

# Engineering Self-Organizing Systems

Report for the 2<sup>nd</sup> Year of PhD Course

Electronics, Computer Science and Telecommunications Engineering



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# Abstract

The increasing complexity of artificial systems is a great challenge for the modern engineer. Specifically, aspects like pervasiveness, heterogeneity and distribution are in contrast with the necessity of a greater reliability.

The theory of self-organization deals with natural systems, typically made of several entities locally interacting with each other in order to preserve or increase the system organization upon environment perturbations.

After introducing self-organization principles and current developments in the multi-agent systems (MAS) research community, it follows a discussion about our activities in that frame. Specifically, here we concentrate on methodological and architectural aspects: despite the inherent robustness of self-organizing systems, their design creates several problems, in particular predictability and reliability. Then, we analyse these problems exploiting formal modelling and stochastic simulation tools.

# Background and Motivations

# Multi-Agent Systems (MAS)

- **Agent**: autonomous proactive entity able to perceive & act into the environment
- **MAS**: A system made of several agents which interact with each other and with the environment
- Is a very multi-disciplinary and active field
- The multi-agent is our reference paradigm when modelling, simulating and designing systems

# Self-Organizing Systems (SOSs)

- SOS: A system that is able to increase and maintain its inner organization via local interaction of its parts, despite environment perturbations
- Often, due to the non-linear interactions between components, **global patterns** or properties emerge
- MAS is the obvious choice when working with SOS...

# Why Studying SOSs?

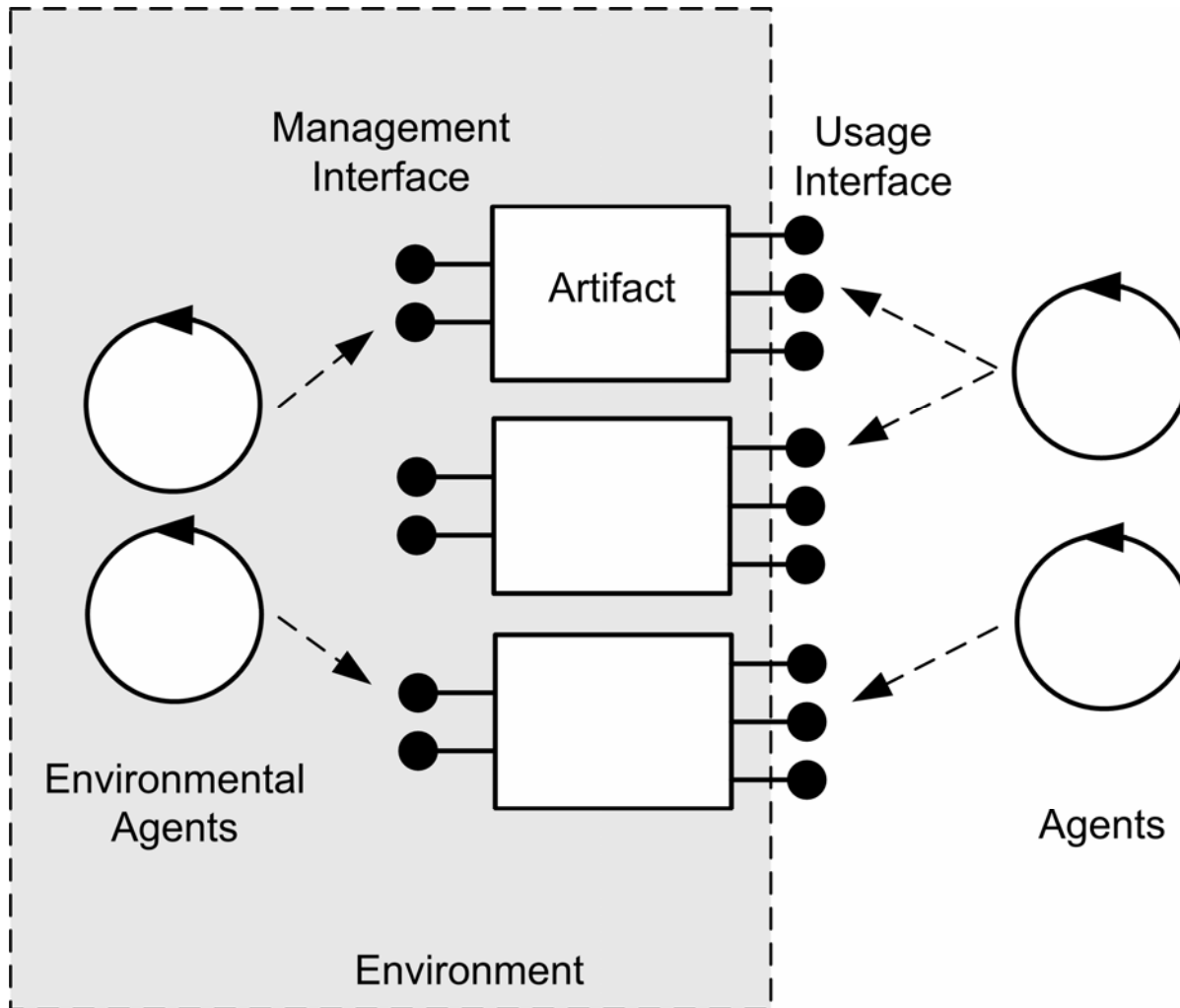
- First SOSs have been observed in natural systems (ants, chemical oscillators...): the strategies exhibited by these systems have proven to be quite robust and efficient
- They are able to develop complex pattern/properties from the interplay of simple rules, hence reducing complexity!
- Indeed, SOSs are the starting point for research initiatives also in the industries, e.g. IBM's Autonomic Computing

