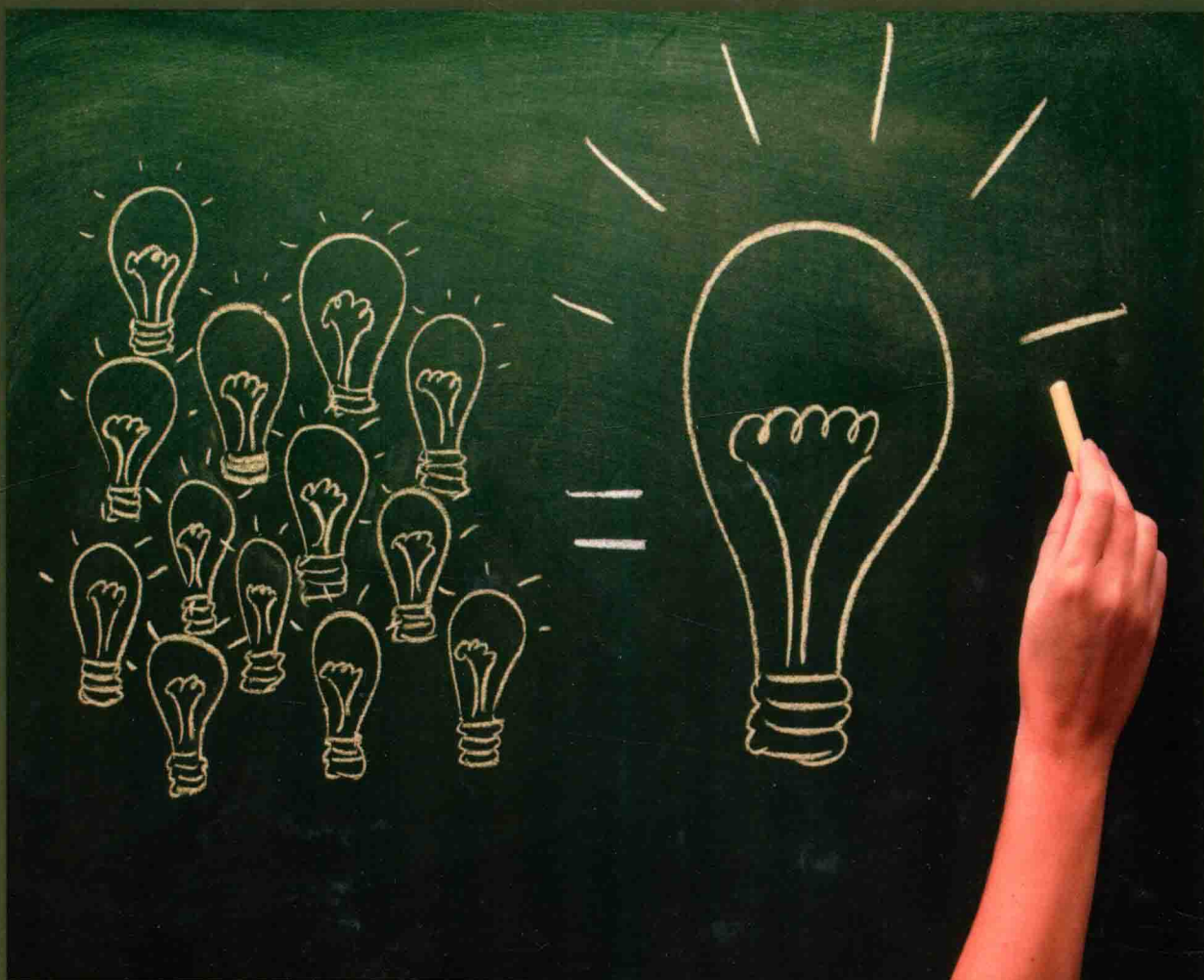


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# **Technological Innovations in Adaptive and Dependable Systems**

Advancing Models and Concepts



**Vincenzo De Florio**

# Technological Innovations in Adaptive and Dependable Systems: Advancing Models and Concepts

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Information Science  
**REFERENCE**

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Published in the United States of America by  
Information Science Reference (an imprint of IGI Global)  
701 E. Chocolate Avenue  
Hershey PA 17033  
Tel: 717-533-8845  
Fax: 717-533-8661  
E-mail: [cust@igi-global.com](mailto:cust@igi-global.com)  
Web site: <http://www.igi-global.com>

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#### Library of Congress Cataloging-in-Publication Data

Technological innovations in adaptive and dependable systems: advancing models and concepts / Vincenzo De Florio, editor.  
p. cm.

