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Whitestein Series
in Software Agent Technologies
and Autonomic Computing

Advanced Autonomic Networking and Communication

Monique Calisti
Sven van der Meer
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Editors

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About Whitestein Technologies

Whitestein Technologies is a leading innovator in the area of software agent technologies and autonomic computing & communications. Whitestein Technologies' offering includes advanced products, solutions, and services for various applications and industries, as well as a comprehensive middleware for the development and operation of autonomous, self-managing, and self-organizing systems and networks.
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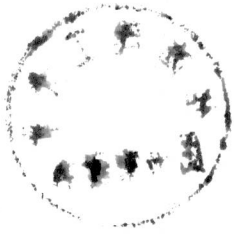

Foreword

This book presents a comprehensive reference of state-of-the-art efforts and early results in the area of autonomic networking and communication. The essence of autonomic networking, and thus autonomic communication, is to enable the autonomic component, device or system to govern the set of services and resources delivered at any given time while protecting context-sensitive business goals. An additional challenge is to provide self-governance in the face of changing user needs, environmental conditions, and business objectives. In other words, an autonomic network understands relevant contextual data and changes to those data, and adapts the services and resources it provides in accordance with business-driven policies that protect user and business interests.

Autonomic computing is often described as self-CHOP (self-configuration, -healing, -optimisation, and -protection). Autonomic networking instead focuses on self-knowledge, which is the foundation to build self-governance. Note that self-CHOP functionality is still provided, but the emphasis of autonomic networking is on the foundation to realise self-CHOP, not in the different self-* technologies and benefits.

Given this foundation, the next challenge is how to apply autonomic networking principles in the network on an application-specific basis. Since networks continue to grow increasingly larger and more complex, they become harder to manage efficiently and reliably. The goal is not to eliminate human personnel, but rather to automate the currently numerous manually-intensive tasks that are so error-prone in today's networks. We advocate a formal systems approach in which autonomic devices, components and systems are able to detect, diagnose and repair faults, as well as adapt their configuration and optimise their performance in the face of changing user needs and environmental conditions. Both of these must be done while protecting and healing themselves in the face of natural problems and malicious attacks. Building adaptive and autonomous control directly into the corresponding network elements enables a shift of focus from the technology used by the network elements to the provisioning of next generation converged services.

This special issue explores different ways in which autonomic principles and techniques can be applied to existing and future networks. In particular, this book is divided into three main parts, each of them represented by three papers discussing a particular aspect from industrial as well as academic perspectives.

The first part focuses on architectures and modelling strategies. It starts with a discussion on current standardisation efforts for defining a technological neutral, architectural framework for autonomic systems and networks. This first paper also defines a set of critical system services that Autonomic Networks require and emphasises (along with the other two papers in this section) that a new framework based on standards must be developed to build a new generation of infrastructures (networks and systems) with inherent autonomic capabilities. The second

paper examines how a telecommunication company utilises autonomic principles to manage its infrastructure. In particular, this paper focuses on defining semantic information as the basis for knowledge. It defines the need to focus on legacy equipment and services, not just new "clean slate" devices, and advocates the use of software agent technologies. The final paper in this section describes a European effort to model distribution and behaviour of and for (autonomic) network management. While a P2P paradigm was used, this approach is suitable for many different topologies. Its key contribution is the use of a metamodel dedicated to modelling the needs of network management.

Part two of this book is dedicated to middleware and service infrastructure as facilitators of autonomic communications. This part starts introducing a connectivity management system based on a resilient and adaptive communication middleware. A key feature of this approach is its potential for sustained connectivity in the event of path disruptions. The second paper of this part combines the concept of a knowledge plane with real-time demands of the military sector to regulate resources. This paper defines a variant of the Knowledge Plane that uses situatedness as a new management paradigm for gathering, computing and exchanging knowledge and control over a large network. This is followed by a profound discussion on how the management of service access can benefit from autonomic principles, with special focus on next generation networks. This paper concentrates on enabling adaptive connectivity management of nomadic end hosts across heterogeneous access networks using loosely-coupled distributed management functions and control methods.

