INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team MAIA

Autnomous and Intelligent MAchine

Lorraine

THEME COG

Activity Report

2005

Table of contents

1. Team

MAIA is common project to INRIA, CNRS, INPL, Henri Poincaré University and Nancy 2 University through LORIA laboratory (UMR 7503). For more details, we invite the reader to consult the team web site at http://maia.loria.fr/.

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Cédric Rose [INRIA Engineer associated with the development of Dialhemo]

2. Overall Objectives

2.1. Overall Objectives

MAIA[1] research belongs to artificial intelligence: our goal is to model, design and simulate computer based entities (agents) that are able to sense their environment, interpret it, and act on it with autonomy. We mainly work on two research themes: 1) stochastic models and 2) self-organization.

3. Scientific Foundations

3.1. Introduction

MAIA research concerns two research themes: 1) stochastic models and 2) self-organization. This section presents the scientific foundations of these themes.

[1]MAIA stands for "MAchine Intelligente et Autonome", that is "Autonomous and Intelligent MAchine"

3.2. Stochastic models

3.2.1. Objectives

We develop algorithms for stochastic models applied to machine learning and decision. On the one hand, we consider standard stochastic models (Markov chains, Hidden Markov Models, Bayesian networks) and study the computational problem that arise, such as inference of hidden variables and parameter learning. On the other hand, we consider the parameterized version of these models (the parameter can be seen as a control/decision of an agent); in these models (Markov decision processes, partially observable Markov decision processes, decentralized Markov decision processes, stochastic games), we consider the problem of a) planning and b) reinforcement learning (estimating the parameters *and* planning) for one agent as for many agents. For all these problems, our aim is to develop algorithmic solutions that are efficient, and apply them to complex problems.

In the following, we concentrate our presentation on parameterized stochastic models, known as (partially observable) Markov decision processes, as they trivially generalize the non-parameterized models (Markov chain, Hidden Markov Models). We also outline how these models can be extended to multi-agent settings.

3.2.2. A general framework

An agent is anything that can be viewed as sensing its environment through sensors and acting upon that environment through actuators. This view makes Markov decision processes (**MDPs**) a good candidate for formulating agents. It is probably why MDPs have received considerable attention in recent years by the artificial intelligence (AI) community. They have been adopted as a general framework for planning under uncertainty and reinforcement learning.

Formally, a Markov decision process is a four-tuple $\langle S, A, P, r\rangle$, where :

- S is the state space,
- A is the action space,
- P is the state-transition probability function that models the dynamics of the system. $P(s, a,s')$ is the probability of transitioning from s to s' given that action a is chosen.
- r is the reward function. $r(s, a,s')$ stands for the reward obtained from taking action a in state s, and transitioning to state s'.

With this framework, we can model the interaction between an agent and an environment. The environment can be considered as a Markov decision process which is controlled by an agent. When, in a given state s, an action a is chosen by the agent, the probability for the system to get to state s' is given by $P(s, a,s')$. After each transition, the environment generates a numerical reward $r(s, a,s')$. The behaviour of the agent can be represented by a mapping $\pi : S \rightarrow A$ between states and actions. Such a mapping is called a policy.

In such a framework, we consider the following problems:

1. Given the explicit knowledge of the problem (that is P and r), find an optimal behaviour, i.e the policy π which maximises a given performance criteria for the agent. There are three popular performance criteria to evaluate a policy:

   - expected reward to target,
   - discounted cumulative reward,
   - the average expected reward per stage.

2. Given the ability to interact with the environment (that is samples of P and r obtained by simulation or real-world interaction), find an optimal behaviour. This amounts to learning what to do in each state of the environment by a trial and error and such a problem is usually called reinforcement learning. It is, as stated by Sutton and Barto, an approach for understanding and automating goal-directed learning and decision-making that is quite different from supervised learning. Indeed, it is in most cases impossible to get examples of good behaviours for all situations in which an agent has to act. A trade-off between exploration and exploitation is one of the major issues to address.
3. Eventually, a general problem, which is useful for the two previous problems, consists in finding good representations of the environment so that an agent can achieve the above objectives.

In a more general case, an agent does not perceive the state in which he stands. The information that an agent can acquire on the environment is generally restricted to *observations* which only give partial information on the state of the system. These observations can be obtained for example using sensors that return some estimate of the state of the environment. Thus, the decision process has hidden state, and the issue of finding an optimal policy is no more a Markov problem. A model that describes such an hidden-state and observation structure is the **POMDP** (partially observable MDP). Formally, a POMDP is a tuple $\langle S, A, P, r, \Omega, O \rangle$ where

- S, A, P and r are defined as in an MDP.
- Ω is a finite set of observations.
- O is a table of observation probabilities. $O(s, a, s', o)$ is the probability of transitioning from s to s' on taking action a in s while observing o. Here s, $s' \in S$, $a \in A$, $o \in \Omega$.

Hidden Markov Models are a particular case of POMDP in which there is no action and no reward. Based on the mathematical framework, several learning algorithms can be used in dealing with Diagnosis and Prognosis tasks. Given a proper description of the *state* of a system, it is possible to model it as a Markov chain. The dynamics of the systems is modeled as *transition probabilities* between states. The information that an external observer of the system can acquire on it can be modeled using *observations* which only give partial information on the state of the system. The problem of diagnosis is then to find the most likely state given a sequence of observations. Prognosis is akin to predicting the future state of the system given a sequence of observation and, thus, is strongly linked to diagnosis in the case of Hidden Markov Model. Given a proper corpus of diagnosis examples, AI algorithms allow the automated learning of an appropriate Hidden Markov Model that can be used for both diagnosis and prognosis. Rabiner [36] gives an excellent introduction to HMM and describes the most frequently used algorithms.