# Main Challenges of SOSs

- There is no methodology to devise the set of rules that let emerge only the desired properties
- How can we provide guarantees about the emergence of specific properties?
- One of our **research goals** is to face these issues: as a byproduct, we are recognising engineering best practices and devising solutions to distributed problems

# Engineering Self-Organizing MAS: Methodology and Architecture

# Our Reference Meta-Model



# A Methodological Approach

- After analysis and before the actual design...
  - **Modelling**: look for the desired global behaviour among the catalogue of known self-organizing systems and model the strategy
  - **Simulation**: preview the dynamics of the abstract models to see if emergent properties actually happens
  - **Tuning**: Tune the model and related parameters to obtain the specific required behaviour and evaluate feasibility

# Modelling

- It is likely that we cannot identify the exact desired behaviour among existing SOSs
- Although, experiences show that it is possible to adapt existing ones to the designer needs
- The model specifies the roles of the entities, i.e. environmental agents, artifacts and user agents
- Artifacts provide agents with services
- Typically the feedback loop is realised by the coupling of user and environmental agents

# Simulation

- Models are expressed in a formal language able to describe stochastic phenomena
- Stochasticity is an essential abstraction tool for handling complexity and non-determinism
- Given a formal specification it is possible to run simulations and investigate model dynamics

# Simulation Tools

- We made some experiences with Stochastic pi-Calculus and the SPiM simulator
- We also extended the MAUDE rewriting language for supporting stochasticity
- To this purpose we implemented a modified Gillespie algorithm (the same of SPiM)

