



HAL
open science

Ambient Intelligence as a Never-Ending Self-Organizing Process: Analysis and Experiments

Jean-Pierre Georgé, Valérie Camps, Marie-Pierre Gleizes, Pierre Glize

► To cite this version:

Jean-Pierre Georgé, Valérie Camps, Marie-Pierre Gleizes, Pierre Glize. Ambient Intelligence as a Never-Ending Self-Organizing Process: Analysis and Experiments. 33rd Annual Convention of the Society for the Study of Artificial Intelligence and the Simulation of Behaviour (AISB 2007), Society for the Study of Artificial Intelligence and Simulation of Behaviour (AISB), Apr 2007, Tyne, United Kingdom. hal-03800712

HAL Id: hal-03800712

<https://hal.science/hal-03800712>

Submitted on 7 Oct 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Ambient Intelligence as a Never-Ending Self-Organizing Process: Analysis and Experiments

Jean-Pierre Georgé and Valérie Camps and Marie-Pierre Gleizes and Pierre Glize**

Abstract. Our team has been working for several years on building adaptive systems using self-organising mechanisms following a specific approach we called the AMAS¹ Theory. Its main originality is that it enables artificial systems to show relevant emergent behaviours by focusing on local cooperative interactions among the agents. This article aims at showing the relevance of this approach specifically, and more generally of any self-organisation approach, for Ambient Intelligence. For this we analyse and discuss AmI problems in the light of our experience in complex systems, as well as show encouraging results in a first experiment in a kind of AmI system (a service providing network of agents).

1. INTRODUCTION

AgentLink Roadmap [Luck, 2005] asserts that agents have their place in spreading fields such as Web Services, Semantic Web, Peer-to-Peer, Grid Computing, Ambient Intelligence, Self* Systems, etc..

“If we assume that agents are abstractions for the interaction within an ambient intelligent environment, one aspect that we need to ensure is that their behaviour is regulated and coordinated, so that the system as a whole functions effectively. For this purpose, we need rules that take into consideration the social context in which these interactions take place, and the whole system begs for an organisation similar to that envisaged by artificial agent societies. The society is there not only to regulate behaviour but also to distribute responsibility amongst the member agents””.

According to the previous citation, we consider that the central problem in Ambient Intelligence societies, which are highly open and dynamic, is to find generic local rules followed by the agents encapsulating numerous types of objects and devices in order to guarantee an efficient and relevant collective behaviour. To face the dynamics and the heterogeneity of AmI systems (such as workload, failures and interoperability of the devices, as well as their addition or suppression), these agents must enable the system to adapt in every context.

We already have proposed the AMAS (Adaptive Multi-Agent Systems) theory [Georgé, 2003b] to solve complex systems such as timetabling management [Picard, 2005] or aircraft design optimisation [Welcomme, 2006]... This way to design artificial systems follows a process defined in the

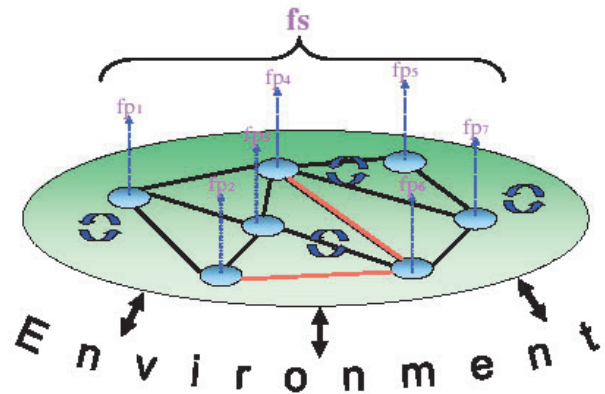


Figure 1: Adaptation - Changing the function of the system by changing the organization.