While substantial progress has been made in planning and control of single agents, a similar formal treatment of multi-agent systems is still missing. Some preliminary work has been reported, but it generally avoids the central issue in multi-agent systems: agents typically have different information and different knowledge about the overall system and they cannot share all this information all the time. To address the problem of coordination and control of collaborative multi-agent systems, we are conducting both analytical and experimental research aimed at understanding the computational complexity of the problem and at developing effective algorithms for solving it. The main objectives of the project are:

- Develop a formal foundation for analysis, algorithm development, and evaluation of different approaches to the control of collaborative multi-agent systems that explicitly captures the notion of communication cost.
- Identify the complexity of the planning and control problem under various constraints on information observability and communication costs.
- Gain a better understanding of what makes decentralized planning and control a hard problem and how to simplify it without compromising the efficiency of the model.

- Develop new general-purpose algorithms for solving different classes of the decentralized planning and control problem.
- Demonstrate the applicability of new techniques to realistic applications and develop evaluation metrics suitable for decentralized planning and control.

In formalizing coordination, we take an approach based on distributed optimization, in part because we feel that this is the richest such framework: it handles coordination problems in which there are multiple and concurrent goals of varying worth, hard and soft deadlines for goal achievement, alternative ways of achieving goals that offer a trade off between the quality of the solution and the resources required. Equally important is the fact that this decision-theoretic approach allows us to model explicitly the effects of environmental uncertainty, incomplete and uncertain information and action outcome uncertainty. Coping with these uncertainties is one of the key challenges in designing sophisticated coordination protocols. Finally, a decision-theoretic framework is the most natural one for quantifying the performance of coordination protocols from a statistical perspective.

3.2.3. Contemporary similar or related work in national and international laboratories

As far as stochastical planning is concerned, since the mid-1990s, models based on Markov decision processes (MDPs) have been increasingly used by the AI research community, and more and more researchers in this domain are now using MDPs. Our research group has participated (for instance, notably in co-organizing workshops of AAAI, IJCAI and ECAI in association with ARC INRIA LIRE and with Philippe Chassaing of the Omega project) and continues to participate in and contribute to the development of this domain through collaborations with Shlomo Zilberstein (on two NSF-INRIA projects) and with NASA (on a project entitled “Self-directed cooperative planetary rovers”) in association with Shlomo Zilberstein and Victor Lesser of the University of Massachussetts, Eric Hansen of the Mississippi State University, Richard Washington of the NASA Ames Research Center and Abdel-illah Mouaddib of CRIL, Lens.

We have been using the strengths of the basic theoretical properties of the two major approaches for learning and planning that we follow, to design exact algorithms that are able to deal with practical problems of high complexity. Instances of these algorithms include the JLO algorithm for Bayesian networks, the Q-learning, TD(λ) and Witness algorithms for problems based on the Markov decision process formalism etc. While it is true that the majority of this work has been done in the United States, the French research community is catching up quickly by developing further this domain on its own. MAIA has been involved directly in making substantial contributions to this development, notably through our active participation in the (informally formed) group of French researchers working on MDPs. Thus, today there are quite a few research labs in France with teams working on MDPs. To name a few, Toulouse-based labs such as IRIT, CERT, INRA, LAAS etc, the Greyc at Caen, and certain Paris-based researchers such as Rémi Munos (Polytechnique) and Olivier Sigaud (Paris VI).

Most of the current work is focused on finding approximate algorithms. Besides applying these algorithms to a multi-agent system (MAS) framework, we have also been focusing on reducing the complexity of implementing these algorithms by making use of the meta-knowledge available in the system being modeled. Thus in implementing the algorithms, we seek temporal, spatial and structural dynamics or functions of the given problem. This is very time-effective in finding approximate solutions of the problem. Moreover, we are seeking ways to combine rigorously these two forms of learning, and to then use them for applications involving planning or learning for agents located in an environment.

3.3. Self-organization

3.3.1. Objectives

One of the research themes of the MAIA project is that of collective intelligence. Collective intelligence concerns the design of reactive multi-agent systems to collectively solve a problem. Reactive systems made up of simple-behavior agents with decentralized control that despite their individual simplicity are able to collectively solve problems whose complexity is beyond the scope of individuals: “intelligence” of the system can be envisaged as a collective property.

One of the difficulties in the design of reactive multi-agent systems is to specify simple interactions between agents and between them and their environment so as to make the society be able to fulfill its requirements with a reasonable efficiency. This difficulty is proportional to the distance between the simplicity of individuals and the complexity of the collective property.

We are interested in the design of such systems by the transposition of natural self-organized systems.

3.3.2. Approach

Reactive multi-agent systems are characterized by decentralized control (no agent has a knowledge of the whole system) and simple agents that have limited (possibly no) representation of themselves, of the others, and of the environment. Agent behaviors are based upon stimulus-response rules, decision-making is based on limited information about the environment and on limited internal states, and they do not refer to explicit deliberation.

Thus the collective observed complexity comes out of the individual simplicity and is the consequence of successive actions and interactions of agents through the environment. Such systems involve two levels of description: one for individual behavior (with no reference to the global phenomena) and one to express collective phenomena.

The design problem can be summarized as the two following questions:

1. Considering a global desired property or behavior, how to build individual behaviors and system dynamics in order to obtain it?
2. Considering a set of individual behaviors and a system dynamics, how to predict (or guarantee) the global property?

Such a methodology is still missing and we will contribute to this purpose. We organize our research in three part:

1. understanding collective intelligence by studying examples of such systems,
2. transposing principles found in example systems to solve problems, and
3. providing a framework to help analyse and formalize such systems.

