of the cooperative internal medium systems. For that, when an agent receives a signal which is uncooperative from its own viewpoint, it must broadcast it inside the internal medium. This guarantees that an agent concerned with the content of this signal will receive it. When an agent has obtained a result and the receiver is not known, the agent broadcasts it in order to join another agent likely to be interested. This broadcast process ends because the number of parts is finite and each of them broadcasts a same message at the most one time.

While the system is not functionally adequate, conditions necessarily occur for its reorganization. From an observer's viewpoint, this system can detect an uncooperative state, when a novelty occurs or when a feedback of a previously erroneous response of the system arises from the environment. Conditions underlying an uncooperative state derive from the definition of ideal cooperation :

Designing a cooperative multi-agent system consists in defining for each component -the agents- all the possible uncooperative states and the actions associated in order to suppress them. When the system is running in a dynamic environment, we observe an internal process consisting in modifying the relations between agents. Thus, the reorganization of the partial functions realized by each agent leads to a modification of the global system function, and non cooperative states due to unexpected events are progressively suppressed. We will show in the last part why a cooperative system is always functionally adequate

5.2 The ideal cooperation specification

Except in virtual applications, all system (even artificial), interacts in our real physical world. For this reason, its functional adequacy depends strongly on the meaning of cooperation in the real world in order to obtain cooperative interactions. Even if ideal cooperation cannot be observed in our real world, we think that it can be closely approached by human beings interacting, or symbiotic living entities, or ecosystems.

Today, and from our knowledge, we have defined some necessary characteristics **:**

Understanding - A perceived signal must be interpreted by a cooperative system. Mutual understanding cannot be a postulate but could emerge from mutual adjustment between the system and its environment**.**

Reasoning - All information (an interpreted signal) must lead to new logical consequences by the system. In other words, an information must bring novelty : a difference with previous information.

Acting - Conclusions of the reasoning process (results of the system function) must be useful to the environment of the cooperative system.

5.3 A new law of nature ?

Two simple mechanisms are the centerpiece of the Darwinian theory of biological evolution by natural selection : reproduction with variation and selection. The reproduction mechanism allows to copy parent's genes, not be considered as exact copies or replicas of themselves due to some random mutations thrown in. Selection is the process in which organisms that are better suited to their environment tend to survive and produce more offspring.

The observed consequence of the natural selection is the existence of adapted species of organisms in the world. Systems having a high fitness tend to maintain for a long time, and/or they leave many offspring (they have produced many other systems). On the opposite, systems, which have insufficient fitness, tend to be eliminated from the natural scene.

We claim that this Darwinian view is incomplete in the sense that the fittest systems have very particular links with their environment: they are very often in cooperative interactions. For example, this is the case for ecosystems. The underlying consequence of this process could be a new law of nature expressed as the following "*The adaptation process between a system and its environment is concomitant with their cooperative exchanges*".

Functional adequacy is also desirable for natural systems in order to increase their lifetime. We have shown that a good way to obtain it, is to have a cooperative attitude. "Everybody will agree that cooperation is in general advantageous for the group of cooperators as a whole, even though it may curb some individual's freedom." [Heylighen,1992]. In this case why do not we observe this behavior in nature ?

- First, natural systems don't need to possess any principle (even valid) prior to their existence. If a being living is not functionally adequate, he will not survive : it is a simpler way to select viable systems than to presuppose specific attitude and abilities.
- Second, even it will be desired, cooperative attitude cannot be observed permanently in nature because a system is unable to perceive and control perfectly its medium. Unexpected events arise frequently explaining that perfect cooperation occurs only in a very restricted space and time zone.

6 CONCLUSION

Generally, learning algorithms are based on a global function evaluation : for choosing the fittest individuals in the selection phase of genetic algorithms or for knowing the output error between the real and desired responses of neural networks. On the opposite, we have been studying the ability of a learning policy in artificial systems when the designer is unaware to specify explicitly or implicitly the global function to obtain. Thus, our work contributes to the elusive task quoted from Adami : "One of the most elusive tasks associated with formulating a theory of learning is the isolation of universal characteristics of the learning process. In fact, the very existence of a universal learning process has yet to be established" [Adami, 1994].
Our theoretic result in order to obtain a desired global function from only local cooperative interactions between subfunctions can be obtained only if all the necessary subfunctions (or agents) are already present. This high constraint is only used for the theory demonstration. In fact, each agent could be also a multi-agent composed of cooperative sub-agents at a lower level. Thus, we have a multi-agent able to converge towards functional adequacy i.e. the "right" subfunction at the upper level. The multi-agent stratum process ends when we have atomic agents. So a system design requires only the implementation of atomic agents.