ADELFE methodology [Bernon, 2005]. Our challenge is now to apply it to ambient systems. We propose in this paper to show how the AMAS theory can tackle these real-time adaptation problems to design system where each agent encapsulates a device. AMAS approach allows the design of complex systems that can be underspecified and for which an *a priori* known algorithmic solution does not exist.

The paper is structured as follows. Section 2 shows how ambient systems can be studied as emergent systems. Then, the AMAS theory dedicated to design system with emergent functionality is presented and its use for ambient systems design is justified. Section 3 details preliminary experiments on a kind of AmI system composed of a large number of devices and some results are described. The paper ends with a discussion highlighting the advantages of self-organising systems for designing ambient systems.

2. AMBIENT INTELLIGENCE, A CLASS OF EMERGENT PHENOMENA

Let us consider for instance a room with a large number of electronic equipments controlled each by an autonomous microchip. This room has a goal: the satisfaction of the users living in it from day to day. The goal itself “user satisfaction” is really imprecise and incomplete, and the way to reach it even more. The specifications of this kind of software are incomplete and the system is often underspecified. Nevertheless, suppose that we are able to define a learning algorithm in order to assign correct behaviours to the objects and devices. These objects could move to other ambient environments such as an airport, a rescue service or a classroom. The interactions of a given device would be quite different with its new neighbours. Because these new situations are quite different from the prior, they need at least new learning algorithms and new cost

¹ Adaptive Multi-Agent Systems [Georgé, 2003b]

² Extract from this ASAmI Symposium call

** IRIT – Paul Sabatier University - 118, Route de Narbonne
31062 Toulouse, Cedex 9, France
email: {george, camps, gleizes, glize}@irit.fr

function for the evaluation of local device behaviours. The devices composing the society have their own behaviour, their own objectives and can be described by the result of the actions they can do such as: order coffee at a shop, make coffee, play music,... The humans evolving in the system are also an important factor. At the society level, we obtain a new function such as the harmony inside the house which can be qualified as emergent phenomena. An emergent phenomena is observed when there is at least two levels, the micro and the macro levels and when to describe the phenomena at the macro level, we cannot use the theory (or the vocabulary) used to describe the parts at the micro levels [Müller, 2004]. More precisely in computer science, we have defined the behaviour of a MAS as emergent when the global function of the system (macro level) is not coded inside the agents (micro level) [Georgé, 2005].

Consequently, we fall in the limitations quoted by Wolpert and MacReady in their "No Free Lunch Theorems" because we must have a learning algorithm universally optimal on all fields. Under these conditions, Wolpert and Macready [Wolpert, 1997] proved that performances of all the optimisation methods using cost functions are equivalent, including the random³. This is very unsatisfactory!

A way to tackle the limitations of these theorems is to find a relevant learning algorithm which does not need a cost function derived from the global criteria to optimise and to design underspecified systems. We showed in previous works⁴ [Picard, 2004], [Georgé, 2003a], [Gleizes, 2002], that algorithms, which do not directly depend on the global function to obtain, are a way to dynamically implement systems able to self-adapt to their contexts. In the case of AmI, these algorithms should use local adaptive behaviour and thus only take into account local knowledge resulting from representation of their neighbourhood. The concept of agent thus becomes natural for a local emergent solving. Because these local behaviour have, neither explicitly nor implicitly, information about the global goal to achieve, the collective behaviour of an ambient intelligence society can be qualified as an emergent phenomena [Di Marzo, 2005]. So, the AMAS theory dedicated to design systems with emergent functionality can be a good candidate for ambient system design.