- The first part is to model existing self-organized phenomena and thus have a better understanding of the underlying mechanisms. For instance, social phenomena in biology provide a lot of examples in which a collection of simple, situated entities (such as ants) can collectively exhibit complex properties which can be interpreted as a collective response to an environmental problem. We have worked with biologists and provided several models of self organized activities in case of spiders and rats.
- Since individual models and system dynamics are established, the second part consists of transposing them in order to solve a given problem. The transposition corresponds to encode the problem such as to be an input for the swarm mechanism; to adapt the swarm mechanism to the specificities of the problem, and if necessary to improve it for efficiency purpose; and then to interpret the collective result of the swarm mechanism as a solution of the problem.
- The third part aims at providing a framework to face the following issues:

    1. Is it possible to describe such mechanisms in order to easily adapt and reuse them for several different instances of the problem (*generic or formal description*)?
    2. If such a generic description of a system is available, is it possible to assess the behaviour of the system in order to derive properties that will be conserved in its instantiations (*analyse and assessment of system*)?

3.3.3. Related work in the national / international research community

Of the two principal approaches to the study of multi-agent systems (MAS), we have been inclined to adopt for our research, the approach of “collective” systems which emphasize the notions of interactions and organization. This is evident in the numerous collaborations that we have undertaken with researchers of this field as well as in the kinds of research groups we associate and work with:

- the AgentLink community in Europe, especially the one which is interested in self-organization, and
- the research group ’Colline’ (under the aegis of GDR I3 and the AFIA) since 1997.

The approach that we have adopted for the design of multi-agent systems is based on the notion of self-organization, and it notably also includes the study of their emerging properties. Even if the research community working in this specific sub-domain is even smaller, it is a growing one, and it is developing interestingly, especially through the work being done at Iremia (at the University of Réunion), at IRIT, at LIRIS in Lyon, at LIRMM, ..., and in certain other laboratories of the UE (D. Van Parunak, R. Brooks for example) and Europe F. Zambonelli (University of Modena Italy), P. Marrow (British Telecom ICT Research Centre UK), G. Di Marzo Serugendo (University of Geneva Switzerland), etc.

Some of these researchers have taken inspiration from biological models to envisage the emerging properties. Principally, this current work is inspired by ant-colony models (such as at LIP6, at Lirmm in France or at the IRIDIA, Brussels). We consider the use of the models such as the spider colonies or the groups of rats as an original contribution from us toward this study, it having never been utilised before. It must be mentioned that this field has been influenced to a considerable extent by the work of Jean-Louis Deneubourg of CENOLI (Brussels) which concerns phenomena involving self-organization in such colonies and the mechanisms of interaction by pheronomes in ant-colonies.

4. Application Domains

4.1. Application Domains

In order to achieve its basic research program, the MAIA team has developed and is developing a strong known-how in sequential or distributed decision making. In particular, mathematical tools such as Markov decision processes, hidden Markov models or Bayesian Networks are appropriate and are used by the team for the development of real applications such as

- monitoring the hydration state of patients suffering from kidney disease
- elderly fall prevention
- infection skin prevention around the catheter used for peritoneal dialyses
- e-maintenance
- collaborative filtering
- ambient intelligence
- learning mediation strategies for heterogeneous agents cooperation.

5. Software

5.1. Software

- Baiabox - It is a toolbox for developping bayesian networks applications.
- The Dialhemo project has the objective to develop a remote surveillance and telediagnosis system adapted to renal insufficiency patients treated by hemodialysis. The main objective is to insure people who are treated either at home, or in self-dialysis centers, the same level of security as in hospital. A first software developped in cooperation with Diatelic Sa, Gambro and ALTIR is currently experimented in several sites. About 150 patients currently benefit of this first system.

6. New Results

6.1. Stochastic models

6.1.1. Autonomous development of basic agent behaviors

Participants: Alain Dutech, Olivier Buffet, François Charpillet.

In [2] we address of automatically designing autonomous agents having to solve complex tasks involving several and possibly concurrent objectives. We propose a modular approach based on the principles of action selection where the actions recommanded by several basic behaviors are combined in a global decision. In this framework, our main contribution is a method making an agent able to automatically define and build the basic behaviors it needs through incremental reinforcement learning methods. This way, we obtain a very autonomous architecture requiring very few hand-coding. This approach is tested and discussed on a representative problem taken from the tile-world.

6.1.2. Optimal control and reinforcement learning with large state spaces

Participant: Bruno Scherrer.

We consider in [8] two machine learning related problems, optimal control and reinforcement learning. We show that, even when their state space is very large (possibly infinite), natural algorithmic solutions can be implemented in an asynchronous neurocomputing way, that is by an assembly of interconnected simple neuron-like units which does not require any synchronization. From a neuroscience perspective, this work might help understanding how an asynchronous assembly of simple units can give rise to efficient control. From a computational point of view, such neurocomputing architectures can exploit their massively parallel structure and be significantly faster than standard sequential approaches. The contributions of this paper are the following: 1) We introduce a theoretically sound methodology for designing a whole class of asynchronous neurocomputing algorithms. 2) We build an original asynchronous neurocomputing architecture for optimal control in a small state space, then we show how to improve this architecture so that also solves the reinforcement learning problem. 3) Finally, we show how to extend this architecture to address the case where the state space is large (possibly infinite) by using an asynchronous neurocomputing adaptive approximation scheme. We illustrate this approximation scheme on two continuous space control problems.

6.1.3. Navigation, harmonic functions and optimal stochastic control

Participants: Amine Boumaza, Bruno Scherrer.

In [13], we address the problem of navigation in continuous time in stochastic environments. We compare two navigation methods the first one based on harmonic functions and the second one based on optimal stochastic control theory. We show that harmonic control is a special case of optimal control : harmonic control is the limit of the optimal control when the displacement noise tends to infinity.

Furthermore we show that all the interesting properties that motivate (for example in the robotics community) the use of harmonic functions are also observed in the models resulting from optimal stochastic control theory. This shows that in the context of navigation, optimal stochastic control theory is strictly more general than harmonic control theory.

6.1.4. Infinite and Finite-Horizon decentralized POMDPs

Participants: Daniel Szer, François Charpillet.