Includes bibliographical references and index.

Summary: "This book provides high quality, effective approaches to design, develop, maintain, evaluate, and benchmark adaptive and dependable systems that are built to sustain quality of service and experience despite the occurrence of potentially significant and sudden changes or failures in their infrastructure and surrounding environments"--Provided by publisher.

ISBN 978-1-4666-0255-7 (hardcover) -- ISBN 978-1-4666-0256-4 (ebook) -- ISBN 978-1-4666-0257-1 (print & perpetual access) 1. Adaptive computing systems--Technological innovations. 2. Adaptive computing systems--Mathematical models. I. De Florio, Vincenzo, 1963-

QA76.9.A3T435 2012

621.39'5--dc23

2011044782

#### British Cataloguing in Publication Data

A Cataloguing in Publication record for this book is available from the British Library.

All work contributed to this book is new, previously-unpublished material. The views expressed in this book are those of the authors, but not necessarily of the publisher.

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## Preface

Often the systems our societies depend upon are built in such a way as to result too inflexible and intolerant to changes. The deployment of such systems in environments where change is the rule rather than the exception leads to situations where quality-of-service and quality-of-experience are often strongly and negatively affected. As a result, there is an urgent need to investigate structuring techniques, architectures, algorithms, tools, and paradigms for the expression and the management of adaptive-and-dependable systems, i.e., software, devices, and services that are built so as to sustain an agreed-upon quality-of-service and quality-of-experience despite the occurrence of potentially significant and sudden changes or failures in their infrastructure and surrounding environments. This need is the primary motivation for this book as well as the core business of several research lines worldwide – including the one I am responsible for in the Performance Analysis of Telecommunication Systems group at the University of Antwerp, Belgium. Research in the above investigation domains is usually carried out through design, development, and evaluation of techniques and models to structure computer systems as adaptive systems – systems that are able to constantly re-optimize in view of *changes*, both exogenous (i.e. either environment- or user-specific) and endogenous (that is, pertaining to internal assets.)

The above concept of constant re-optimization is far from being new – probably the first to put it forth was the great Aristotle, who introduced the key idea of *entelechy* as the ability to maintain their own (functional and non-functional) “identity” or, as Sachs cleverly pointed out, the *ability to pursue completion* (that is, one’s optimal behavior) by continuously re-adjusting in order to retain an optimal or “healthy” state whatever chain of events may take place (Sachs, 1995). Such chains of events clearly include the series of faults, errors, and failures threatening the services supplied by computer systems (Laprie, 1985; Laprie, 1992; Laprie, 1995; Laprie, 1998; Avizienis, Laprie, and Randell, 2004; Avizienis, Laprie, Randell, and Landwehr, 2004). Fault, errors, and failures are in fact the main study subjects for *dependability* – a group of disciplines studying “the trustworthiness of a computing system which allows reliance to be justifiably placed on the service it delivers”. Interestingly enough, though both adaptability and dependability emerged quite some while ago, it was only recently that the *combination* of these two disciplines began being investigated. Often adaptability’s privileged focus is on functional behavior, while the system assumptions on top of which dependable systems are traditionally built are usually fixed and immutable. System adaptation itself may produce faults, errors, and failures reverberating in the dependability management modules, while system lifecycle maintenance brought about e.g. by fault-tolerance methods is likely to generate events resulting in internal context changes triggering the action of the adaptability management modules. Despite this strong interplay, it was only recently that the research and industrial communities started addressing advancing models and concepts coupling adaptability and dependability together. Such models and concepts are particularly urgent nowadays,

