Engineering Self-Organizing Systems

Report for the 2nd 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, tipically 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?

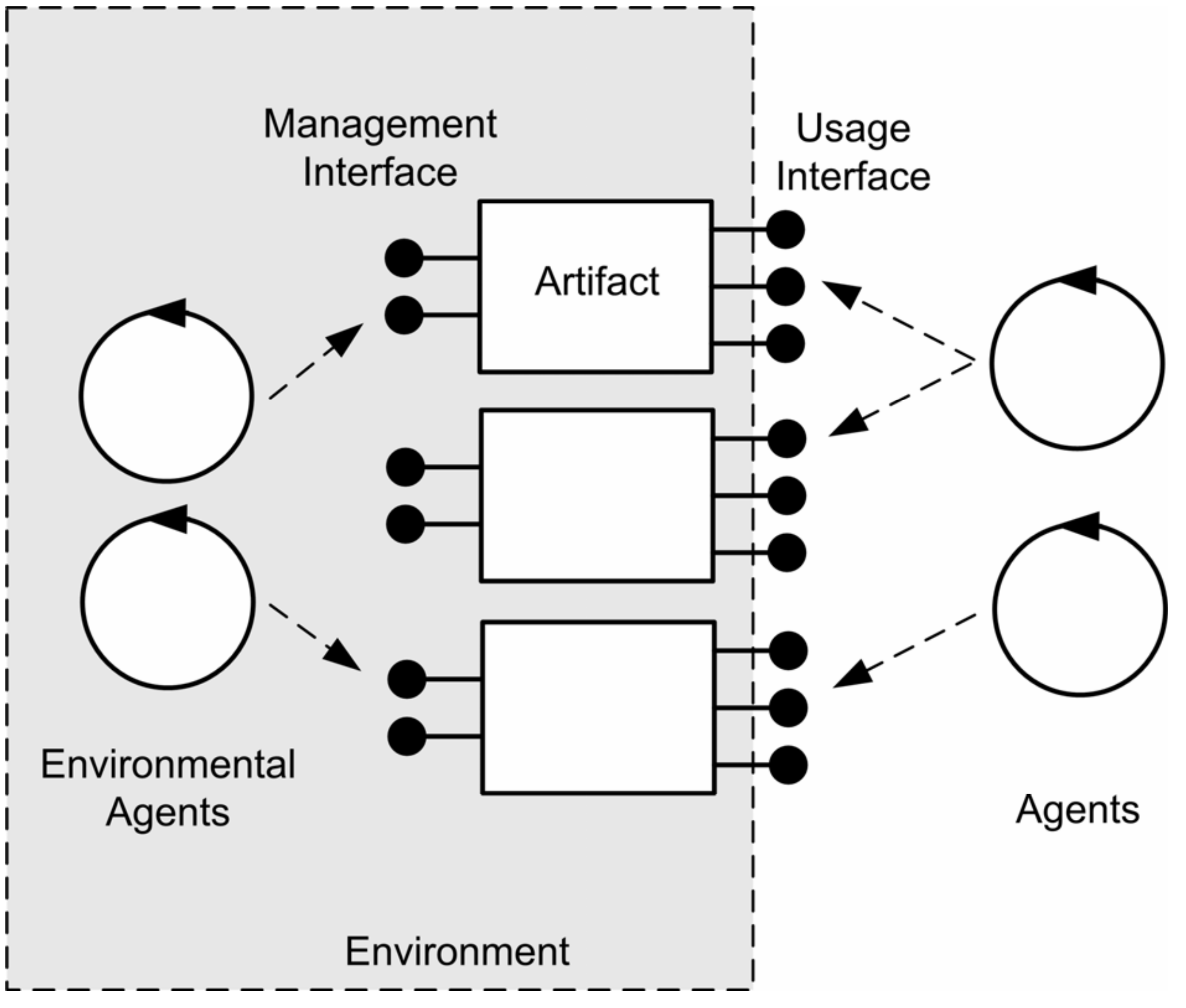
- First SOSs have been observed in natural systems (ants, chemical oscillators…): the strategies exhibited by these systems have proven to be quite robust and efficient
- They are able to develop complex pattern/properties from the interplay of simple rules, hence reducing complexity!
- Indeed, SOSs 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
- Tipically 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)