In the domain of decentralized Markov decision processes, we develop [30], [33] the first complete and optimal algorithm that is able to extract deterministic policy vectors based on finite state controllers for a cooperative team of agents. Our algorithm applies to the discounted *infinite horizon* case and extends best-first search methods to the domain of decentralized control theory. We prove the optimality of our approach and give some first experimental results for two small test problems. In [32], [31], we develop multi-agent A* (MAA*), the first complete and optimal heuristic search algorithm for solving decentralized partially-observable Markov decision problems (DEC-POMDPs) *with finite horizon*. The algorithm is suitable for computing optimal plans for a cooperative group of agents that operate in a stochastic environment such as multi-robot coordination, network traffic control, or distributed resource allocation. Solving such problems effectively is a major challenge in the area of planning under uncertainty. Our solution is based on a synthesis of classical heuristic search and decentralized control theory. Experimental results show that MAA* has significant advantages. We introduce an anytime variant of MAA* and conclude with a discussion of promising extensions such as an approach to solving infinite horizon problems. We believe this to be an important step forward in learning and planning in stochastic multi-agent systems.

6.1.5. Cooperation in stochastic games through communication

Participants: Raghav Aras, Alain Dutech, François Charpillet.

We describe in [10], [11] a process of reinforcement learning in two-agent general-sum stochastic games under imperfect observability of moves and payoffs. In practice, it is known that using naive Q-learning, agents can learn equilibrium policies under the discounted reward criterion although these may be arbitrarily worse for both the agents than a non-equilibrium policy, in the absence of global optima. We aim for Pareto-efficiency in policies, in which agents enjoy higher payoffs than in an equilibrium and show agents may employ naive Q-learning with the addition of communication and a payoff interpretation rule, to achieve this. In principle, our objective is to shift the focus of the learning from equilibria (to which solipsistic algorithms converge) to non-equilibria by transforming the latter to equilibria.

6.1.6. Decision-Theoretic Scheduling of Resource-Bounded Agents

Participants: Simon Le Gloannec, Abdel-Illah Mouaddib, François Charpillet.

Markov Decision processes have been widely used to control the execution of a static set of tasks with limited resources. But little attention has been paid to adapt these techniques to cope with changes in the environment. This is a problem of the dynamic optimisation of resource allocation to a changing set of tasks. In [23], we transform this problem into a dynamic composition of local policies (each of which controls a task) to approximate the optimal control policy. Our main claim in this paper is that it is possible to dynamically compute good decisions without completely calculating the optimal policy. We develop an approach which provides more flexibility for MDPs to deal with dynamic environments. This approach is made up of two steps. The first step consists of an off-line pre-processing of tasks and the compilation of policies for all possible available resources. The second step concerns a quick on-line approximation of the policy of executing the current task taking into account the current state of the queue. We present a preliminary analysis of the performance of our approach.

6.1.7. Meta-Level Control for Handling Multiple Consumable Resources

Participants: Simon Le Gloannec, Abdel-Illah Mouaddib, François Charpillet.

Most of works on planning under uncertainty in AI assumes rather simple action models, which do not consider multiple resources. This assumption is not reasonable for many applications such as planetary rovers or robotics which much cope with uncertainty about the duration of tasks, the energy, and the data storage. In [24], we outline an approach to control the operation of an autonomous rover which operates under multiple resource constraints. We consider a directed acyclic graph of progressive processing tasks with multiple resources, for which an optimal policy is obtained by solving a corresponding Markov Decision Process (MDP). Computing an optimal policy for an MDP with multiple resources makes the search space large. We cannot calculate this optimal policy at run-time. The approach developed in this paper overcomes this difficulty by combining: decomposition of a large MDP into smaller ones, compression of the state space by exploiting characteristics of the multiple resources constraint, construction of local policies for the decomposed MDPs using state space discretization and resource compression, and recomposition of the local policies to obtain a near optimal global policy. Finally, we present first experimental results showing the feasibility and performances of our approach.

6.1.8. Interac-DEC-MDP : a formalism to build automatically interactions in reactive MAS

Participants: Vincent Thomas, Christine Bourjot, Vincent Chevrier.

This work [35], [19] is about the design of multi-agent systems. It focuses on formalism based approach and aims in the long run to build, automatically and in a decentralized way, the behaviours of cooperative agents which must solve a collective problem. The goal of this work was to propose new techniques to build the behaviour of social agents, able to consider the presence of other agents in the system.

Existing formalism like DEC-POMDPs manage to formalize multi-agents problem but they don't represent at the agent level the concept of interaction which is fundamental in collective systems. It induces a important complexity in the algorithms used to build the behaviours of the agents. In order to give the agent the ability to consider the presence of other agents in the system and to structure implicitely multi-agents systems, this thesis proposes an original formalism the Interac-DEC-POMDP inspired by the DEC-POMDP formalism and Hamelin, a simulation developped during this thesis and inspired by collective biological phenomenon. The specificity of this new formalism lies in the ability given to the agents to interact directly and locally among them. It allows them to make decision at a level between global level and individual level.

Furthermore, we have proposed an decentralized algorithm based on reinforcement learning techniques and on distribution of individual rewards among agents during interactions. We have conducted experiments and validated our proposal : this algorithm manage to produce adaptive collective behaviour without the need for the agents to have a global vision of the system.

6.2. Self-organization

6.2.1. Cognitive abilities in social differentation among rats' groups

Participants: Vincent Thomas, Christine Bourjot, Vincent Chevrier, Dider Desor, Henri Schroeder, Marie-Caroline Cotel.

Groups of rats confronted to an increasing difficulty to reach food organize themselves. The emergent organizational structure is characterized by a distribution of two different behavioral profiles among the rats. This specialization is stable, robust and presents adaptive properties.

In past years, we proposed a reactive model to reproduce such a phenomenon. However, some questions arise when examining carefully results of simulations and comparing then to the real process. Hamelin model reproduces differentiation but makes also appear profiles inversion. This latter is in contradiction with actual phenomenon[35], [19].