for the ever increasing system complexity only exacerbates the problem – think for instance of complex adaptation systems that are built through several concurrent control loops stimulating each other in stigmergic cooperation. Solutions are being sought, which may find a source of inspiration in yet another blend of seemingly unrelated disciplines – for instance, the study of natural and biological systems and eco-systems. After all, in this respect nature appears to be way ahead of computer scientists – it suffices to consider for instance the complexity and relative robustness exhibited by natural systems such as the human autonomic nervous system. The term that recently emerged to describe such adaptive-and-dependable systems and their properties is *resilience*, which in fact is very much related to Aristotelian entelechy: Resilience is the ability to tolerate (or even profit from) the onset of unanticipated changes and environmental conditions that might otherwise cause a loss of acceptable service (Meyer, 2009). Resilience represents a measure of a system’s persistence of both functional *and non-functional* features under specified and unforeseen perturbations (Jen, 2004) – a measure of its entelechy in fact.

The continuous progress of computer and communication technologies forces the scientific and industrial communities to focus their attention to advancing models and concepts to enhance systems’ resilience and hence engineer the design of truly adaptive-and-dependable systems despite the ever increasing complexity of services appointed to computers. As I wrote in the preface to my book (De Florio, 2009), “Human society more and more expects and relies on good quality of complex services supplied by computers. More and more these services become vital, in the sense that lack of timely delivery ever more often can have immediate consequences on capitals, the environment, and even human lives”. Such a statement could not be any more self-evident today, hence devising and crafting resilient systems more and more becomes a necessary requirement for the future progress of our societies. I strongly believe that learning and practicing in the design of systems constructed in such a way as to be both adaptive and dependable will ultimately lead to truly resilient computer system and services. Obviously an increasingly important “hot topic” in this context as well as a necessary ingredient towards mastering the design processes for such systems becomes *resilience assurance*, viz. concepts, models, approaches, and tools to make sure that evolving systems retain their features – again, both functional and otherwise – while they autonomically adjust themselves to changes and while they tolerate dependability and security impairments and threats. In this ever more complex play of unanticipated changes and unexpected events – a veritable “*Comedy of Errors*” (not to mention faults & failures, if you will allow me the pun!) – two other disciplines that are likely to play important roles towards future adaptive-and-dependable systems and services, especially in view of dealing with complexity issues, are self-management of computer systems and autonomic computing. It is nowadays clear that only by appointing the management of our machines to yet other machines our society shall be able to cope with the gigantic complexity of its own organizations and services – think for instance of the increasing costs of traditional human organizations such as healthcare.

In fact socio-technical systems are nothing but another case of systems that may or may not exhibit resilience or robustness. As discussed e.g. in (De Florio and Blondia, 2010; De Florio, 2011), often societal systems are designed in a sub-optimal way that bounds their performance and cost-effectiveness due to several misinterpretations of the status quo. Stark calls this situation a “lock-in”, which he defines as “*the process whereby early successes can pave the path for further investments of new resources that eventually lock in to suboptimal outcomes*” (Stark, 1999). Making use of the well-known classification of systems proposed by Boulding (1956), in (De Florio and Blondia, 2010) we provided practical examples of “resilient societal services”, that is, societies and communities that exploit the inherent and abundant redundancy of computer- and human-based services so as to actuate “ongoing reconfigurations



of organizational assets” (Stark, 1999) and realize what Boulding referred to as “Social Organizations” (Boulding, 1956), *viz.*, the highest class of adaptive and dependable real-life systems. We refer to such systems as Entelechial Societies. In fact socio-technical systems such as our Mutual Assistance Community (Sun, De Florio, and Blondia, 2006; Sun, De Florio, Gui, and Blondia, 2007; Sun, De Florio, Gui, and Blondia, 2009), which extend the service-oriented computing paradigm by considering systems as a set of members and roles (one may consider them as agents, each characterized by a set of properties such as abilities, competences, know-how, availability, policies, and locations), may be thought of as examples of Entelechial Societies in that they exhibit high adaptability and dependability without significant increase in service complexity. Service organizations such as these are the result of intelligent orchestrations of the above mentioned members and roles as dynamic resources that may be supplied by human- and computer-based services alike. Interestingly enough, both in societal organizations as in eco-systems, *diversity* appears to play a key role in being able to evolve satisfactorily in the face of changes and in particular in escaping societal lock-ins. User diversity, on the other hand, calls for yet another form of adaptive and dependable service: *Personalization*, which I believe is going to play a role of ever increasing relevance in the near future. The user-in-the-loop paradigm will need to be turned into a veritable user-is-the-loop concept if we want the promised advent of novel ambient intelligence services to turn into reality. Novel advancing models and concepts in this area are to be expected, which will pave the way to breaking the current usability barriers (Millward, 2003) and help reducing the chance of interaction faults – which are known to account for up to 80% of operational failures (Perrow, 1984).