Part three focuses on how current networks can be equipped with autonomic functionality and thus be migrated to autonomic networks. We start this part by analysing the difference between traditional network management and autonomic network management and learn how the latter enables cross-layer optimisation. This paper emphasises the use of simple and dependable elements that can self-organise to produce more sophisticated behaviours. The second paper shows how a multi-agent system helps to manage a combined MPLS DiffServ-TE Domain. An architecture is described that defines a novel LSP creation strategy that reduces the number of LSPs and hence, the number of signalling operations in the network. Finally, this part concludes with a very interesting approach that applies game theory to autonomically manage the available spectrum in wireless networks in order to improve spectrum efficiency and maximise network revenue. Two different games (revenue-sharing and price) model the spectrum sharing and spectrum trading behaviours between inter-operator radio access networks, leading to a novel bargaining based dynamic spectrum sharing approach that simplifies reaching agreements.

We would like to thank all people who helped us providing this book for you. First of all, all the authors who submitted papers and who made their current research available for this book. Second, our colleagues from Birkhäuser, who gave us the chance of publishing our view on Autonomic Communications. Last not

least a special thanks to Roberto Ghizzioli from Whitestein Technologies, who worked very hard over the last summer and constantly pushed us to our limits.

We hope you enjoy and learn from this book as much as we have!

Monique Calisti, Sven van der Meer, John Strassner
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Whitestein Series in Software Agent Technologies and Autonomic Computing

Edited by
Marius Walliser, Stefan Brantschen, Monique Calisti and Stefan Schinkinger

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■ **Calisti, M.**, Whitestein Technologies AG, Zürich, Switzerland / **van der Meer, S.**, Waterford Institute of Technology, Ireland / **Strassner, J.**, Motorola, Inc., Schaumburg, IL, USA (eds.)

Advanced Autonomic Networking and Communication

This book presents a comprehensive reference of state-of-the-art efforts and early results in the area of autonomic networking and communication.
The essence of autonomic networking, and thus autonomic communications, is to enable the self-governing of services and resources within the constraints of business rules. In order to support self-governance, appropriate self-* functionality will be deployed in the network on an application-specific basis. The continuing increase in complexity of upcoming networking convergence scenarios mandates a new approach to network management.
This volume explores different ways that autonomic principles can be applied to existing and future networks. In particular, the book has 3 main parts, each of them represented by three papers discussing them from industrial and academic perspectives.
The first part focuses on architectures and modeling strategies. Part two is dedicated to middleware and service infrastructure as facilitators of autonomic communications, and the last part addresses autonomic networks, specifically how current networks can be equipped with autonomic functionality and thus migrate to autonomic networks.

2007. 200 pages. Softcover.
ISBN 978-3-7643-8568-2

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2007. 156 pages. Softcover.
ISBN 978-3-7643-8546-0

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2007. 180 pages. Softcover.
ISBN 978-3-7643-8570-5

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Issues in Multi-Agent Systems The AgentCities.ES Experience

The agent paradigm has been a subject of research for the last years, and the purpose of this book is to present current status of this technology by looking at its application in different domains, such as electronic markets, e-tourism, ambience intelligence, and complex system analysis.

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ISBN 978-3-7643-8542-2

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Emerging Web Services Technology

2007. 182 pages. Softcover.
ISBN 978-3-7643-8447-0

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■ **Cervenka, R. / Trencansky, I.**, both Whitestein Technologies, Bratislava, Slovakia

The Agent Modeling Language - AML. A Comprehensive Approach to Modeling Multi-Agent Systems

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2002. 168 pages. Softcover.
ISBN 978-3-7643-6917-0

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III. Networks

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Technology Neutral Principles and Concepts for Autonomic Networking

Sven van der Meer, Joel Fleck, Martin Huddleston, Dave Raymer, John Strassner and Willie Donnelly

Abstract. The 2006 MACE workshop [1, 28] has presented the drivers and challenges of Autonomic Networking [2] and fostered an understanding of emerging principles for this new type of networks [3]. In this paper, we present concepts and principles that define a technological neutral, architectural perspective of Autonomic Networks. The work presented in largely based on work within the Architecture team of the TeleManagement Forum (Technological Neutral Architecture, [4]) and joined research work of industrial and academic research teams (for example Ericsson [5], HP & QinetiQ [6] and Motorola [7]). The goal of this paper is to provide the reader with manageability guidelines and architectural patterns leading to the development of manageable autonomic software and communication systems. We present a component-based, distributed system architecture and an associated set of critical system services that Autonomic Networks require. Since we tackle the problem from a technologically neutral angle, this paper will not prescribe a single new technology, but rather provide a means that allows for federating different technologies, each of which offers particular advantages at business and system levels. In particular, it enables business concepts and principles to drive system design and architectures. This may be further implemented using currently available distributed systems information technologies.