This motivated to develop a new model for Hamelin in which individuals are using explicit references to others in the group.

6.2.2. Applications of Self-Organising Multi-Agent Systems

Participants: Vincent Chevrier, Carole Bernon, Vincent Hilaire, Paul Marrow.

A lot of work is devoted to formalizing and devising architectures for agents' cooperative behaviour, for coordinating the behaviour of individual agents within groups, as well as to designing agent societies using social laws. However, providing agents with abilities to automatically devise societies so as to form coherent emergent groups that coordinate their behaviour via social laws, is highly challenging. These systems are called self-organised. We are beginning to understand some of the ways in which self-organised agent systems can be devised.

Inside a Technical Forum Group, we proposed several criteria to analyse self-organized systems. We provided several examples [3] of multi-agent systems in which self-organisation, based on different mechanisms, is used to solve complex problems and used several of the proposed criteria in order to compare the self-organisation mechanisms of different applications.

6.2.3. From Self-Organized Systems to Collective Problem Solving

Participant: Vincent Chevrier.

The reactive multi-agent approach emphasizes individual simplicity over the collective complexity of the task being performed. However, to apply such an approach to a problem, the components of the multi-agent system have to be designed in such a way that the society is able to fulfill its requirements with a reasonable efficiency. Inspiration from natural self-organized systems is a way to solve this conception issue. We illustrated [4] two cases of how natural self-organized systems can be transposed to engineer societies of agents that collectively solve problems. We present two original self organized models conceived in cooperation with biologists (spidel collective weaving and rats' specialization) and detail how transposition principles have been used to design collective problem solving systems.

6.2.4. Bio-inspired Mechanisms for Artificial Self-organised Systems

Participants: Christine Bourjot, Jean-Pierre Mano - IRIT, Pierre Glize - IRIT, Gabriel Lopardo - ARL.

Self-organization is a growing interdisciplinary field of research about a phenomenon that can be observed in the Universe, in Nature and in social contexts. Research on self-organization tries to describe and explain forms, complex patterns and behaviours that arise from a collection of entities without an external organizer. As researchers in artificial systems, our aim is not to mimic self-organizing phenomena arising in Nature, but to understand and to control underlying mechanisms allowing desired emergence of forms, complex patterns and behaviours. In collaboration with researchers from the Agents Research Laboratory (University of Girona-Spain) and Irit (University Paul Sabatier- Toulouse) we analyse three forms [7] of self-organization: stigmergy, reinforcement mechanisms and cooperation. The amplification phenomena founded in stigmergic process or in reinforcement process are different forms of positive feedbacks that play a major role in buildi ng group activity or social organization. Cooperation is a functional form for self-organization because of its ability to guide local behaviours in order to obtain a relevant collective one. For each forms of self-organisation, we present a case study to show how we transposed it to some artificial systems and then analyse the strengths and weaknesses of such an approach.

6.2.5. Experiment with MAS to approximate the behavior of complex systems

Participants: Vincent Chevrier, Christine Bourjot, Francois Klein.

This study [22] is about the understanding and control of complex systems modeled by a multi agent system. We propose an approach to experimentally approximate the behavior of the system as a function of its parameters. The originality of our proposition is the ability to dynamically generate data to train the model and therefore reducing the number of executions needed to build the approximation while maximizing its accuracy. We applied our proposition on a toy example to assess its viablity. The obtained results showed that such an approach enables the reduction of the number of replication.

6.2.6. Learning environment dynamics from self-adaptation.

Participant: Amine Boumaza.

Self-adaptation has become a very important property in evolutionary computation (EC). The idea of self-tuning strategy parameters by the algorithm during the evolutionary process has proved very powerful and very successful on a wide range of problems. In dynamic environments, self-adaptation plays an important role providing the agents the ability to control their behavior (exploration vs. exploitation) according to the changes in the environment.

The self-adaptation process can be observed in the parameters undergoing adaptation, their evolution reflects the behavior of the agents. A legitimate question we can ask is : if from observing these parameters thus observing the behavior, can we say anything of the changes in the environment? In other words, are the adapted parameters quantitatively related to the changes of the environment?

This is the main issue addressed in [12]. Experiments conducted in controlled environment with known dynamics using different self-adaptation methods, show that the dynamics of the environment are reflected in the evolution of the adaptation parameters which in turn shows that there is a tight link between the type of the dynamic and the adaptation parameters throughout the evolutionary process.

This preliminary study shows that it is possible for the agents to learn useful information on their changing environments, using the feedbacks of their performance and their actions. A further step would be to give the agents the ability to exploit the information learned on the environment from their adaptation, and use it to adjust their internal parameters to the environment.

6.3. Applications

6.3.1. A Distributed Information Filtering

Participants: Sylvain Castagnos, Anne Boyer, François Charpillet.

The term of collaborative filtering denotes techniques using the known tastes of a group of users to predict the unknown preference of a new user. The distinctive feature of current collaborative filtering processes is to be centralized. The scientific problems have consisted in finding a way to distribute calculus, in order to provide scale for several ten thousands of people, or then to preserve anonymity of users (personal data remain on client side). The impact of a model combining several existing methods to share out tasks between the server and users terminals is examined in [17]. A partnership with the company ASTRA allows to turn to their database and to carry out life-sized tests in order to verify efficiency of proposed solutions. In [16] we provide a preliminary report which presents information filtering solutions designed within the scope of a collaboration between our laboratory and the company of broadcasting per satellite SES ASTRA. The latter have finalized a system sponsored by advertisement and supplying to users a high bandwidth access to hundreds of web sites for free. This project aims at highlighting the benefits of collaborative filtering by including such a module in the architecture of their product. Our problem has consisted in finding a way to provide scale for hundreds thousands of people, while preserving anonymity of users (personal data remain on client side). Thus, we use an existing clustering method, that we have improved so that it is distributed respectively on client and server side. Nevertheless, in the absence of numerical votes for marketing reasons, we have chosen to do an innovative combination of this decentralized collaborative filtering method with a user profiling technique. We have also been submitted to constraints such as a short answer time on client side, in order to be compliant with the ASTRA architecture.

