Preface

This volume collects a set of papers accompanying the lectures of the 16th International School on Formal Methods for the Design of Computer, Communication and Software Systems (SFM). This series of schools addresses the use of formal methods in computer science as a prominent approach to the rigorous design of the aforementioned systems. The main aim of the SFM series is to offer a good spectrum of current research in foundations as well as applications of formal methods, which can be of help to graduate students and young researchers who intend to approach the field. SFM 2016 was devoted to the quantitative evaluation of collective adaptive systems and covered topics such as self-organization in distributed systems, scalable quantitative analysis, spatio-temporal models, and aggregate programming. The eight papers of this volume represent the broad range of topics of the school.

The paper by Talcott, Nigam, Arbab, and Kappé proposes a framework called Soft Agents, formalized in the Maude rewriting logic system, to describe systems of cyber-physical agents that operate in unpredictable, possibly hostile, environments using locally obtainable information. Ghezzi’s paper is a tutorial on how to design adaptable and evolvable systems that support safe continuous software deployment to guarantee correct operation in the presence of dynamic reconfigurations. Bortolussi and Gast study the limiting behavior of stochastic models of populations of interacting agents, as the number of agents goes to infinity, in the case that classical conditions ensuring the validity of mean-field results based on ordinary differential equations do not hold. The paper by Loreti and Hillston illustrates CARMA, a language recently defined to support specification and analysis of collective adaptive systems, and its tools developed for system design and analysis. Galpin’s paper provides an overview of models of individuals and models of populations for collective adaptive systems, in which discrete or continuous space is explicitly represented. Ciancia, Latella, Loreti, and Massink also address spatial aspects of collective adaptive systems through a topology-inspired approach to formal verification of spatial properties, which is based on the logics SLCS and STLCS and their model-checking algorithms. The paper by Vandin and Tribastone shows how to efficiently analyze quantitative properties of large-scale collective adaptive systems by reviewing algorithms that reduce the dimensionality of models in a way that preserves modeler-defined state variables. Finally, Beal and Virolı present aggregate programming, a new paradigm for coping with an ever-increasing density of computing devices that raises the level of abstraction in order to allow programmers to reason in terms of collections of interacting devices.

We believe that this book offers a useful view of what has been done and what is going on worldwide in the field of formal methods for the quantitative evaluation of collective adaptive systems. This school was organized in collaboration with the EU FP7 project QUANTICOL, whose support we gratefully
VI

acknowledge. We wish to thank all the speakers and all the participants for a lively and fruitful school. We also wish to thank the entire staff of the University Residential Center of Bertinoro for the organizational and administrative support, as well as the Springer editorial office for the assistance with the editing of this book and the kind sponsorship.

June 2016

Marco Bernardo
Rocco De Nicola
Jane Hillston
# Table of Contents

Formal Specification and Analysis of Robust Adaptive Distributed Cyber-Physical Systems ........................................ 1  
*Carolyn Talcott, Vivek Nigam, Farhad Arbab, Tobias Kappé*

Dependability of Adaptable and Evolvable Distributed Systems ........ 41  
*Carlo Ghezzi*

Mean-Field Limits Beyond Ordinary Differential Equations .......... 81  
*Luca Bortolussi, Nicolas Gast*

Modelling and Analysis of Collective Adaptive Systems with CARMA and its Tools .................................................. 121  
*Michele Loreti, Jane Hillston*

Spatial Representations and Analysis Techniques ....................... 161  
*Vashti Galpin*

Spatial Logic and Spatial Model Checking for Closure Spaces .......... 201  
*Vincenzo Ciancia, Diego Latella, Michele Loreti, Mieke Massink*

Quantitative Abstractions for Collective Adaptive Systems .......... 241  
*Andrea Vandin, Mirko Tribastone*

Aggregate Programming: From Foundations to Applications .......... 281  
*Jacob Beal, Mirko Viroli*

**Author Index** .................................................................... 321
Formal Specification and Analysis of Robust Adaptive Distributed Cyber-Physical Systems

Carolyn Talcott, Vivek Nigam, Farhad Arbab, Tobias Kappé
 dependability of adaptable and evolvable
distributed systems

Carlo Ghezzi
Mean-Field Limits Beyond Ordinary Differential Equations

Luca Bortolussi, Nicolas Gast
Modelling and Analysis of Collective Adaptive Systems with CARMA and its Tools

Michele Loreti, Jane Hillston
Spatial Representations and Analysis Techniques

Vashti Galpin
Spatial Logic and Spatial Model Checking for Closure Spaces

Vincenzo Ciancia, Diego Latella, Michele Loreti, Mieke Massink
Quantitative Abstractions for Collective Adaptive Systems

Andrea Vandin, Mirco Tribastone
Author Index

Arbab, Farhad 1
Beal, Jacob 281
Bortolussi, Luca 81
Ciancia, Vincenzo 201
Galpin, Vashti 161
Gast, Nicolas 81
Ghezzi, Carlo 41
Hillston, Jane 121
Kappé, Tobias 1

Latella, Diego 201
Loreti, Michele 121, 201
Massink, Mieke 201
Nigam, Vivek 1
Talcott, Carolyn 1
Tribastone, Mirco 241
Vandin, Andrea 241
Viroli, Mirko 281