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# Engineering Self-Organising Systems

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Revised Selected Papers

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# Preface

The idea that self-organisation and emergence can be harnessed for the purpose of solving tricky engineering problems is becoming increasingly accepted. Researchers working in many diverse fields (such as networks, distributed systems, operating systems and agent systems) are beginning to apply this new approach. This book contains recent work from a broad range of areas with the common theme of utilising self-organisation productively.

As distributed information infrastructures continue to spread (such as the Internet, wireless and mobile systems), new challenges have arisen demanding robust and scalable solutions. In these new challenging environments the designers and engineers of global applications and services can seldom rely on centralised control or management, high reliability of devices, or secure environments. At the other end of the scale, ad-hoc sensor networks and ubiquitous computing devices are making it possible to embed millions of smart computing agents into the local environment. Here too systems need to adapt to constant failures and replacement of agents and changes in the environment, without human intervention or centralised management.

Self-organising applications (SOAs) are able to dynamically change their functionality and structure without direct user intervention to meet changes in requirements and their environment. The overall functionality delivered by SOAs typically changes progressively, mainly in a non-linear fashion, until it reaches (emerges to) a state where it satisfies the current system requirements and therefore it is termed self-organising or emergent behaviour. Self-organising behaviour is often the result of the execution of a number of individual application components that locally interact with each other aiming to achieve their local goals, for example, systems that are based on agents or distributed objects. The main characteristic of such systems is their ability to achieve complex collective tasks with relatively simple individual behaviours, without central or hierarchical control.

However, in artificial systems, environmental pressures and local interactions and control may lead to unpredicted or undesirable behaviour. A major open issue is therefore how to engineer desirable emergent behaviour in SOAs and how to avoid undesirable ones given the requirements and the application environment. To address this issue, approaches originating from diverse areas such as non-linear optimisation, knowledge-based programming and constraint problem solving are currently been explored. Furthermore, SOA engineers often take inspiration from the real world, for example from biology, chemistry, sociology and the physical world. Typical examples of SOAs are systems that reproduce socially based insect behaviour, such as ants-based systems, artificial life, or robots. Although the results achieved so far are promising, further work is required until the problem is sufficiently addressed.

More specific fundamental questions that need an answer are: How do we structure the application components and their interactions, so that the self-organisation process results in the desired functionality? How do we validate that the application performs to the requirements within the range of scenarios expected during deployment? What means of influencing the dynamics of the application do we have available and how effective are they? On the one hand, multi-agent simulations and analytic modelling can be used to study emergent behaviour in real systems. On the other hand, results from complexity theory can be applied in engineering of both multi-agent systems and self-organising systems.

To address these issues the ESOA series of workshops was established. The aim is to open a dialog among practitioners from diverse fields, including: agent-based systems, software engineering, information systems, distributed systems, complex systems, optimisation theory and non-linear systems, neural networks, and evolutionary computation. Although backgrounds are diverse, the focus is always clear – to harness self-organising principles to solve difficult engineering problems.

This book includes revised and extended papers presented at the Third ESOA workshop held during the 4th International Joint Conference on Autonomous Agents and Multi-Agent Systems (AAMAS) conference held in Utrecht, The Netherlands in July 2005. The workshop received 25 submissions, out of which 12 papers were selected for a long presentation and 6 papers for short presentation.

The first workshop (ESOA 2003) followed a theme of applying nature-inspired models to fields as diverse as network security, manufacturing control, and electronic markets. The second workshop (ESOA 2004) included papers on self-assembly of software, robots task allocations, design methods, and stigmergy-based applications. Both workshops were held during the AAMAS conferences in 2003 and 2004 respectively and post-proceedings are published by Springer, (volumes LNAI 2977 and 3464).

ESOA 2005 included a number of papers related to methodologies and engineering practices. This shows that research in the field of self-organising applications is maturing from novel techniques that work in specific contexts to more general engineering proposals. This book is structured into three parts reflecting the workshop session themes.

**Part I presents novel self-organising mechanisms.** Jelasity et al. present a self-organising mechanism for maintaining and controlling topology in overlay networks based on gossiping. Georgé et al. describe "emergent programming" through self-organisation of a program's instructions. Picard et al. show how cooperation among agents serves as a self-organisation mechanism in the framework of a distributed timetabling problem. Nowostaswski et al. present the concept of "evolvable virtual machines" architecture for independent programs to evolve into higher levels of hierarchical complexity; Hales presents a P2P re-wiring protocol that allows peers with different skills to spontaneously self-organise into cooperative groups. Dimuro et al. present a self-regulation algorithm for multi-agent systems based on a sociological model of social exchanges.

Armetta et al. discuss a protocol for sharing critical resources based on a two-level self-organised coordination schema.

**In Part II methodologies, models and tools for self-organising applications are presented.** Brueckner et al. present an agent-based graph colouring model favouring distributed coordination among agents with limited resources in a real-world environment. Marrow et al. describe applications using self-organisation based upon the DIET multi-agent platform. Saenchai et al. present a multi-agent-based algorithm solving the dynamic distributed constraint satisfaction problem. De Wolf et al. present an approach combining simulation and numerical analysis for engineering self-organising systems with some guaranteed macroscopic behaviour. Gardelli et al. discuss self-organising security mechanisms based on the human immune system, and their verification through simulation. Renz et al. discuss the need of using mesoscopic modeling to provide descriptions of emergent behaviour.

**Part III presents specific applications of self-organising mechanisms.** Ando et al. apply the stigmergy paradigm to automated road traffic management. Fabregas et al. discuss a model inspired from bee behaviour and apply this model to an example of cultural heritage. Van Parunak et al. discuss a sift and sort algorithm for information processing inspired by ants sorting and foraging. Tatara et al. present an agent-based adaptive control approach where local control objectives can be changed in order to obtain global control objectives. Hadeli et al. discuss measures of reactivity of agents in a multi-agent and control approach based on stigmergy.

Finally, we wish to thank all members of the Programme Committee for returning their reviews on time (all papers submitted to the workshop were reviewed by two to three members of the Programme Committee) and for offering useful suggestions on improving the workshop event. Also we thank all those who attended the workshop and contributed to the lively discussions and question and answer sessions.

January 2006

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Organising Committee
ESOA 2005

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