As the famous quote eloquently goes, “every solution breeds new problems,” and providing advancing new solutions to these new problems is in fact the aim of a journal like IJARAS – the International Journal of Adaptive, Resilient, and Autonomic Systems – which I started and I have been serving as editor-in-chief to date. IJARAS is currently in its third year and despite its young age it has already attracted the attention of a wide audience of readers and contributors. Top researchers from all over the world published several outstanding contributions through our journal, and this trend of excellence appears to be confirmed by submissions for next year. Aim of this book is to provide widespread access to this treasure’s trove of knowledge on advancing concepts and models in adaptive and dependable systems also allowing their authors to update and augment their contributions. The latter are also presented here in a structured way by dividing the book in several chapters each of which is devoted to one facet of this fascinating multi-dimensional and multidisciplinary problem space. In what follows we present the structure and contents of this book.

The first part of this book is devoted to *middleware based adaptive and dependable systems*. As well known, middleware is becoming a central focus of attention for researchers in adaptive and dependable systems. As it stands between the low level architecture and the higher level services, it can efficiently play a role of a mediator of multiple concerns – e.g. platform transparency and efficient use of resources. Several paradigms have been devised and employed in modern middleware, allowing to reach conflicting design goals such as efficiency and flexibility. An example of this is reported in “Resilient and Timely Event Dissemination in Publish/Subscribe Middleware”, by C. Esposito and D. Cotroneo, both with the “Federico II” University of Naples, Italy. Adaptability strongly relies on the ability to react timely to context changes, hence strong guarantees on the timely and reliable dissemination are crucial to achieve autonomic behaviors. In their paper the authors address this crucial problem by proposing a FEC approach to guarantee timely delivery of event notifications in publish/subscribe middleware. The authors also prove the cost-effectiveness of their approach through simulation-based experiments.

In “Towards Adaptive and Scalable Context Aware Middleware” A. Corradi, M. Fanelli, and L. Foschini, all from the Bologna University, Italy, also address adaptable and dependable context data dissemination, though also focusing on scalability issues. Their design goals are reached via a distributed hierarchical architecture, lightweight and adaptive context data dissemination algorithms, as well as through the adoption of statistical context data/query replication techniques. In this case validation is carried out by extensive testing in a real-life environment – their wireless university campus testbed.

A third work in the area of middleware was again contributed by A. Corradi, this time with his colleagues E. Lodolo and S. Monti, all with the Bologna University. “Dynamic Reconfiguration of Middleware for Ubiquitous Computing” deals with the shortcomings of those middleware services that are designed in a static way that forbids their services to be entelechies – that is systems able to dynamically re-optimize in the face of context changes. The proposed solution is a middleware for heterogeneous ubiquitous and pervasive computing scenarios that is able to adjust dynamically both its application and non-functional logics.

In the last work of this part of our book, paper “A Multi-User Ad-Hoc Resource Manager for Public Urban Areas”, G. Huerta-Canepa and D. Lee, both of KAIST, South Korea, present a multi-user ad-hoc resource manager for smart urban areas, that is a smart environment able to complement and support dynamically and adaptively the services of mobile devices. This is reached by allowing public resources to perform tasks on behalf of mobile devices, at the same time guaranteeing fair use and minimal interference with other users as well as with the original purpose of public resources. Both conflict avoidance and resource management are carried out without a central infrastructure. Positive results indicate that such system is indeed able to meet its intended design goals.