6.3.2. Bayesian Networks and Hemodialysis

Participants: Cédric Rose, Cherif Smaili, François Charpillet.

Telemedicine is a mean of facilitating the distribution of human resources and professional competences. It can speed up diagnosis and therapeutic care delivery and allow peripheral healthcare providers to receive continuous assistance from specialized centers. The need of specialized human resources becomes critical with the aging of the population. The treatment of renal failure is an example where telemedicine can help to increase care quality. Over the last decades Bayesian networks has become a popular representation for encoding uncertain expert knowledge. Dynamic Bayesian networks are an extension of Bayesian networks for modeling dynamic processes. In [25], [28], [29], we developed a dynamic Bayesian network adapted to the monitoring of the dry weight of patients suffering from chronic renal failure treated by hemodialysis. An experimentation conducted at dialysis units indicated that the system is reliable and gets the approbation of its users.

6.3.3. *Human motion capture for Gait analyis*

Participants: Jamal Saboune, François Charpillet.

In [26], we made a study, the aim of which is to detect balance disorders and a tendency towards the falls in the elderly, knowing gait parameters. In this paper we present a new tool for gait analysis based on markerless human motion capture, from camera feeds. The system introduced here, recovers the 3D positions of several key points of the human body while walking. Foreground segmentation, an articulated body model and particle filtering are basic elements of our approach. No dynamic model is used thus this system can be described as generic and simple to implement. A modified particle filtering algorithm, which we call Interval Particle Filtering, is used to reorganise and search through the model's configurations search space in a deterministic optimal way. This algorithm was able to perform human movement tracking with success. Results from the treatment of a single cam feeds are shown and compared to results obtained using a marker based human motion capture system. In [27], we present a new approach for marker less human motion capture from conventional camera feeds. Our approach is based on foreground segmentation, an articulated body model and particle filters. In order to be generic and simple no restrictive dynamic modelling was used. A new modified particle filtering algorithm was introduced. It is used efficiently to search the model configuration space. This new algorithm which we call Interval Particle Filtering reorganizes the configurations search space in an optimal deterministic way and proved to be efficient in tracking natural human movement. Results for human motion capture from a single camera are presented and compared to results obtained from a marker based system. The system proved to be able to track motion successfully even in partial occlusions.

7. Other Grants and Activities

7.1. Regional initiatives Actions

7.1.1. *MIBOCA*

Participants: Christine Bourjot, Vincent Chevrier [project leader], Vincent Thomas.

This action is part of the PRST (Programme de Recherche Scientifique et Technique) “Software Intelligence” in the project TOAI (teleoperation and intelligent assistance). The aim of this action (called Biologically-Inspired Methods for the Organization of a Comunity of Assistants)is to study and implement one or more methods that enable a society of agents to organize themselves in a decentralized and dynamical manner. More precisely, we put this work in the context of swarm intelligence and propose to use a novel and original model we built in cooperation with biologists: the Hamelin model. Hamelin model reproduces a specialization phenomenon that can be observed in groups of rats. This year, the work focused on an improved model in which we introduced a social cognition at individual level.

Additionnaly, the MAIA team and the biologists animated a demonstration during the “Fête de la Science” event.

7.2. National initiatives Actions

7.2.1. *RNTS PROJECT PARAChute*

Participants: Loic Pélissier, Jamal Semoune, François Charpillet, Anne Boyer, Amine Boumaza.

PARAChute is a RNTS project dedicated to the prevention off falls by elderly people. The partners involved in this project are either research departments (Université Technologique de Troyes or the MAIA team from Loria), medical institution (CHU Nancy-Brabois, Institut Régional de Réadaptation, Institut de Myologie de Paris, Laboratoire de Physiologie neuromusculaire) or industrial partners (ACDM Concept - Nancy-, Application Electronique de Champagne) with the endorsement of the Région Champagne Ardennes, Téfal, Association Française contre les Myopathies and the CCAS of Nancy.

Falls by elderly people are a major problem of health services because of their frequency and their medical and social consequences. In France, about two million people over sixty five year fall every year. Falls are responsible for an important morbidity (50 000 fractures of the thighbone upper extremity each year in France), a mortality evaluated to 13 000 deaths per year (more than the number of deaths due to road accidents). As falls are a major risk, it is a key challenge to design systems able to detect falls as fast as possible in order to alert the relevant assistance service. Our task in MAIA is to create a non-invasive monitoring of the elderly subject's locomotive behaviour in his/her environment in order to isolate parameters whose values will serve as an alert signal. Our approach of an intelligent monitoring for fall prevention is based on an ecological analysis of the walk. It will thus be a question of in-place walk's telemonitoring. MAIA is then working on the development of a behavioral model based on the observations made via camera. The modeling relies on a notion of signature (set of features caracterising the walk behaviour).

A first feasibility study was carried out in LORIA. About twenty people were filmed walking in a corridor by a single standard CCD camera with a fixed position. We used a standard algorithm for motion detection. From these data, we determined some indicators like the trajectory on the ground, the mean speed, the immediate speed, the acceleration, the height and the orientation of the person. This set of parameters, used as a first estimation of a signature, gave us encouraging results as for the precision and the reproducbility of the calculated parameters.

Recent links between image analysis and image synthesis show that many problems in image analysis can be addressed as optimization problems. These new trends lead the scientific community to introduce bio-inspired optimization techniques (ant algorithms, artificial evolution, swarm intelligence, social spiders ...) as problem solving methods for image analysis.

In the frame of the PARACHUTE project where the problem is to monitor a person's locomotive behavior, a new evolutionary approach will be used to extract a set of parameters that characterize the person's walk. Using a body model, the algorithm explores the parameter space in order to find the set of parameters that fits the observations in the images.