2.1. Agents' Self-Organisation by AMAS Approach

We consider an AmI system as a multi-agent system S having a global function f_s to achieve. Each part P_i realizes only a partial function f_{p_i} (Figure 1). f_s is the result of the combination of the partial functions f_{p_i} , noted by the operator " \bullet ". The combination being determined by the current organization of the parts, we can deduce $f_s = f_{p_1} \bullet f_{p_2} \bullet \dots \bullet f_{p_n}$. As generally, $f_{p_1} \bullet f_{p_2} \neq f_{p_2} \bullet f_{p_1}$, by transforming the multi-agent organization, the combination of the partial functions is changed and therefore the global function f_s changes. This is a powerful way to adapt the system to the environment. A pertinent technique to build this kind of systems is to use adaptive multi-agent systems. As in Wooldridge's definition of multi-agent systems [Wooldridge 2002], we will be referring to AmI systems constituted by

several autonomous agents, plunged into a common environment and trying to solve a common task.

2.2. The Theorem of Functional Adequacy

Cooperation was extensively studied in computer science by [Axelrod, 1984] and [Huberman, 1991] for instance. "Everybody will agree that co-operation is in general advantageous for the group of co-operators as a whole, even though it may curb some individual's freedom" [Heylighen, 1992]. Relevant biological inspired approaches using cooperation are for instance Ants Algorithms [Dorigo, 1999] which give efficient results in many domains. In order to show the theoretical improvement coming from cooperation, we have developed the AMAS (Adaptive Multi-Agent System) theory [Georgé, 2003b] which is based upon the following theorem. This theorem describes the relation between cooperation in a system and the resulting functional adequacy⁵ of the system.

Theorem. *For any functionally adequate system, there is at least a cooperative internal medium system that fulfills an equivalent function in the same environment.*

Definition. *A cooperative internal medium system is a system where no Non-Cooperative Situations exist.*

Definition. *An agent is in a Non-Cooperative Situation (NCS) when: (1) a perceived signal coming from the environment is not understood or is ambiguous; (2) perceived information does not produce any activity of the agent; (3) the conclusions are not useful to others.*

The cooperation failures are called "Non Cooperative Situations" (NCS) and can be assimilated to "exceptions" in traditional programming. Our definition of cooperation is based on three local meta-rules the designer has to instantiate according to the problem to solve:

- Meta-rule 1 (c_{per}): Every signal perceived by an agent must be understood without ambiguity.
- Meta-rule 2 (c_{dec}): Information coming from its perceptions has to be useful to its reasoning.
- Meta-rule 3 (c_{act}): This reasoning must lead the agent to make actions which have to be useful for other agents and the environment.

The theorem of functional adequacy means that we only have to use (and hence understand) a subset of particular systems (those with cooperative internal mediums) in order to obtain a functionally adequate system in a given environment. We concentrate on a particular class of such systems, those with the following properties [Gleizes, 2002]:

- The system is plunged into an environment.
- The system is composed of interacting parts called agents.
- The system is cooperative and functionally adequate with respect to its environment. The agents do not 'know' the global function the system has to achieve via adaptation.
- The system adapts itself to its environment. It has not an explicitly defined goal, rather it acts using its perceptions of

³ It is not contradictory with many existing applications showing in practice that very good algorithms exist in specific limited contexts.

⁴ For more details see also the website www.irit.fr/SMAC

⁵ "Functional" refers to the "function" the system is producing, in a broad meaning, i.e. what the system is doing, what an observer would qualify as the behavior of a system. And "adequate" simply means that the system is doing the "right" thing, judged by an observer or the environment. So "functional adequacy" can be seen as "having the appropriate behavior for the task".

the environment as a feedback in order to adapt its behaviour that leads to have an adequate global function. The adaptation is realized at the agent level by their specific behaviour. It consists in trying and maintaining cooperation using their skills, representations of themselves, of the other agents and of the environment.

- Each agent only evaluates whether the changes taking place in the system are cooperative from its point of view - it does not have to know if these changes are a direct result of its own past actions.

