MINEMA

Self-Organization and Coordination for Multi-Agent Systems

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Abstract

This document is a scientific report about my visit to Katholieke Universiteit Leuven, Leuven—Belgium. This project has been supported by the European Science Foundation (ESF) MiNEMA Scientific Programme, Grant no. 805.

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1 Introduction

In this document I describe the activities and results achieved during my visit to AgentWise taskforce of the DistriNet group at Katholieke Universiteit Leuven, Leuven—Belgium. The project lasted six weeks, from November 3 up to December 15, 2005: it has been supported by the European Science Foundation (ESF) MiNEMA Scientific Programme, Grant no. 805.

During the period, there have been several informal meetings in order to freely discuss about the role of self-organisation in the engineering of distributed systems. In order to explain some of the approaches that my group and I promote, I gave two presentations, one about cognitive stigmergy [GRV+05] and the other one related to formal methods [Gar05b]. For the remaining period, we agreed to concentrate on the latter. At the end of the project I gave another presentation summarising the results [Gar05a].

During the period, my group and I submitted a related paper [GVO06] to the 18th European Meeting on Cybernetics and Systems Research.

Furthermore, the AgentWise group and I are actively working on a paper about the applicability of formal methods to real industrial case studies: we want to give guarantees about emergence of global system properties in self-organising systems. That paper will be submitted to the *Environments for Multi-agent Systems* (E4MAS) workshop of the *5th International Joint Conference on Autonomous Agents and Multi-Agent Systems* (AAMAS 2006).

The report is organised as follows: in Section 2 we briefly describe the theory of self-organisation and give some details about its main challenges; in Section 3 we provide some details about the applicability of formal methods for the analysis and design of multi-agent systems; finally in Section 4 we draw conclusions and describe our schedule for future works.

2 Self-organisation theory

In nature we can observe complex patterns, e.g. zebra fur, and ordered structures, e.g. termites nests. Although these phenomena may seem completely unrelated, actually there are underlying common mechanisms regulating these systems [CDF+01]. The theory of self-organisation, first developed in physics and biology, attempts to explain how these patterns arise.

We define a system to be *self-organising* if it is able to re-organise itself upon environment changes, via local interactions of its components. Often, the complex dynamics of the system produces phenomena—like the ones described above—that are not explainable only considering the parts by themeselves, but as a very result of interactions. We say that these properties are *emergent*.

These definitions mainly derived from natural science apply in systems engineering as well—and for what we are concerned—in computer systems engineering. Self-organisation theory—and similar initiatives [KC03]—provides a very appealing framework, because it promotes systems built upon simple rules and the complex patterns.

One of the biggest challenges in self-organising systems engineering is the need to give guarantees about the emergence of the desired properties, and avoiding side-effects. In the next section we describe our approach to tackle this issue.

3 Application of formal methods to self-organising systems

Formal methods are a wide class of mathematically grounded tools built in order to help the process of system engineering. In particular, there is a class of formal languages, *Process Algebra*, whose scope is to describe and analyse the behavior of concurrent systems. CCS, Calculus of Communicating Systems, was one of the first process algebras and it has been developed by Robin Milner . Later, π-*calculus* has been built on top of CCS: in particular the most notable extension is process mobility [MPW92].

Since π-calculus is targeted to describe concurrent systems where components may interact, we considered it to be a valuable tool for self-organising system engineering. In particular we found interesting its extension which accounts for stochastic phenomena, i.e. the *Stochastic* π-*calculus* [Pri95].

We already applied this tool to an intrusion detection case study: specifically we wanted to explore the dynamics of an Abnormal Behavior Detection System built on top of TuCSoN coordination infrastructure for multi-agent systems [OZ99].

Our approach involves three stages [GVO05]: (i) system modeling, (ii) simulation of the system specifications, (iii) analysis of the results and parameter tuning. In [GVO06], we noticed that the dynamics of malicious agents and inspector agents populations—for certain parameters values—resembles to the cyclic dynamics of prey-predator systems [CDF$^+$01], see Figure 1. Exploiting these phenomena let us control the spreading of malicious agents within the system. These results have been obtained during the visit to KULeuven and are documented in [GVO06].

During the visit, we also modelled several systems known from the literature in order to explore the current limits in the π-calculus specification process [Gar05a]. We consider that current extensions of π-calculus cannot be easily exploited when situatedness is a main concern, i.e. situatedness affects the way agents interact. We propose an extension in order to provide at least syntactic support to locality of agents [Gar05a].

Furthermore, we want to add a fourth step to the previously described process in order to give mathematical guarantees about the emergence of system properties. After a survey of the literature we considered the possibility of exploiting model checking algorithms and tools to give such guarantees: after simulating the system we can formulate a statement in temporal logic and use existing tools in order to evaluate if that statement holds in the given system.

We agreed to apply that process to an industrial case study about Automated Guided Vehicles developed at KULeuven [WSH05]. The resulting paper will be submitted to the *Environments for Multi-agent Systems* (E4MAS) workshop of the *5th International Joint Conference on Autonomous Agents and Multi-Agent Systems* (AAMAS 2006).