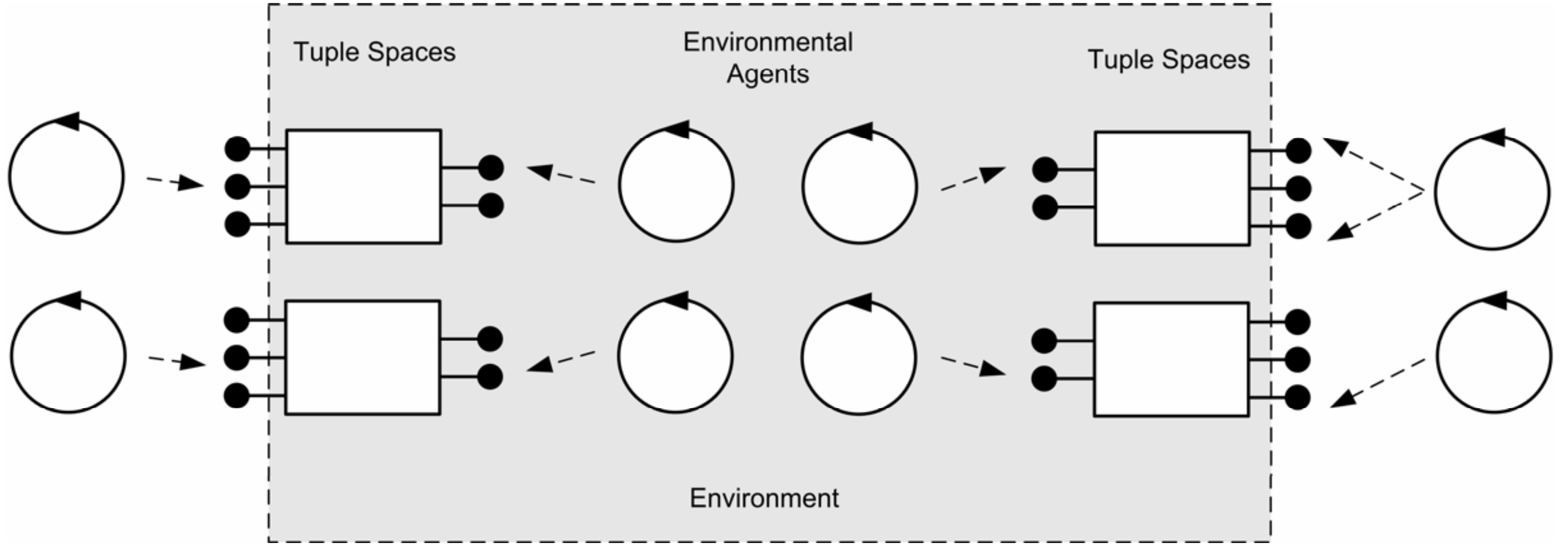
Tuning

- Due 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;

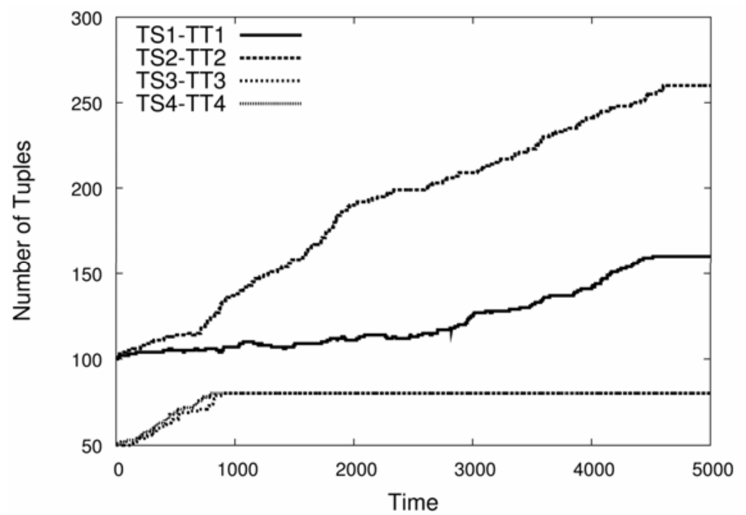
2) draws a kind k of tuple;

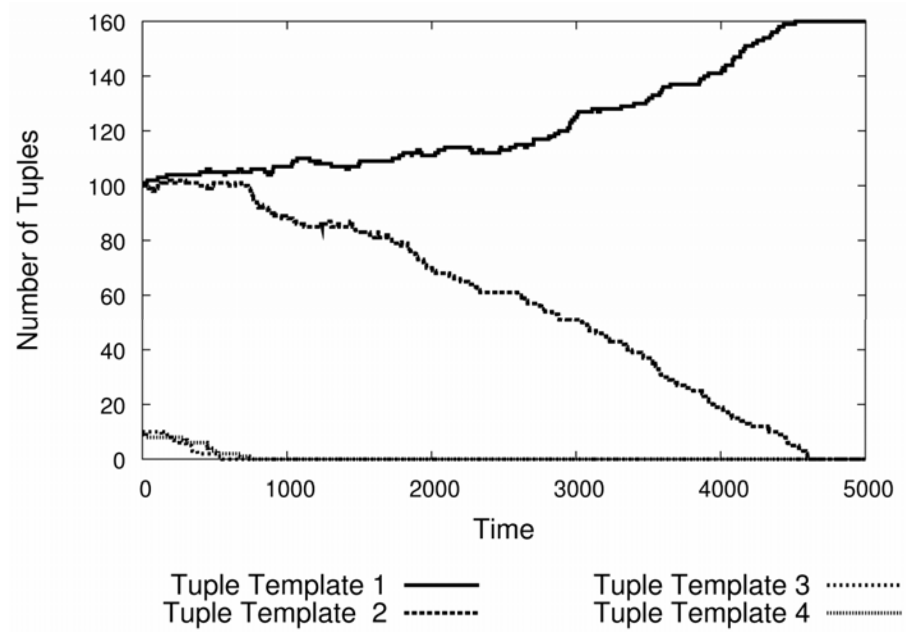
3) (uniformly) reads a tuple T1 from TSS;