Keywords. Technological Neutral Architecture, Autonomic, Contract.

The 1st IEEE Workshop on Modelling Autonomic Communication Environments was part of MANWEEK 2006 (October 25-26, 2006, Dublin, Ireland); organised by the founder of the Autonomic Communications Forum (Radu Popescu-Zeletin, FhG FOKUS), the ACF Chair (John Strassner, Motorola Labs) and the ACF Academic Co-Chair (Willie Donnelly, WIT).

Most of the work presented in this paper is based and extracted from the TMF TNA as described in [4]. Sven is the current editor of this document. Dave, John and Joel are Distinguished Fellows, Joel leads the Architecture Team in the TMF, Martin leads the Service Providers Leadership Council. All co-authors have actively contributed to the TNA [4].

1. Introduction

The technical basis of communication is shifting from typical insular solutions towards interworking environments. Services influence many parts of our daily life and all places people live and work at. With the convergence of data and telecommunications, the complexity, heterogeneity and size of the networks supporting the industry is rapidly increasing. The proliferation of multiple types of smart devices, each with many ways to connect to different networks, complicates not just end-to-end service delivery, but also billing, provisioning and other aspects of creating and managing the lifecycle of services.

From a network operator's or service provider's perspective, Operation Support Systems (OSSs) are no longer capable of easily managing the complex nature of the infrastructure. Future OSSs must take into account not only vastly increased amount of hardware, but also manage the increasing complexity of applications and services in different contexts running on multiple networks.

Autonomic Networks, as an academic concept as well as a commercial opportunity, are seen as a business tool for competitive success overcoming today's roadblocks of innovation by

- managing the increasing business, system, and operational complexity of these environments, and
- reinforcing the ability of the business to determine the specific network services and resources to offer at any given time [22].

Autonomic Networks address the service providers' needs to increase operational efficiency by an order of magnitude and reduce time to market of competitive services. At the same time, software developers and system integrators will find completely new ways of quickly producing profitable solutions. More importantly, services and resources provided by an Autonomic Network will be able to be easily changed by appropriate business goals and policies.

Our work is aimed at the heart of this challenge. We provide the principles and concepts, in a technological neutral way, that allow for a re-thinking on the part of information and communication service providers on how they run and manage their business. We also provide a new way for software developers to embrace these concepts by defining a new way to specify, design and develop management software. The ultimate goal is to define a framework that provides stakeholders all means to dynamically adapt their services and software to the changing needs of customers.

In this paper, we focus not on implementation, but on a logical (*technological neutral*) framework, with appropriate definitions and specifications, that can be published and discussed in order to provide the concepts and tools for (*technological specific*) implementations and deployments. This *architectural* framework will allow for self-aware and self-healing service *creation.* In their *deployment*, these services will be self-adapting, self-optimising and self-configuring. In their operation, these services are envisioned to be self-protecting, self-managing and self-composing. These features, in turn, enable Autonomic Networks to adapt to

(rapidly) changing business needs, technological innovations and environmental conditions with no (or very limited) human intervention. With this goal, our work is supporting the development of an Autonomic Communications Framework, whose mission is to support the development of different (autonomic) elements targeted at essential business needs.

The remainder of this paper is organised as follows: Section 2 provides an insight of what MACE has identified as Autonomic Networking. We provide an overview of the general components (or functional blocks) of an Autonomic Network and we introduce the FOCALE architecture, which defines the closed control loop that we are applying to our work. Section 3 provides the bases to define a technological neutral architectural framework, which effectively is a set of concepts and principles using the same terminology and taxonomy to identify challenges in defining a technological neutral architecture. Section 4 uses all basic concepts of section 3 and defines the Distributed Interface Orientated Architecture by means of a conceptual model. This Conceptual Model defines the areas of concern, shows how governance tasks are realised (or supported), and provides a layered approach combining all these aspects. Section 5 then defines the four basic artefacts: Contract, Component, Service, and Policy plus one specification for an Operation. Finally, section 6 gives an overview of the TMF TNA specifications, including framework services and domains. The paper is summarised in section 7 (where we also discuss current work items) and the acknowledgments followed by the list of used references.