2.3. The Engine for Self-organization

The designer provides the agents with local criterion to discern between cooperative and NCSs. The cooperative attitude between agents constitutes the engine of self-organization. The agents have to try to choose the more cooperative action when they can and also when NCSs occur to detect them and to remove them. Depending on the real-time interactions the multi-agent system has with its environment, the organization between its agents emerges and constitutes an answer to the difficulties of ambient intelligence problems (indeed, there is no global control of the system). In itself, the emergent organization is an observable organization that has not been given first by the designer of the system. Each agent computes a partial function f_{pi} , but the combination of all the partial functions produces the global emergent function f_s . Depending on the interactions between themselves and with the environment, the agents change their interactions i.e. their links. This is what we call self-organization. By principle, the emerging purpose of a system is not recognizable by the system itself, its only criterion must be of strictly local nature (relative to the activity of the parts which make it up). By respecting this, the AMAS theory aims at being a theory of emergence. So, our proposition to design ambient systems is to encapsulate the device in an agent with cooperative attitude that is transforming a device in a cooperative agent.

3. EXPERIMENTS OF SELF-ORGANIZING DEVICES

The first class of AmI systems we worked on in this paper are systems composed of a large number of distributed, heterogeneous and dynamic devices modelling specific services behaviours and implementing temporal resources, processes and tasks to be solved [Cabanis, 2006]. Basically, these devices need to exchange relevant informations with each other. A cooperative agent encapsulates a device and the objective of each agent is to permanently maintain cooperative relations with agents which are relevant for it: this agent set constitutes its functional neighbourhood. Conversely, it tries to remove from this neighbourhood, agents having uninteresting skills. This is done by the detection and the treatment of NCSs. For each agent, the updating of the representations of its neighbourhood leads to the organisation changes.

3.1. NCSs Detection and Treatment

Listed NCSs were deduced from the meta-rules 1 and 3 presented in the section 2.2:

- NCS 1 ($\neg c_{per}$): An agent cannot associate a meaning to the received message. This NCS can be declined into three more specific NCSs :

(1) *Total incomprehension*: the agent cannot associate a meaning to the received message. In this case, because the agent is cooperative, it does not ignore the message but it sends it, according to its representations, towards an agent it considers relevant for the resolution without changing the name of the sender (this action is called "restricted relaxation").

(2) *Partial incomprehension*: only one part of the received message has a meaning for the agent. In this case, the agent sends a partial answer corresponding to the understood part to the sender and it sends the remainder to an agent which it believes qualified (restricted relaxation).

(3) *Ambiguity*: the received message has several meanings for the agent. In this case, the agent returns the message to the sender for clarification.

- NCS 3 ($\neg c_{act}$): Two agents want to reach a third one proposing a limited resource and their request exceeds the offer (they are faced with a conflict situation such as storage capacity or computing performance). In this case, because the third agent is cooperative, it guides one of the former agents towards another having similar resource. All the agents being encapsulated by the same cooperative behaviour, an agent can thus recommend agents having similar competences when it is overloaded. It knows (because they are all cooperative) that it can later benefit from such advantages if a concurrent agent is overloaded. The treatment of these NCSs involves changes of organisation which leads to the creation, the update (reinforcement, reduction) or the removal of the representations (interaction links) possessed by each involved agent.

3.2. Simulations

We then made simulations⁶ on an AmI network composed of a set of devices. Each device is dedicated to one of the four following tasks: Grid Calculus (distributed mathematical calculus), Grid Storage (distributed storage of data), P2P (specialised in data exchange) or Web Service (providing services to be composed with others). We have identified some important characteristics of the different tasks needed to implement the agents and used to specify the NCS management in this problem. They are split into the seven following classes:

1. A device can use specific standard. For example, communication protocols would not be the same between two geographically close devices. A restricted relaxation must be activated to ensure connexion.