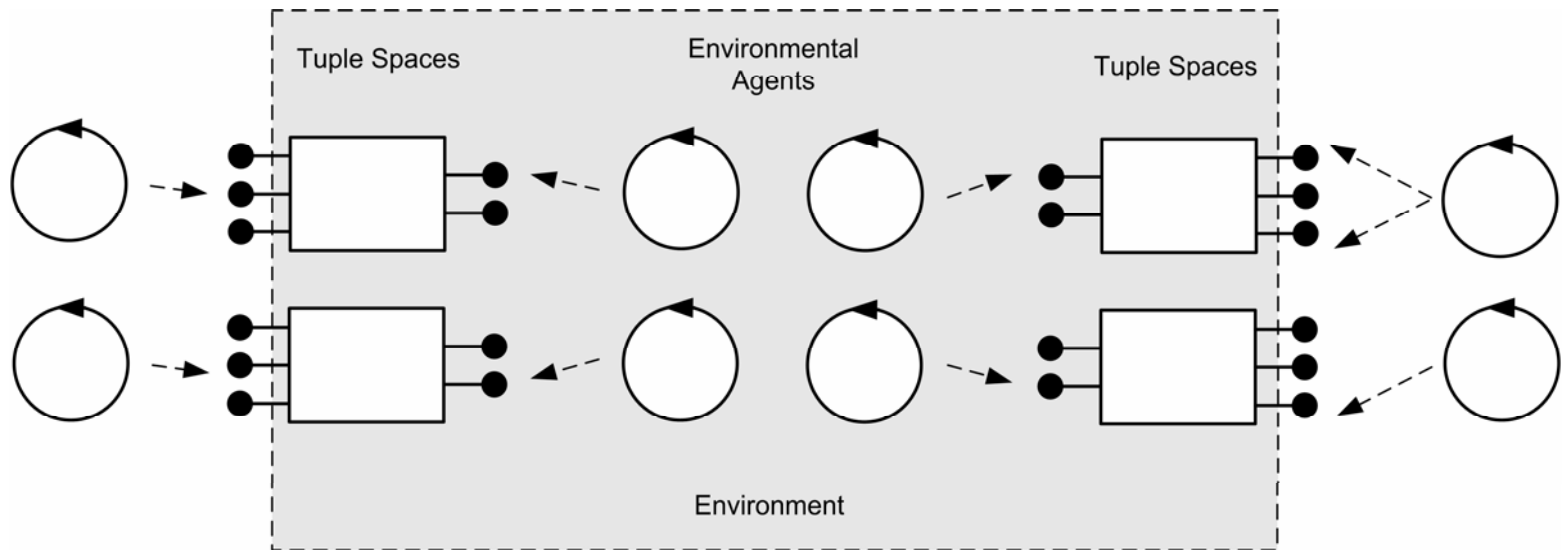
# Tuning

- Due to the chaotic behaviour of SOSs, it is necessary to tweak parameters several times before capturing the desired behaviour
- Tuning may end up to a set of suitable parameters or providing evidence of unfeasibility
- In case of unfeasibility then it is necessary to tune the model

# Engineering Self-Organizing MAS: Collective Sort Case Study

# Problem definition

- We want to provide a service of tuple clustering for an environment where agents deploy tuples without caring of the tuple space content
- The solution must be provided online, saving computational power for other tasks