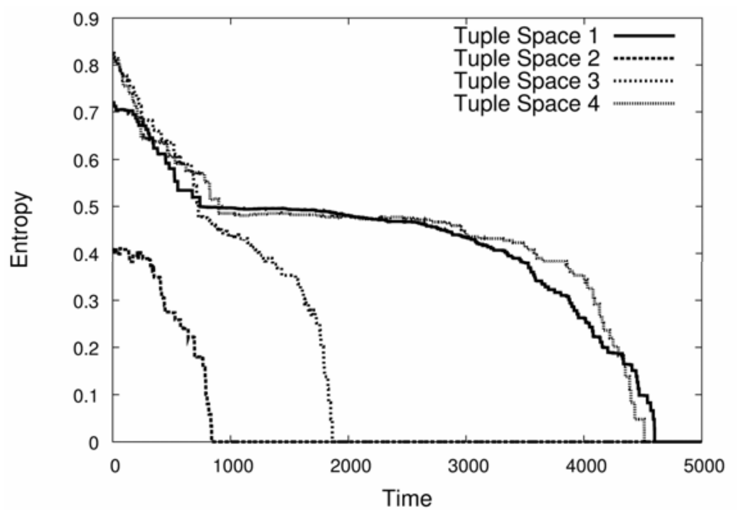
4) (uniformly) reads a tuple T2 from TSD;

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

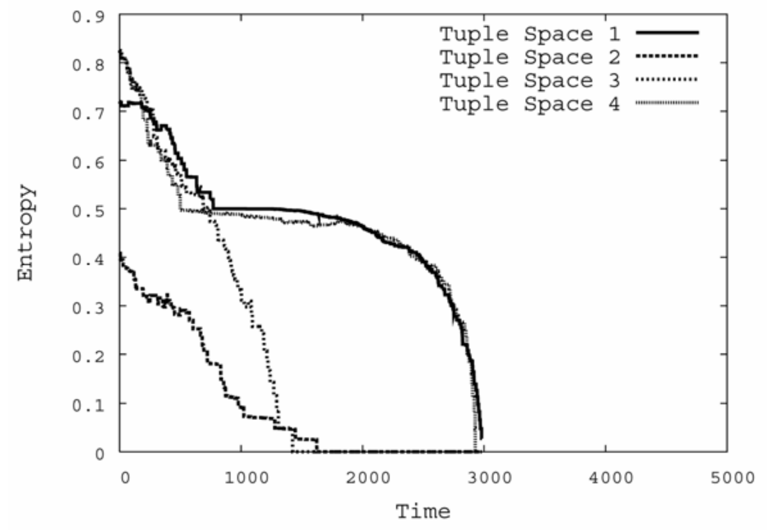


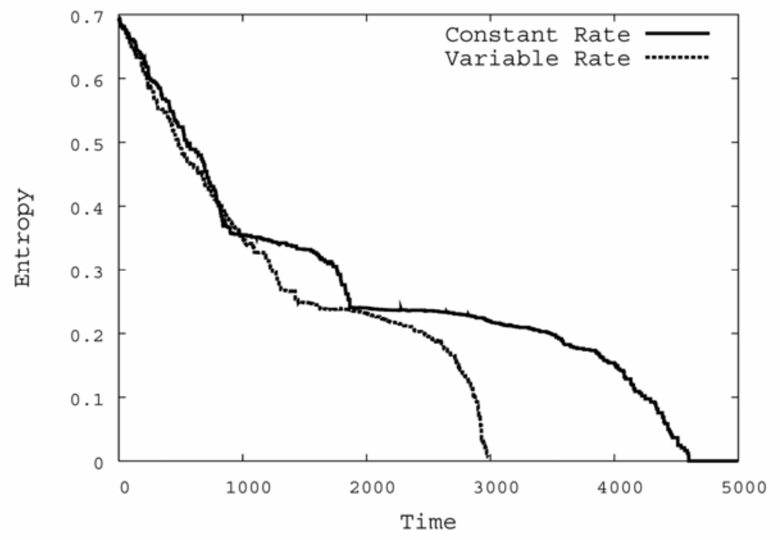




Collective Sort: Tuning

- 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

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