⁶ Developed in JavAct. See www.irit.fr/recherches/ISPR/IAM/JavAct.html

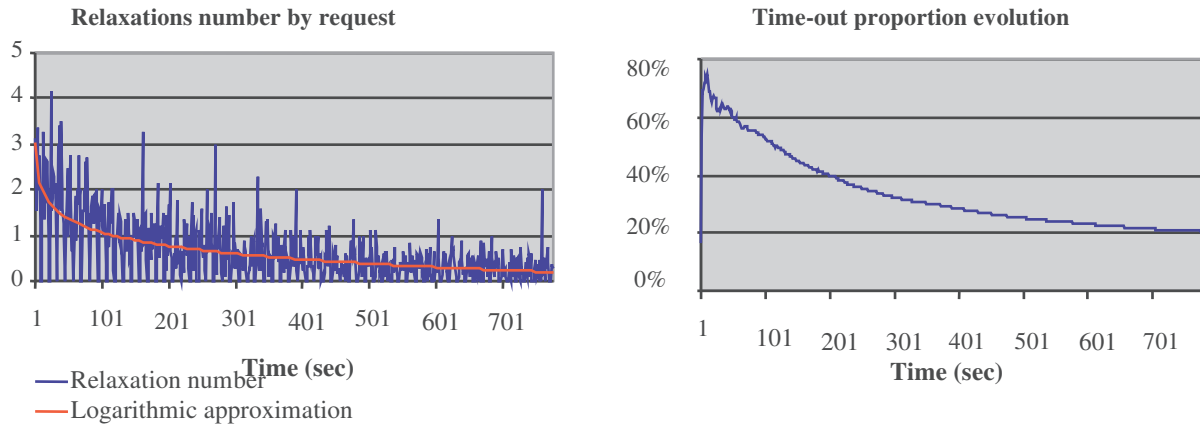


Figure 2: Cooperation contribution in an AmI system

2. At a time, a device can have calculation capabilities useful for another device. This is this type of request sent during the simulation presented below.
3. A device can have high capacity storage useful for neighbours. Two neighbours can be in conflict when they want to use simultaneously the remaining available memory.
4. A device needs bandwidth (upload or download) when a transfer is time consuming.
5. In some critical AmI applications, reliability could be an important criterion to consider. In this case, a device chooses neighbours having this property.
6. For confidentiality reason, a device could not be allowed to associate a meaning to a received message (encryption). Nevertheless it could relax it to another device able and authorized to decode.
7. An AmI system is typically open, and we could not have an equal confidence (or trust) in all neighbours. This information is an important selection criterion when choosing a new partner or for restricted relaxation.

The adaptive behaviour previously presented through the different detection and treatment of NCSs has been instantiated to this context by taking into account the above characteristics for the four given types of tasks. As indicated in the table 1, only some characteristics are relevant for a given task.

	Type of task			
	Grid Calculus	Grid Storage	P2P	Web Services
Standard	✓	✓	✓	✓
CPU	✓			
Capacity		✓		
Bandwidth (download)		✓		
Bandwidth (upload)			✓	
Reliability	✓	✓	✓	
Access right				✓
Confidence				✓

Table 1: Criteria taken into account in the simulation

The simulations realized consist of 100 agents, 80% of which are devoted to Grid Computing (GC) calculus. Initially, the AmI system is represented by a graph of agents randomly connected so their functional neighbourhood is composed at the beginning with relevant and not relevant agent. This graph evolves according to interactions between agents.

Randomly, a skill or a specific task to achieve (for example a light control device or a coffee machine) is given to each agent (which represents a device). Then, messages are sent to agents

by the simulator to simulate the end-user's requests. The agents also communicate to each other by message sending. The messages can contain an explicit user request, a perception coming from sensors or even information exchanges between agents. In the simulation results (figure 2), 90 requests of GC calculus are submitted each second to different agents of the system. Each task can be relaxed a limited number of times (4 times in this simulation), i.e the number of times a task can be sent from an agent to another. Beyond this number, the task is removed and the sender agent considers its task as being without response after a given time limit (time-out). It then adjusts consequently its representations on the agent to which it has sent the request. Representations of the seven characteristics of the neighbours of an agents are expressed by using measurements of need (standards and access rights in Web Services...), measurements of probability (for the reliability of the services) and measurements of weighted averages for apparent performances (CPU, ...).