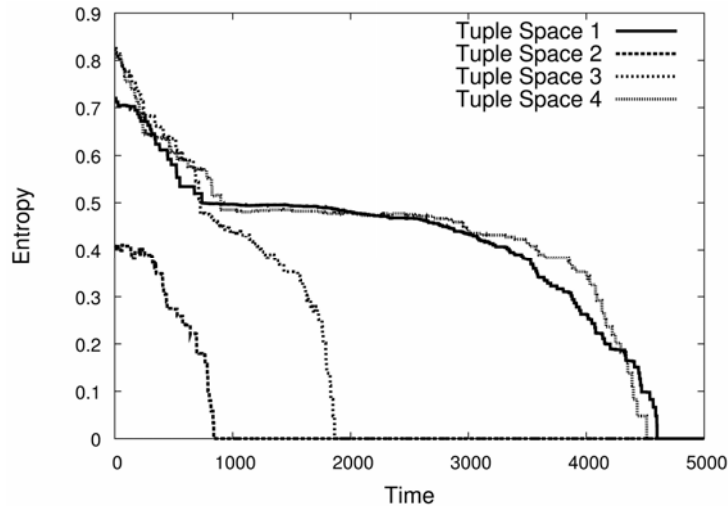
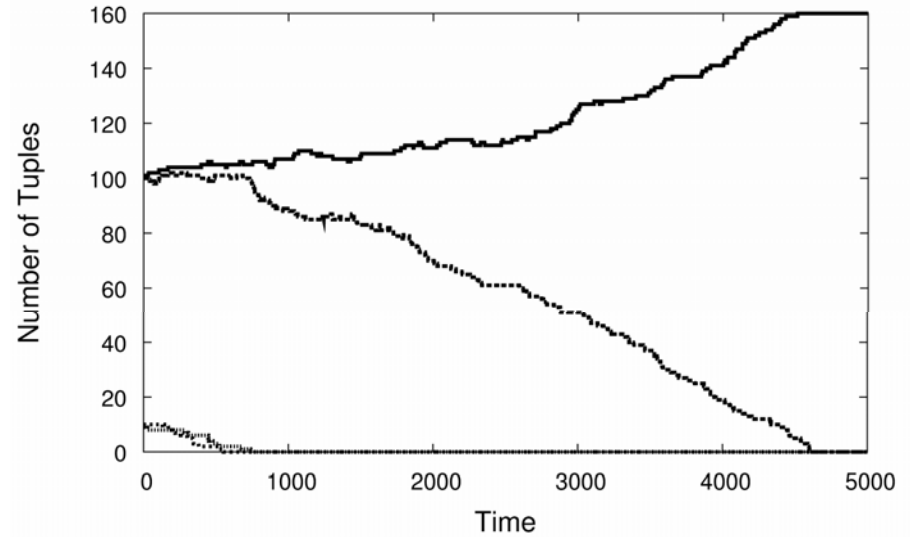
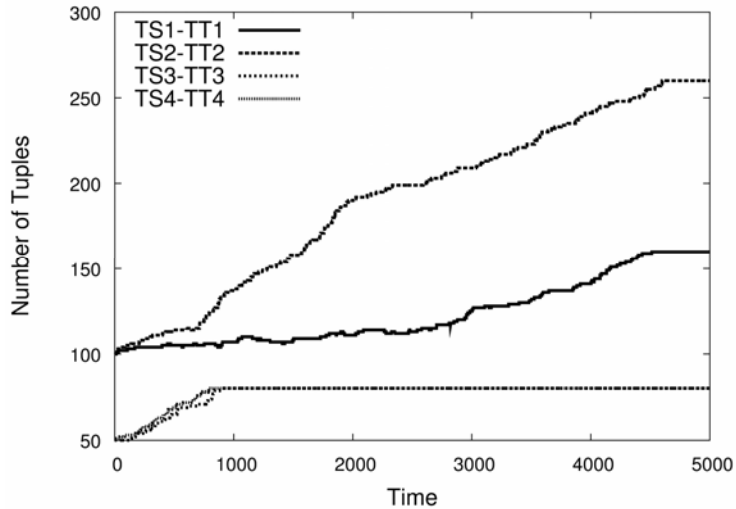
# Collective Sort: Model

- We recognise a suitable solution to our case study in the problem known as **brood sorting**
- Hence, we devise a strategy supporting more “kinds” of broods