A second part of this book focuses on *adaptation in wireless sensor networks*. Wireless sensor nodes have been successfully employed in many a domain ranging from the military to the industrial and the consumer. Applications seem uncountable and pertain many an application area, ranging e.g. from healthcare (e.g. in body area network and wearable computing) to crisis management (for instance when deployed to aid fire brigades) and from environmental monitoring (e.g. in areas subjected to volcanic or seismic phenomena) to telecommunication – to name but a few fields. In general wireless area networks are deployed wherever an unstable environment needs to be monitored and, to some extent, reacted upon. Having said what above, it is then obvious that adaptive and dependable features play a key role in wireless sensor network applications – which explains the relatively large number of papers focusing on that subject that were submitted to IJARAS. This section comprises three such works. The first contribution is “Adaptive Modeling of Routing Algorithms for Wireless Sensor Networks”, by M. Cinque and C. Di Martino, “Federico II” University of Naples, Italy, which deals with the problem of effective simulation of routing algorithms for highly dynamic environments such as those characterizing Wireless Sensor Networks (WSNs). A novel adaptive modeling approach is proposed. It is shown that the reported approach is able to cope with the complexity of simulating routing algorithms in environments characterized by events such as route updates or node crashes. Experimental results are reported as evidence of the effectiveness of the approach with respect to several routing algorithms.

A second contribution is entitled “iCAAS: An Interoperable and Configurable Architecture for Accessing Sensor Networks” and contributed by C. Di Martino and A. Testa (“Federico II” University of Naples) with G. D’Avino (STRAGO, Italy). The problem addressed by this paper is a result of two factors: the increasing complexity and heterogeneity of WSNs and the diverse user needs often cross-cutting through multiple WSNs. The proposed solution is iCAAS – an architecture to collect, store, manage, and publish users data received from multiple heterogeneous WSNs. iCAAS allows to adaptively deliver



data to users taking into account their specific interests and adopted terminals as well as the network context. iCAAS is experimented in real world application scenarios in which it proved to meet its design goals, including scalability with respect to the number of parallel queries.

S. Ortmann, M. Maaser, and P. Langendoerfer, from IHP microelectronics, Germany, are the authors of “Self-Adapting Event Configuration in Ubiquitous Wireless Sensor Networks”, whose key contribution is a novel approach for self-adapting on-node and in-network processing in WSNs. The proposed approach autonomously adapts to available resources and environmental conditions and achieves fine-grained fault tolerance with configurable adaptation rate. Addressed goals include maintainability and energy efficiency – both of which are particularly important requirements in WSNs.

The third part of this book targets the main requirements and challenges towards resilience, dependability, and adaptability. Title of this part is *Resilient Computing: Reflections and Challenges*. It consists of two papers. The first one, “Technological and Educational Challenges of Resilient Computing” by L. Simoncini, University of Pisa, Italy, is an interesting and thorough reflection on the requirements and challenges brought about by the advent of resilient and ubiquitous computing. A veritable revolution is upon us, and social organizations themselves need to adjust to the imminent change. This includes educational systems and curricula, which need to be timely adjusted so as to reflect the new contexts brought about by e.g. ambient intelligence. Failing to do so would result in a new generation of designers and developers that are not prepared – let alone aware – of the new requirements expected from them; a veritable forge of “endengineers”, in the sense I gave to such word in (De Florio, 2009). Professor Simoncini discusses this problem and reports about the M.Sc. curriculum in Resilient Computing that was one of the results of the European Network of Excellence “ReSIST” (Resilience for Survivability in IST, <http://www.resist-noe.org/>).

The second paper, “Adaptation and Dependability and Their Key Role in Modern Software Engineering”, is authored by me and C. Blondia (University of Antwerp, Belgium). “*Does it still make sense at all to design software systems as immutable, context-agnostic entities?*” is the main question addressed. Not surprisingly enough, the paper claims that being able to constantly re-optimize in the face of endogenous and exogenous changes and failures (that is, designing *software entelechies*) is an important ingredient for current and future software systems. Novel software engineering paradigms are therefore required in order to provide effective system structures for adaptive and dependable services while limiting at the same time counterproductive aspects such as design complexity.

The fourth part of this book discusses adaptive and dependable *Algorithms*. Its first contribution is “Optimizing User Quality of Experience through Overlay Routing, Bandwidth Management and Dynamic Trans-Coding”, by M. Wijnants et al. from various Belgian universities. The main focus of this work is maximizing the end-to-end quality of experience for the users of multimedia services offered over wireless networks. The paper introduces an optimization platform that uses overlay routing to circumvent or mitigate network problems occurring at any stage of the provider-to-customer service delivery trajectory. Such platform supports in particular last mile optimizations through automatic bandwidth management and adaptive management of multimedia flows. A case of the latter is the core subject of this paper, namely an adaptive trans-coding service that enables the dynamic transformation of H.264/AVC video flows to an arbitrary bitrate. This is used by the authors to improve quality of experience by tuning dynamically the bandwidth distributions.