In order to test a theory (by falsification or validation) a great amount of experiments must be done in various fields. For this reason, we have implemented our theory on cooperative self-organization on three applications :

- ♦ the first was the tileworld game [Piquemal, 1995] in which we have experimentally verified that cooperative agents have better results than selfish ones.
- ♦ the second concerns an application of cooperative information systems with France-Telecom [Camps, 1996], [Camps, 1997] and with Deutsch Telekom [Camps,1998], [Athanassiou, 1998], [Gleizes, 1998]. In these software, the agents representing the users and the services create a dynamic network of mutual interest based on the cooperative self-organization process.
- ♦ the last is about a national multi-disciplinary project about natural and artificial collective intelligence. The first results of a cooperative self-organized ants society application gives performances at least better than natural simulated insects.

But the better way to validate this theory is its propagation towards other scientific team in using it in various adaptive complex systems.

7 BIBLIOGRAPHY

Adami C. 1994. Learning and complexity in genetic auto-adaptive systems - Physica D

Athanassiou E., Camps V., Glize P., Gleizes M-P., Leger A., Lakoumentas N. 1998 - A Framework for Agent Based Information Brokerage Services in Electronic Commerce - International Conference EMSEC

Bollen J. , Heylighen F. 1996. Algorithms for the self-organisation of distributed, multi-user networks. Possible application to the future World Wide Web, Cybernetics and Systems'96, R. Trappl (Ed.)

Camps V., Gleizes M.P.˙, Glize P. 1998 - Une théorie des phénomènes globaux fondée sur des interactions locales - Journées francophones sur l'Intelligence Artificielle Distribuée & les Systèmes Multi-Agents (JFIAD&SMA), Pont à Mousson, Éditions Hermès

Camps V., Gleizes M.P. 1997. Une technique multi-agent pour rechercher des informations réparties, cinquièmes JFIAD&SMA, La Colle sur Loup, Éditions Hermès, pp. 29 - 46

Camps V., Gleizes M.P. 1996. Cooperative and mobile agents to find relevant information in a distributed resources network, Workshop on Artificial Intelligence-based tools to help W3 users, Fifth international conference on World Wide Web, Paris

Crutchfield James P., 1994- The evolution of emergent computation - Santa Fe Institute Technical Report 94-04-012

Edmonds B. 1995. What is Complexity ? The philosophy of complexity per se with application to some examples in evolution.

Forrest S. 1991. Emergent computation : Self-organizing, Collective, and cooperative phenomena in Natural and Artificial Computing networks - Special issue of Physica D - MIT Press / North-Holland.

Gasser I., Ishida T.A. 1991. Dynamic Organisational Architecture for Adaptative Problem Solving, AAAI91 p. 185-190

Gleizes M-P., Léger A., Athanassiou E., Glize P. - Abrose : Self-Organisation and Learning in Multi-Agent based Brokerage Services – International Conference ISN - 1999

Goldman C.V., Rosenschein J.S. 1994. Emergent Coordination through the Use of Cooperative State-Changing Rule - AAAI

Guichard F. 1996. La réorganisation dynamique dans les systèmes multi-agents - Thèse de doctorat de l'Université de Savoie

Heylighen F. 1992. Evolution, Selfishness and Cooperation

Hogg T., Huberman B.A. 1992. Better than the best: The power of cooperation - Lectures notes in complex systems - Addison Wesley

Mataric Maja J. 1994. Interaction and Intelligent Behavior PHD of Philosophy Massachussetts Institute of Technology May 1994

Piquemal-Baluard C., Camps V., Gleizes M.P., Glize P. 1995. Cooperative agents to improve adaptivity of multi-agent systems, Intelligent Agent Workshop of the British Computer Society in Specialist Interest Group on Expert Systems & Representation and Reasoning, Oxford

Piquemal-Baluard C., Gleizes M-P, Camps V., Glize P. 1996 - Une Thèse pour l'auto-organisation des systèmes artificiels - 3rd Systems Science European Congress, Rome, Italy,

Salome T., Bersini H. 1994. An algorithm for self-structuringural net classifiers - 2th IEEE conference on neural networks

Sekaran M., Sen S. 1995. To help or not to help - Seventeenth Annual Cognitive Sciences Conference - Pitsburg Pennsylvannia

Sen S., Sekaran M. 1995 Using reciprocity to adapt to others - IJCAI

Steels L. 1996 . The spontaneous Self-organization of an Adaptive Language, Machine Intelligence 15 - Oxford University Press - Oxford - Muggleton S. (Ed.) - March 29, 1996

Von Foerster H., Zopf G. W. 1962. Editors - Principles of self-organization - Pergamon Press
Weiß G. 1993. Learning To Coordinate Actions In Multi-Agent Systems - in Proceedings of the International Joint Conference on Artificial Intelligence.
Weiß G. 1996. Adaptation and Learning in Multi-Agent Systems. In Lecture Notes in Artificial Intelligence 1042. Springer Verlag