The results (figure 2) show a progressively decreasing number of relaxations (synonymous to NCSs) and a decreasing number of time-outs (unresolved requests/tasks) during the system functioning. These results mean that gradually each agent finds its right place in the organisation in spite of unforeseeable events that can occur during the system functioning. The right place means that the agent interacts with the right agents to achieve its goal. In the second curve an asymptotic limit to 20% of time-out can be seen. It is reached when all agents devoted to GC are busy; so the system tends towards its optimality. These preliminary results show that the AmI network, as a collective, adapts itself to the characteristics of each device, only by local perception of criteria and treatments which are independent of any global cost function knowledge.

4. DISCUSSION

The ISTAG (Information Society Technologies Advisory Group) has been engaged since 2000 [ISTAG, 2001], [ISTAG, 2003] in a scenario-planning exercise for European Community. The goal is to give ideas (see also the Philips Homelab [HomeLab] or visions and achievements in AmI from Lindwer and al. [Lindwer, 2003]) about what the daily life might be in an AmI environment in the year 2010. There will probably exist

numerous approaches to these scenarios. Our approach considers them as emergent phenomena and we try to solve them by providing an approach enabling to build self-organising systems.

4.1. Ad-hoc versus Emergent Scenarios

The usual way to fit with these scenarios is to define ad-hoc middleware, infrastructure or protocols supporting them. From our point of view, this is not a complete relevant approach because in functioning, new scenarios always occur and don't match with these ad-hoc solutions. As quoted by Emiliano and Stephanidis [Emiliani, 2005] "*In such a context, the concepts of universal access and design for all acquire critical importance in facilitating the incorporation of accessibility in the new technological environment through generic solutions*".

Because the global behaviour of an AmI system evolves constantly, it cannot be a priori defined: it is a really emergent phenomenon resulting from the dynamic coupling between evolving human needs and mobile networked devices having limited capabilities. So, the design of ambient systems needs new models new tools which deals with their complexity, distribution, heterogeneity and openness. Systems able to provide emergent phenomenon represents one way but not the unique way to build them. In this paper, we focus on self-organising multi-agent systems to conceive ambient applications, where the self-organising mechanisms lead to the emergence of the goal of the applications.

4.2. Properties of Self-Organizing Systems

Self-organizing systems show a lot of properties needed in AmI systems. These properties are the following:

- Robustness. An AmI system is a very stressful environment for all the devices. Nevertheless, the previous experiments show that they are able to function correctly after a short delay of adaptation: this is basically a robustness property.
- Self-repair. When a part of a self-organizing system fails, its neighbours have to find new acquaintances related with their needs. This is exactly the goal of the cooperative self-organizing process shown in the previous parts. Thus, the global AmI system falls into a graceful degradation, according to the missing skills of the failing device.
- Scalability. An SoS has inherently the ability to grow incrementally without re-engineering the process because the adaptation process is self-contained in each autonomous device.
- Openness. Removing a device in a self-organizing system is a self-repair process for its old neighbours. Adding a new device is also a self-repair process from the new device point of view.
- Complexity reduction. The design of a self-organizing AmI system is bounded by the specification complexity of the cooperative behaviours of its isolated devices. Moreover, as we have done in the experiments, these specifications are for each generic class of devices only and not for the individuals. Consequently, the complexity of a self-organizing AmI is equal to the more complex device to design, and not to the scale of its global organization.

5. CONCLUSION AND PERSPECTIVES

Modern and future artificial systems, for which AmI systems are typical cases, show an extremely high dynamism, resulting in very complex and unpredictable interactions among their distributed components, making it impossible to normally reason about the global behaviour. This is the reason why the authors of the ambient intelligence roadmap consider that "*the traditional techniques for building distributed applications, are no more usable in such complex systems: they are only thought to operate in centralised and client server environments*" [Friedewald, 2003].