2. The Vision of Autonomic Networking

One result of the MACE Workshop [1] was that the presented novel methodologies, architectures, processes and algorithms have been following a similar vision: Autonomic Networking. In essence, this vision describes the ability of a communications system to self-govern its behaviour within the constraints of the business goals that the system as a whole seeks to achieve. To achieve autonomic networking, information and data modelling captures knowledge related to network capabilities, environmental constraints and business goals/policies. Unlike other approaches, Autonomic Networking combines the knowledge from these models with information from a set of ontologies. This produces an augmented set of data structures that, together with reasoning and learning techniques, can be used to reason about network conditions. Knowledge embedded within system models will be used by policy-based network management systems (together with translation/code generation and policy enforcement processes) to automatically configure network elements in response to changing network conditions, environmental changes and changing business goals.

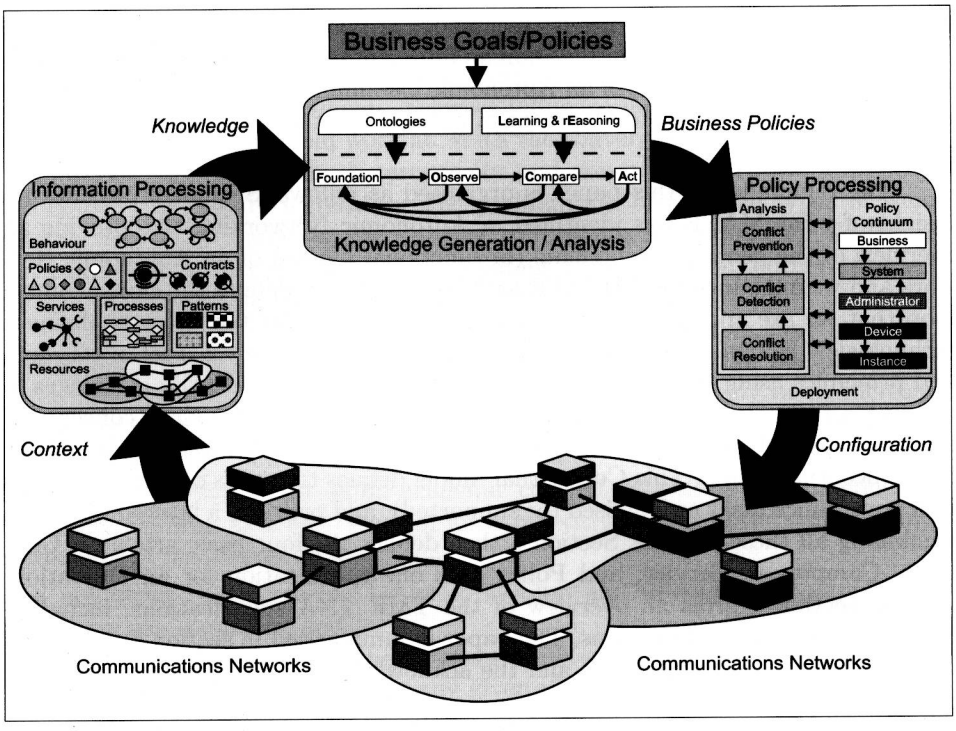

FIGURE 1. Autonomic Network and Closed Autonomic Control Loop [27]

The model-centric approach (Fig. 1) delivers considerable improvements over existing statically configured systems, since it supports the reconfiguration of networks with minimal human intervention. However, to deliver full Autonomic Network capabilities, we believe it is also necessary to introduce processes and algorithms into the system infrastructure to maintain optimal or near-optimal behaviour in terms of global stability, performance, robustness and security (i.e., as developed in [25]).

This yields a high-level approach based on one or more control loops which augments and complements the business models (using for example, eTOM [13] or ITIL® [23]) which are used to govern business tasks. Each activity in the business model can be represented by a set of classes, such as those from DEN-ng [12] that describes the characteristics and features of this activity. This set can then represent the activity lifecycle by being used to construct one or more Finite State Machines (FSM). As the system changes, code is dynamically generated according to the appropriate FSM(s) to protect business goals.