A second contribution is “Web Distributed Computing Systems Implementation and Modeling”, by F. Boldrin and G. Mazzini of the University of Ferrara, Italy, and C. Taddia, with Lepida S.p.A., Italy. In their paper the authors propose a self-managing “volunteer computing” platform that makes use of

web browsers as clients. The concept is similar to the one of the SETI@HOME project (Anonymous, 2011) but does not require any software to be pre-installed, hence the solution is referred to as “client-free”. Such system is shown to be self-healing and self-configuring in that it is able to organize the scheduling of the processes and the error management in an autonomic manner. The paper introduces a mathematical model to measure the effectiveness and applicability of this approach. Testing of two use cases through different performance metrics and in different environments provides evidence of the feasibility of this approach.

The third paper of this section is “Efficient Adaptation Decision Making Algorithms for Context-Aware Applications”, by Y. Vanrompay and Y. Berbers of the Catholic University of Leuven, Belgium, and T. Smits, from AE, Belgium. The main focus of this paper is algorithms for adaptation planning – namely the “P” stage of the MAPE autonomic computing “loop”. In other words, rather than focusing on the monitoring, analyzing, or executing aspects, the authors address the decision-making phase that is crucial towards being able to adjust a software entity and let it optimally adapt to changed conditions. Planning algorithms consider the current context and select a software variant best matching the changed environment. As the resulting search space is usually very huge, an important requisite towards e.g. feasibility and scalability is given by algorithms able to prune that space in a convenient and sensible way. The authors present and evaluate two algorithms to handle this problem.

A fifth section of this book focuses on *Adaptation in the system and network layers* and comprises of five papers. A first important contribution is provided by S. Munaga and F. Catthoor, both with IMEC/SSET and the Catholic University of Leuven, Belgium. Their paper is entitled “Reliability-Aware Proactive Energy Management in Hard Real-Time Systems: A Motivational Case Study”. In their work the authors propose an adaptive approach to overcome the shortcomings in reliability characterizing advanced technologies such as sub-45nm CMOS and 3D integration. The authors advocate that managing temperature and reliability at run-time is necessary in order to overcome those shortcomings without incurring in significant cost penalties. The authors propose an advancing concept that they term as “gas pedal”: a truly proactive controller that can efficiently manage system slack with future in perspective. A motivational case study is discussed, in which the proposed concept is used in the reliability-aware dynamic energy management of a processor running AVC motion compensation.

A second paper in this section is “A Machine Learning Based Meta-Scheduler for Multi-Core Processors”, by J. Kumar Rai et al. at the University of Hyderabad and ANURAG, India. As the title suggests, the authors propose an adaptive meta-scheduler, which dynamically adjusts its processing in view of reducing the contention for shared L2 caches on multi-core processors. The meta-scheduler makes use of a machine learning algorithm to adapt its scheduling decisions taking into account e.g. the multi-core system topology as well as the L2 cache related characteristics of processes. The resulting schedules are shown to systematically reduce the contention of shared L2 caches. Observed performance is up to 12% higher than that obtained with the common process scheduler of the Linux kernel.

In their contribution “Autonomic QoS Optimization of Real-Time Internet Audio Using Loss Prediction and Stochastic Control”, L. Roychoudhuri (Carroll University, USA), and E. S. Al-Shaer (University of North Carolina, USA) propose a self-adaptive framework for joint Error and Rate Control based on packet loss prediction and on-line quality assessment. The Error Control part makes use of Markov Decision Processes and stochastic inventory control to select FEC parameters proactively in view of preserving quality with optimal bandwidth. The Rate Control part uses a quality optimization model to determine the optimal dispersion over single or multiple paths. Simulation and experiments are used to prove how the proposed algorithms outperform similar alternative solutions.