An environmental agent

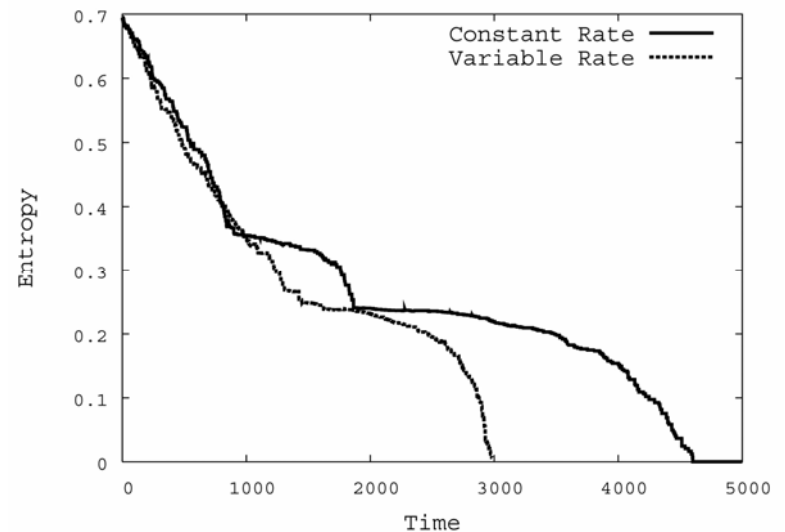
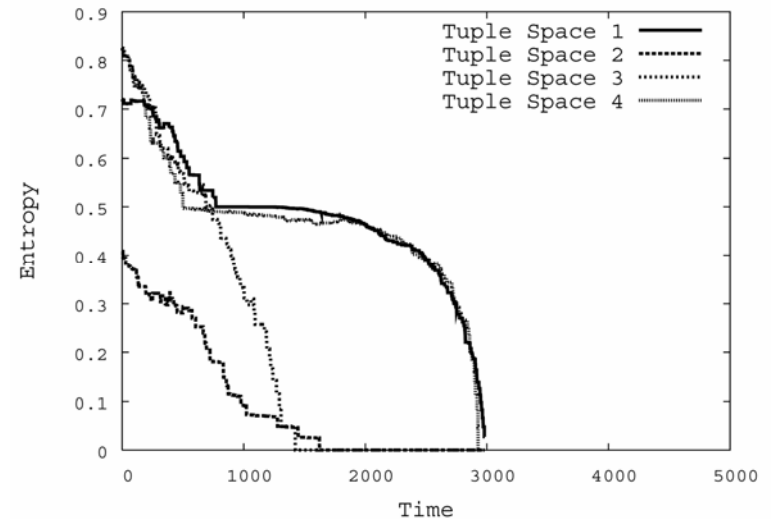
- 1) draws a destination tuple space TSD different from the source one TSS;
- 2) draws a kind  $k$  of tuple;
- 3) (uniformly) reads a tuple  $T1$  from TSS;
- 4) (uniformly) reads a tuple  $T2$  from TSD;
- 5) if the kind of  $T2$  is  $k$  and it differs from the kind of  $T1$ , then it moves a tuple of the kind  $k$  from TSS to TSD.

# Collective Sort: Simulations



# Collective Sort: Tuning

- We want the strategy to converge faster
- Let the spatial entropy drive the clustering process
- Spatial entropy has also a meaning in natural systems



# Future Directions

# Goal: Self-Organization Theory

- Understand the mechanisms underlying emergent phenomena
- Provide best practices for reverse engineering the set of rules that lead to the target emergent phenomena

# Goal: Methodology

- Refine the methodology
- Apply the methodology to build further prototypes of SOS
- Integrate results from formal methods community

# Goal: Meta-Model

- Validate the meta-model with further case studies and eventually improve it
- Compare the meta-model with the needs of MAS community

# Goal: Formal Tools

- Push for innovations in formal methods community and provide feedback from the application of these techniques
- Test extensions to formal languages, and provide tool support for these extensions

# References

# Publications in 2006 (1/2)

- [Mirko Viroli](#), [Matteo Casadei](#), [Luca Gardelli](#)  
*A Case of Self-Organising Environment for MAS: the Collective Sort Problem*. 4th European Workshop on Multi-Agent Systems (EUMAS 2006). December 2006 - Lisbon - Portugal
- [Matteo Casadei](#), [Luca Gardelli](#), [Mirko Viroli](#)  
*Simulating Emergent Properties of Coordination in Maude: the Collective Sorting Case*. 5th International Workshop on the Foundations of Coordination Languages and Software Architectures (FOCLASA 2006) a satellite workshop of CONCUR. August 2006 - Bonn - Germany
- [Matteo Casadei](#), [Luca Gardelli](#), [Mirko Viroli](#)  
*Collective Sorting Tuple Spaces*. Dagli oggetti agli agenti: Sistemi Grid, P2P e Self-\*, AI\*IA/TABOO Joint Workshop (WOA 2006). September 2006, Catania – Italy
- [Luca Gardelli](#), [Mirko Viroli](#), [Matteo Casadei](#)  
*Engineering the Environment of Self-Organising Multi-Agent Systems Exploiting Formal Analysis Tools*. AICA 2006 - Associazione Italiana per l'Informatica e il Calcolo Automatico. September 2006, Cesena - Italy