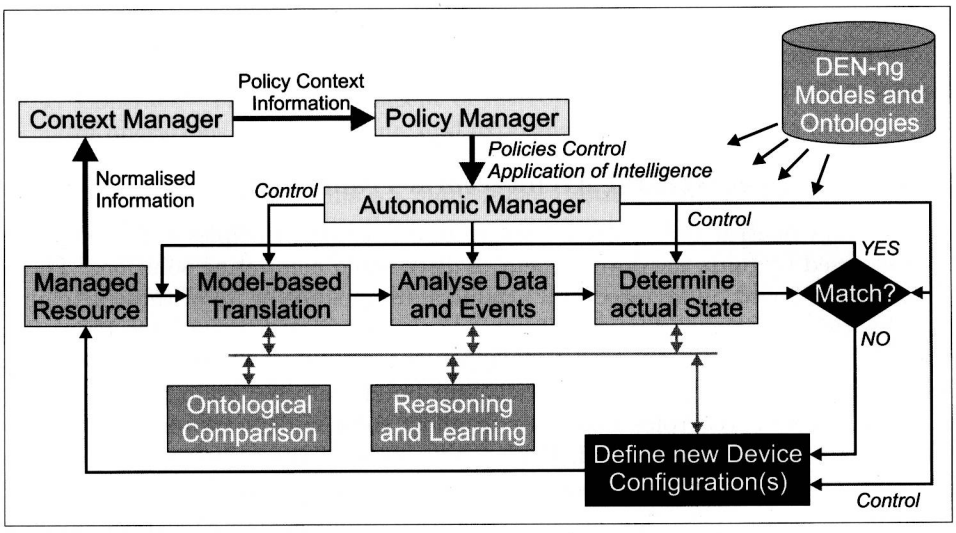

FIGURE 2. FOCALE Architecture – Closed Control Loop (based on [22])

Central to this approach is the presence of one or more system models that abstract the static structure, functionality and dynamic behaviour of the underlying network infrastructure, management functionality and offered services. Also modelled is the governance model of the system, realised as a continuum of policies reflecting business, system, network, device and device instance views [12]. The FOCALE architecture ([3] and [22]) shows how these models are continuously updated in response to the changing operational context of the network, environment, and/or changing business goals. It also describes how this knowledge embodied within the models is utilised to automatically generate configurations that maximise the degree to which the network satisfies business goals given its current operational context.

The basic assumption here is: complexity is everywhere. Thus, FOCALE is first and foremost, a way to manage complexity. Inspired by the autonomic nervous system, FOCALE is using the following analogy: if the autonomic system can perform manual, time-consuming tasks (such as configuration management) on behalf of the network administrator, then that will free the system and the administrator to perform higher-level cognitive functions, such as planning and optimisation. In essence, FOCALE defines the self-adjusting control loop. Inputs to the control loop consist of various status signals from the system or component being controlled, along with policy-driven management rules that orchestrate the behaviour of the system or component. Outputs are commands to the system or components to adjust its operation, along with status towards other autonomic

elements. The approach used in FOCALE architecture (cf. Fig. 2) is a policy-driven autonomic control loop incorporating two different loops and allowing for managing legacy components as well as autonomic elements.

3. Technological Neutral Architectural Framework

A technology neutral architectural framework consists of principles and procedures that are used to guide the development of distributed computing solutions. These solutions are based on architectural artefacts, using some or all of these artefacts through the creation and re-use of artefacts retained in a knowledge base. For example, operator deployment teams apply the procedures to identify business needs, model solutions, validate models and build run-time systems. Each team is staffed to fulfil the roles necessary to allow their understanding of the solution to be properly documented. Each team's view of the solution space will be rendered as a set of specifications created by drawing on the artefacts available from the knowledge base. The artefacts retrieved from the knowledge base support building a model (problem, constraints and answer) of the proposed solution. The resulting model is used as the basis for reconciling implementation and realisation decisions once construction on the actual distributed system solution is underway. This methodology, called SANRR for Scope, Analyse, Normalise, Rationalise and Rectify, is described in [14].

The types of artefacts available for use in constructing the solution model are varied, but fall into four general categories:

1. *Process Context* - business process flows, system process plans and process realisation scripts,
2. *Information Context* - business entities, (shared) information models and realisation data models,
3. *Operational Context* - contracts, policies, components, instances and testing systems and
4. *Infrastructure* - technology neutral and technology specific frameworks.

The process and information contexts provide a way to focus on a particular dimension of the solution space. The process context emphasises the high-level behavioural aspects of the solution space while the information context describes specific details regarding the factual aspects (i.e., the static data and dynamic aspects, as well as behaviour and interaction, between components of the solution space. [14]) In FOCALE [22], changes in context cause a potentially new set of policies to be loaded, which adjusts the current governance model to suit the new context. These new policies then control the current functionality that is being offered.

3.1. Terminology

The following is terminology that is used in this document. This terminology is based on the NGOSS TNA specification [4], which incorporates definitions from