The project began on October 2003, with a two years duration.

7.2.2. DialHémo : Telemedicine System for kidney disease Patients undergoing hemodialysis

Participants: Cédric Rose, Cherif Smaili, Jamal Semoune, François Charpillet, Anne Boyer (project leader).

This project has been funded by INRIA Development Action DialHémo.

The goal of this project is to develop a telemonitoring and diagnosis aid system for the patients undergoing continuous hémodialysis at home, or at the hospital. The input data to the system are returned by the dialysis machine (duration of the session, volume of blood) or by other sensors (weight, blood pressure). The results of data analysis will be available to nephrologists. Organisations which combine their efforts in the HemoDial project are : the research project MAIA at LORIA, the DIATELIC society, technology company stemming from LORIA, partners of the medical and health world in Lorraine (CHU de Nancy, ALTIR), the GAMBRO society, world leader on the market of dialysis machines.

The system intends to monitor the dry weight of the patient which is the weight a normally hydrated patient should have. An experimental platform developed this year by Diatelic by Diatelic SA, is used for acquiring and transmitting medical data to a database, making it accessible to physicians.

Maia team developed a first version of an expert system which analyses the evolution of pre and post dialysis blood pressure and body weight in order to produce a diagnosis of the dry weight and generate an alert when it is diagnosed as inappropriate for the patient. A dynamic bayesian network (DBN) is used to produce this diagnosis. Baysian networks algorithms have been implemented in a tool box which could be used for other projects.

Currently an evaluation of the system is being made by 150 patients treated with hemodialysis at the ALTIR (St Jacques unit) of the CHU of Brabois and at Gerarmer. The centres of Essey, Epinal, Mont Saint Martin and Metz are due to join the experimentation soon. A measurement of care quality is established by following the hypertension statistics among centres.

The first analysis of the care quality is promising. Alerts generated by the expert system are reliable and the diagnosis is most of the time in agreement with the physician decisions. Signals produced directly by the dialysis device, will be added to the expert system. It seems that some of these signals could help in anticipating the dry weight evolution. Currently we are evaluating the use of hemoscan, which measures blood volume variations during the dialysis.

7.2.3. PREDIT PROJECT MOBIVIP

Participants: Amine Boumaza, Maan El Badaoui, El Nadjar, François Charpillet.

Intelligent Autonomous Vehicles currently hold the attention of many researchers because they can bring solutions to many applications related to transport of passengers in urban environments. An example of such a vehicle is the Cycab. The Mobivip project reach several goals in the domain of mobility services (www.inria.fr/mobivip). In the framework of Mobivip project, MAIA team search to play a part in the navigation and guidance system of the Cycab in his evolution environment.

Outdoor positioning and navigation systems often rely on road map database and GPS. However, GPS suffers from satellite masks occurring in urban environments, under bridges, tunnels or in forests. GPS appears then as an intermittently-available positioning system that needs to be backed up by other localization sensors. The MAIA team, and in order to obtain an accurate positioning and ameliorate position tracking process of the Cycab, propose to augment the road map database by a 3D model of the Cycab environment geo-localised (matched) on the digital road map. The accuracy of DGPS geo-localisation of the Cycab on the map database is not sufficient for autonomous navigation. The idea is to ameliorate the metric localization provided by such a system to centimetric localization accuracy by using the 3D model which have a centimeteric geo-accuracy. Sensors and information sources used for this task are GPS, inertial central, stereovision, Laser range sensor and road map database managed by a Geographical Information Sytem. The approach of position tracking under study at MAIA project is based on the use of Particle Filter and Extended Kalman Filter (El Najjar 2004, Gustafsson 2002) for multi-sensor fusion, Belief theory and Hidden Markov Model for Road Reduction Filter [2].

Recent links between image analysis and image synthesis show that many problems in image analysis can be addressed as optimization problems. These new trends lead the scientific community to introduce bio-inspired optimization techniques (ant algorithms, artificial evolution, swarm intelligence, social spiders ...) as problem solving methods in image analysis. The fly algorithm is a stereo 3-D reconstruction algorithm based on a evolutionary strategy that explores the 3-D space searching for the set of points that best describe the scene. Objects in the scene are represented by a set of points (the flies) that are subject to evolution. Best fit flies, ones which position reflects the true positions of obstacles in the scene, are selected and survive throughout the generation. The algorithm has been implemented on a CyCab an electric vehicle designed by INRIA, and applied to obstacle detection. When an obstacle is detected by the fly algorithm within a minimum safety distance from the vehicle an alarm is raised.

7.3. European initiatives

7.3.1. TFG

Participants: Christine Bourjot, Vincent Chevrier.

MAIA is member of AgentLink that is the European Commission's IST-funded Coordination Action for Agent-Based Computing (http://www.agentlink.org). Vincent Chevrier is promoter of the Technical Forum Group “Self Organization” in AgentLink (http://www.irit.fr/TFGSO/). The aim of the TFG is to work on self-organisation in the complex distributed systems such as Multi-agent systems.

7.4. International initiatives

7.4.1. Decision-theoretic framework for collaborative multi-agent systems

Over the past years, a very fruitful research collaboration has been established between the MAIA group at INRIA, directed by François Charpillet, and the RBR group at the University of Massachusetts, directed by

[2] El Najjar M. E. and Ph. Bonnifait. (2004) "Road-Matching Method for Precise Vehicle Localisation using Kalman Filtering and Belief Theory" Journal of Autonomous Robots, S.I. on Robotics Technologies for Intelligent Vehicles. Kluwer Academic Publishers.

Shlomo Zilberstein. The collaboration was conceived at a meeting that took place in 1995 at the International Joint Conference on Artificial Intelligence in Montreal. During this meeting, we identified a high degree of overlap between our interests, research projects, and solution techniques. These common interests relate to the development of planning and monitoring techniques for autonomous systems that can operate in real-time and can cope with uncertainty and limited computational resources. At the time, the U.S. team investigated a solution technique based on "anytime algorithms" and the French team investigated the "progressive processing" model.