# Publications in 2006 (2/2)

- [Luca Gardelli, Mirko Viroli, Andrea Omicini](#)  
*On the Role of Simulations in Engineering Self-Organizing MAS: the Case of an Intrusion Detection System in TuCSoN*. Lecture Notes in Computer Science. LNAI 3910. pp 153-166. Springer, 2006 3rd International Workshop “Engineering Self-Organising Applications” (ESOA 2005), Utrecht, The Netherlands (NL), July 2005. Selected Revised Papers
- [Luca Gardelli, Mirko Viroli, Matteo Casadei](#)  
*On Engineering Self-Organizing Environments: Stochastic Methods for Dynamic Resource Allocation*. The Third International Workshop on Environments for Multiagent Systems (E4MAS 06). To be held at The Fifth International Joint Conference on Autonomous Agents & Multiagent Systems ([AAMAS 2006](#)) - Future University-Hakodate, Japan, May 8, 2006
- [Alessandro Ricci, Andrea Omicini, Mirko Viroli, Luca Gardelli, Enrico Oliva](#)  
*Cognitive Stigmergy: A Framework Based on Agents and Artifacts*  
The Third International Workshop on Environments for Multiagent Systems (E4MAS 06). To be held at The Fifth International Joint Conference on Autonomous Agents & Multiagent Systems ([AAMAS 2006](#)) - Future University-Hakodate, Japan, May 8, 2006
- [Luca Gardelli, Mirko Viroli, Andrea Omicini](#)  
*Exploring the Dynamics of Self-Organising Systems with Stochastic pi-Calculus: Detecting Abnormal Behaviour in MAS*. Fifth International Symposium "From Agent Theory to Agent Implementation" (AT2AI-5). To be held at the 18th European Meeting on Cybernetics and Systems Research ([EMCSR 2006](#)) - Vienna, Austria (AT). April 2006.

# Publications in 2005

- [A. Ricci](#), [A. Omicini](#), [M. Viroli](#), [L. Gardelli](#), [E. Oliva](#)  
*Cognitive Stigmergy: A Framework Based on Agents and Artifacts.*  
EUMAS 2005 - The Third European Workshop on Multi-Agent Systems, Brussels, Belgium (BE). December 2005
- [Luca Gardelli](#), [Mirko Viroli](#), [Andrea Omicini](#)  
*On the Role of Simulations in Engineering Self-Organizing Systems: Detecting Abnormal Behavior in MAS.* Dagli oggetti agli agenti: simulazione e analisi formale di sistemi complessi, AI\*IA/TABOO Joint Workshop (WOA 2005), Camerino (MC), Italy (IT). November 2005.
- [Luca Gardelli](#), [Mirko Viroli](#), [Andrea Omicini](#)  
*On the Role of Simulations in Engineering Self-Organizing MAS: the Case of an Intrusion Detection System in TuCSoN.* 3rd International Workshop “Engineering Self-Organising Applications” (ESOA 2005), Utrecht, The Netherlands (NL), July 2005.
- [Luca Gardelli](#), [Mirko Viroli](#), [Andrea Omicini](#)  
*Engineering Self-Organizing MAS with Coordination Artifacts and ACCs*  
7th International Conference “Coordination Languages and Models” (COORDINATION 2005), Namur, Belgium (BE). April 2005.