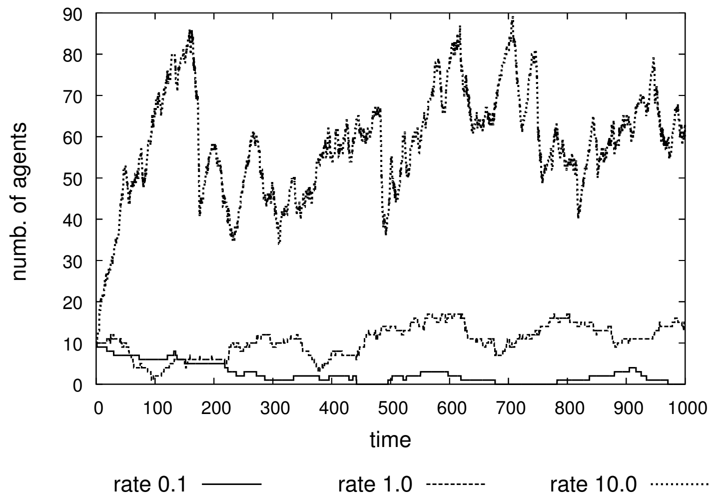

Figure 1: The dynamics of an abnormal behavior detection system: notice that these dynamics are typical of a prey-predator system.

4 Conclusion

In this report we have summarised the activities in the joint project between Alma Mater Studiorum—Università di Bologna and Katholieke Universiteit Leuven. The main achievements relate to the exploration of Stochastic π-Calculus specifications of self-organising systems. Although there has not been a lot of effort in combining these two fields, we consider process algebras to be a valuable tool both to simulate system dynamics and give guarantees of global behavior.

We showed that π-calculus is able to model a lot of different mechanisms but it not suitable for systems in which situatedness is a main concern. We proposed three possible extensions to model locality issues, which will be explored in following research activities.

I consider this experience at KULeuven very fruitful since we have achieved several goals:

- advances in my main research topic;
- knowledge sharing between researchers on self-organising systems, multi-agent systems and formal methods;
- plans for joint future works.

These achievements have been possible thanks to the European Science Foundation (ESF) Minema Scientific Programme.

References

[CDF+01] Scott Camazine, Jean-Louis Deneubourg, Nigel R. Franks, James Sneyd, Guy Theraulaz, and Eric Bonabeau. *Self-Organization in Biological Systems.* Princeton Studies in Complexity. Princeton University Press, 41 William Street, Princeton, New Jersey 08540, USA, 2001.

[Gar05a] Luca Gardelli. Experiences on stochastic π-calculus, December 13 2005. Seminar - Available online at www.alice.unibo.it.

[Gar05b] Luca Gardelli. On pi-calculus and its applications, November 10 2005. Seminar - Available online at www.alice.unibo.it.

[GRV+05] Luca Gardelli, Alessandro Ricci, Mirko Viroli, Andrea Omicini, and Enrico Oliva. Applying stigmergy to cognitive agents societies, November 14 2005. Seminar - Available online at www.alice.unibo.it.

[GVO05] Luca Gardelli, Mirko Viroli, and Andrea Omicini. On the role of simulation in the engineering of self-organising systems: Detecting abnormal behaviour in MAS. In Flavio Corradini, Flavio De Paoli, Emanuela Merelli, and Andrea Omicini, editors, *AI*IA/TABOO Joint Workshop "Dagli oggetti agli agenti: simulazione e analisi formale di sistemi complessi" (WOA 2005)*, pages 85–90, Camerino, MC, Italy, 14–16 November 2005. Pitagora Editrice Bologna.

[GVO06] Luca Gardelli, Mirko Viroli, and Andrea Omicini. Exploring the dynamics of self-organising systems with stochastic π-calculus: Detecting abnormal behaviour in mas, 2006. Submitted to *From Agent Theory to Agent Implementation (AT2AI-5)* session of the 18th European Meeting on Cybernetics and Systems Research (EMCSR 2006).

[KC03] Jeffrey O. Kephart and David M. Chess. The vision of autonomic computing. *Computer*, 36(1):41–50, January 2003.

[MPW92] Robin Milner, Joachim Parrow, and David Walker. A calculus of mobile processes, part I. *Information and Computation*, 100(1):1–40, September 1992.

[OZ99] Andrea Omicini and Franco Zambonelli. Coordination for internet application development. *Autonomous Agents and Multi-Agent Systems*, 2(3):251–269, 1999.

[Pri95] Corrado Priami. Stochastic pi-calculus. *The Computer Journal*, 38(7):578–589, 1995.

[WSH05] Danny Weyns, Kurt Schelfthout, and Tom Holvoet. Exploiting a virtual environment in a real-world application. In Danny Weyns, H. Van Dyke Parunak, and Fabien Michel, editors, *Second International Workshop on Environments for Multiagent Systems, E4MAS*, AAMAS 2005, Utrecht, The Netherlands, July 2005.