This is the main reason we search for a local adaptive approach based on Adaptive Multi-Agent Systems. It enables to build systems in which agents only pursue a local goal while trying to keep cooperative relations with other agents embedded in the system. This approach has been partially instantiated in a simulation of heterogeneous devices network. These first encouraging results convinced us of the need to apply it on a large scale real world AmI application in order to demonstrate thoroughly in the near future the properties enunciated in section 4.2.

In their roadmap for AmI, Friedewald and Da Costa claim that there is the need to use new paradigms in the design of such systems. They suggest for example that self-organising software will be available by 2006-2010. "*A key characteristic of a self-organizing system is that structure and function of the system "emerge" from interactions between the elements. The purpose should not be explicitly designed, programmed, or controlled. The components should interact freely with each other and with the environment, mutually adapting to reach an intrinsically "preferable" or "fit" configuration (attractor), thus defining an emergent purpose for the system*" [Gershenson, 2004].

We are not really sure that 2010 is the deadline for true self-organizing applications, nevertheless we agree that SoS are central for tackling the main problems of Ambient Intelligence systems. Our approach aims at providing a generic framework by using cooperative self-organisation rules to build these SoS.

6. REFERENCES

- [Axelrod, 1984] R. Axelrod. The Evolution of Cooperation. Basic Books, New York, 1984
- [Bernon, 2005] Bernon C., Camps V., Gleizes M-P, Picard G. – "Engineering Adaptive Multi-Agent Systems: The ADELFE Methodology" in "Agent-Oriented Methodologies", B. Henderson-Sellers, P. Giorgini (Eds.), Idea Group Pub, NY, USA, pp. 172-202, juin 2005.
- [Cabanis, 2006] Cabanis V., "Etude de la dynamique auto-organisationnelle du Web fondée sur l'activité coopérative de ses composants", Master of research report of Paul Sabatier University, June 2006.