In “Impact of Cross-Layer Adaptations of Mobile IP on IEEE 802.11 Networks on Video Streaming”, by P. De Cleyne and C. Blondia, of the University of Antwerp, Belgium, the authors provide us with their lessons learned while self-adapting mobile video-streaming applications. Context-aware algorithm for optimized handover is the main contribution of this paper, whose performance are also analyzed through simulation.

Yet another important contribution to the state-of-the-art in adaptive and dependable systems comes from “Beernet: Building Self-Managing Decentralized Systems with Replicated Transactional Storage”, by B. Mejías and P. Van Roy (Université catholique de Louvain, Belgium). Decentralized and self-managing systems constitute the main focus of this paper, which contributes a structured overlay network that autonomically self-organizes and self-heals, realizing a transactional replicated storage characterized by excellent scalability.

The sixth and last part of this book focuses on *Models and Approaches for Adaptive and Dependable Services*. It consists of three papers. In the first paper, “An Architecture-Based Adaptation Framework for Soft Real-Time Applications,” N. Gui, H. Sun, and C. Blondia of the University of Antwerp, Belgium, propose an approach to overcome the limitations exhibited by existing frameworks and component models with respect to dynamic environments in view of meeting real-time design goals. The authors propose to overcome such limitations by making use of an architecture-based framework for managing both the dependence and the life-cycle of real-time components. It is also shown how the main focus of the paper (real-time applications) may be extended with other constraint resolving policies and dependence descriptions languages. A performance analysis on a simulated control application concludes this contribution.

The second contribution, “Mixing Workflows and Components to Support Evolving Services”, was contributed by F. Baude et al. (Université de Nice Sophia-Antipolis, France) and H. Pfeffer et al. (Technische Universität Berlin, Germany). The paper introduces a distributed software component model to represent and easily manage the set of local or remote services involved in the service composition. The proposed model also includes a novel timed-automata based workflow language. The combination of such language and the component model makes it explicit the separation between functional and non-functional concerns, which reduces complexity and helps in the design of effective service composition and evolution.

Finally, “Optimization of WS-BPEL Workflows through Business Process Re-Engineering Patterns”, by J. Buys, C. Blondia and myself (University of Antwerp, Belgium), proposes to inject business process re-engineering patterns into WS-BPEL specifications so as to overcome the intrinsic limitations of the static workflow model of WS-BPEL. Well-known concepts from computer architecture research are put to use and shown to enhance autonomically the performance and the reliability of WS-BPEL specifications.

As a final word before leaving you to the just presented contributions I would like to stress the unitary sense shared by such a seemingly diverse offer of topics and concerns involving as different a domain as cross-layer adaptation for mobile devices and business process re-engineering. In fact each of these contributions proposes the same “gestalt” – they focus that is on entelechial systems and propose advancing models and concepts for the construction and management of this new generation of self-organizing, self-managing, and self-healing machines. It is my opinion that this concept marks as fundamental a milestone as the advent of the first calculating machines was for societies of the last Century. The dream of “calculating by machinery” (Anonymous, 1870) or, with Babbage’s words, “by steam” (Buxton and Hyman, 1988) is now being replaced by another one in which “managing by machinery” is the key concept. More and more machinery are going to manage themselves and be built in such a

way as to do so in an optimal way with respect to the ever changing conditions around them – including those conditions brought about by the users and their activity. We hope that contributions such as those presented in this book will help turning such dream into concrete new services and organizations for our societies, as well as a tool to enhance the awareness on the novel advancing concepts and models required to meet the challenges in front of us.

*Vincenzo De Florio*  
*University of Antwerp,*  
*Belgium October 2011*

## ACKNOWLEDGMENTS

Managing the editorial tasks of an international journal such as IJARAS would never be possible without the constant advise and the valuable assistance of many. It is only fair that here I express my gratitude to these renowned scientists and experts who joined me as members of the IJARAS' Editorial Board. It is also thanks to their kind availability and support that this book now can see the light. I also would like to express my thanks to the people at IGI-Global and especially to Heather Probst for her guidance and friendship. Last but not the least, my love goes to my dearest wife and child for their Love and support, as well as to Mariella, now and forever enshrined in my heart.

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Section 1

# Middleware Based Adaptive and Dependable Systems

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