Since then, we have worked together on both of these models and exploited the synergy to improve their applicability and effectiveness. This year this collaboration has been funded by INRIA as an associated team. This association of the two research teams has focused on the development of a decision-theoretic framework for planning and control of collaborative multi-agent systems by formalizing the problem as decentralized control of a Markov process. The overall goal is to develop sophisticated coordination strategies that stand on a formal footing. This enables us to better understand the strengths and limitations of existing heuristic approaches to coordination and, more importantly, to develop new approaches based on these more formal underpinnings. There is a wide range of application domains in which decision-making must be performed by a number of distributed agents that are trying to achieve a common goal. This includes information-gathering agents, distributed sensing, coordination of multiple distributed robots, decentralized control of a power grid, autonomous space exploration systems, as well as the operation of complex human organizations. These domains require the development of a strategy for each decision maker assuming that decision makers will have limited ability to communicate when they execute their strategies, and therefore will have different knowledge about the global situation.

8. Dissemination

8.1. Visits, national and international relations

Maia is a leading force in the PDMIA group (Processus Decisionnels de Markov et Intelligence Artificielle) and took a great part in the annual meeting of the group. This year, the group held its annual meeting in Lille. This meeting took the form of a very informal workshop with scientific presentations and many open discussions.

8.2. Conference, workshop, PHD and HDR committees, invited conferences

- Anne Boyer, Vincent Chevrier and François Charpillet are members of several Specialist Committees (commissions de spécialiste) respectively in Nancy2 and Strasbourg, Nancy 1, Paris 13.
- Anne Boyer is a member of the editorial committee of the journal in computer science called "Technique et Science Informatiques".
- Anne Boyer is the "chargée de mission" of the President of the university "Universisité Nancy 2" for Information System and Technology of Information and Communication. She is in charge for the university of the coordinatation of the project "Unire" (Université Numérique InterRégionale de l'Est).
- Anne Boyer was reviewer in the PHD commitee of Nourredine Hayari. Title of the PHD: "Cartes auto-organisatrices et approche évolutionniste pour les problèmes de tournées de véhicules avec regroupements"
- Christine Bourjot and Vincent Chevrier are members of the working group 'Colline' (AFIA, GDR I3).
- Christine Bourjot is Member of the scientific council of « Réseau Grand Est des Sciences Cognitives » Responsible of the M2 professional Master in Cognitive Science at the University of Nancy2

- Vincent Chevrier was an invited speaker at Engineering with Complexity and Emergence, a Satellite workshop of the European Conference on Complex Systems ECCS'05; and at "Building miwed societies of robots and animals", Les Treilles, 2005 .
- Vincent Chevrier is a member of
  - the editorial board of Interstices, a site to disseminate research work about computer science for french-speaking people,
  - the editorial board of the "Lettre du LORIA" (til September),
  - advisory board of EUMAS, the European Workshop on Multi-Agent Systems
  - the program committee of MA4CS'05, Multi-Agents for modeling Complex Systems, PAris, November 2005.
  - the program committee of JFSMA05, Journées Francophones sur les Systèmes Multi-Agents, November , 2005.
  - the program committee of ESAW05, Engineering Societies in the Agents' World, 26 - 28 October, 2005, TURKEY.
- Vincent Chevrier was member/reviewer in the following Phd Committees:
  - Sami Bhiri, Approche transactionnelle pour assurer des compositions Fiables de Services Web, Loria, Nancy, as member.
  - Ludovic Coquelle, simulation de comportements individuels instinctifs d'animaux dans leur environnement (de la description éthologique à l'exécution de comportements réactifs), CERV, Brest, as reviewer.
- Vincent Chevrier is the moderator of the mailing list of the french-speakers' community on multi-agent systems.
- François Charpillet and Vincent Chevrier are members of the steering committee of the research theme 'TeleOperation and Intelligent Assistant' in the PRST 'Software Intelligence'.
- François Charpillet was a member of the program committees of AAMAS, IJCAI, AI&Math, EWRL, EUMAS, MFI, and Journées Inria Industrie Santé 2006.
- François Charpillet is co-editor of the special issue RIA PDMIA 2006
- François Charpillet was reviewer in the following Phd Committee: *Approche auto-adaptative à base d'agents mobiles et inspirée du système immunitaire de l'homme pour la découverte de services dans les réseaux* de Mohamed Bakhouya UTBM,
- François Charpillet was member in the following Phd Committees:*Approche symbolique et heuristique de la planification en environnement incertain : Optimisation d'une stratégie de déplacement et de prise d'information* de Florent Teichteil-Konigsburg CERT, *From Analysis to design of holonic muli-agent systems: a framework, methodological guidelines and applications* de Sébastien Rodriguez, UTBM,
- François Charpillet was reviewer in the following HDR Committee: *Algorithmes pour la planification* de Pierre Regnier IRIT.
- François Charpillet is an elected member of "bureau de l'école doctorale".
- François Charpillet is member of the scientific council of the GREYC laboratory at Caen.
- Bruno Scherrer was a member of the program committee of AAMAS, ECML and IJCAI.

8.3. Popularization activity

8.3.1. Swarm intelligence or how making complexity from simplicity

Participants: Vincent Chevrier, Aurelien St-Dizier.

This work concerns the dissemination of research results to non specialists. It concerns the domain of swarm intelligence. The article presents the basis of such an approach and provides illustrations through applets. The article is accessible on line at http://interstices.info [5].

8.3.2. Cycab demonstration on Stanislas Place in Nancy

Participants: Amine Boumaza, Maan El Badaoui, El Nadjar, François Charpillet.

The Maia Team organized the evolution review of Mobivip in Nancy. Real demonstrations were proposed by Mobivip partners on the Stanislas Place. Ten CyCabs took part to this show.

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Miscellaneous

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