- [Di Marzo, 2005] Di Marzo Serugendo G., Gleizes M-P., Karageorgos A.. Self-Organization in Multi-Agent Systems. Dans : The Knowledge Engineering Review, Cambridge University Press, Simon Parsons (Eds), Cambridge, UK, V. 20 N. 2, p. 165-189, juin 2005.
- [Dorigo, 1999] M. Dorigo and G. Di Caro. The Ant Colony Optimization Meta-Heuristic. McGraw-Hill, 1999.
- [Emiliani, 2005] P. L. Emiliani and C. Stephanidis, Universal access to ambient intelligence environments: Opportunities and challenges for people with disabilities, IBM Systems Journal, Volume 44 Number 3, 2005
- [Friedewald, 2003] M. Friedewald, O. Da Costa, Science and Technology Roadmapping: Ambient Intelligence in Everyday Life, (AmI@Life) - JRC/IPTS - ESTO Study - Compiled and Edited by: Michael Friedewald Olivier Da Costa, 2003
- [Georgé, 2005] Georgé J-P., Gleizes M-P., Experiments in Emergent Programming Using Self-organizing Multi-Agent Systems, In Multi-Agent Systems and Applications IV, Proc. of the 4th International Central and Eastern European Conference on Multi-Agent Systems (CEEMAS'05), Budapest, Hungary, 15-17 September 2005, Springer Verlag, LNAI 3690, pp. 450-459.
- [Georgé, 2003a] Georgé J-P, Gleizes M-P, Glize P., Régis C., "Real-time Simulation for Flood Forecast: an Adaptive Multi-Agent System STAFF", dans AISB'03 symposium on Adaptive Agents and Multi-Agent Systems, University of Wales, Aberystwyth, Society for the Study of Artificial Intelligence and the Simulation of Behaviour, 2003.
- [Georgé, 2003b] J-P. Georgé, The AMAS Theory for Complex Problem Solving based on Self-Organizing Cooperative Agents, First European Workshop on Multi-Agent Systems (EUMAS'03), Oxford, UK, 2003
- [Gershenson, 2004] C. Gershenson and F. Heylighen, Protocol Requirements for Self-organizing Artifacts: Towards an Ambient Intelligence, In Proc. Int. Conf. on Complex Systems (New England Institute of Complex Systems), 2004
- [Gleizes, 2002] Gleizes M-P, Glize P., "ABROSE: Multi Agent Systems for Adaptive Brokerage", in Fourth International Bi-Conference Workshop on Agent-Oriented Information Systems (AOIS-2002), Toronto, Ontario, Canada, mai 2002.
- [Heylighen, 1992] F. Heylighen. Evolution, selfishness and cooperation; selfish memes and the evolution of cooperation. Journal of Ideas, 2(4):70-84, 1992.
- [HomeLab] 365 days' Ambient Intelligence research in HomeLab, Philips, www.research.philips.com/technologies/misc/homelab/downloads/homelab_365.pdf.
- [Huberman, 1991] B. Huberman. The performance of cooperative processes. MIT Press / North-Holland, 1991.
- [ISTAG, 2001] Scenarios for Ambient Intelligence in 2010, ISTAG report (Information Society Technologies Advisory Group) of the European union, <ftp://ftp.cordis.lu/pub/ist/docs/istagscenarios2010.pdf>, 2001.
- [ISTAG, 2003] Ambient Intelligence: from vision to reality, report of the Information Society Technologies Advisory Group European Union, ftp://ftp.cordis.lu/pub/ist/docs/istag-ist2003_draft_consolidated_report.pdf, 2003.
- [Lindwer, 2003] M. Lindwer, D. Marculescu, T. Basten, R. Zimmermann, R. Marculescu, S. Jung, E. Cantatore, Ambient Intelligence Visions and Achievements: Linking Abstract Ideas to Real-World Concepts, Proc. Design Automation & Test in Europe (DATE), 2003.
- [Luck, 2005] Luck M., McBurney P., Shehory O., Willmott S. and the AgentLink Community "Agent Technology : Computing as Interaction – A Roadmap for Agent Based Computing", Compiled, ISBN 085432 845 9, <http://www.agentlink.org/roadmap>, 2005.
- [Müller, 2004] Müller JP., " Emergence of Collective Behaviour and Problem Solving ", in Engineering Societies in the Agents World IV, Fourth International Workshop ESAW-2003, Revised Selected and Invited Papers, pages 311-327, LNAI 3071 Springer Verlag 2004
- [Picard, 2005] Picard G., Bernon C., Gleizes M-P., ETTO : Emergent Timetabling Organization, In Multi-Agent Systems and Applications IV, Proc. of the 4th International Central and Eastern European Conference on Multi-Agent Systems (CEEMAS'05), Budapest, Hungary, 15-17 September 2005, Springer Verlag, LNAI 3690, pp. 440-449.
- [Picard, 2004] Picard G., "Agent Model Instantiation to Collective Robotics in ADELFE", in Fifth International Workshop on Engineering Societies in the Agents World (ESAW'04), Toulouse, France, Springer Verlag, LNCA 3451, p. 209-221, october 2004.
- [Welcomme, 2006] Welcomme J-B., Gleizes M-P., Redon R., Druot T., in Self-Regulating Multi-Agent System for Multi-Disciplinary Optimisation Process, Proceedings of the 4th European Workshop on Multi-Agent Systems (EUMAS'06), Lisbon, Portugal, December 14-15, 2006. B. Dunin-Keplicz, A. Omicini & J. Padget Eds. ISSN 1613-0073.
- [Wolpert, 1997] Wolpert D.H, Macready W.G., "No Free Lunch Theorems for Optimization", IEEE Transactions on Evolutionary Computation, Vol.1, N°.1, 1997.
- [Woolridge, 2002] [96] M. Wooldridge. An introduction to multi-agent systems. John Wiley & Sons, 2002.