Implementing Semantic Web Services
The SESA Framework

Dieter Fensel
Mick Kerrigan
Michal Zaremba (Eds.)
Implementing Semantic Web Services
Dieter Fensel · Mick Kerrigan · Michal Zaremba
Editors

Implementing
Semantic
Web Services

The SESA Framework
Dieter Fensel
Mick Kerrigan
Michal Zaremba

STI Innsbruck
ICT – Technologie Park
Technikerstr. 21a
6020 Innsbruck, Austria

dieter.fensel@sti2.at
mick.kerrigan@sti2.at
michal.zaremba@sti2.at


Library of Congress Control Number: 2007940953


© 2008 Springer-Verlag Berlin Heidelberg

This work is subject to copyright. All rights are reserved, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilm or in any other way, and storage in data banks. Duplication of this publication or parts thereof is permitted only under the provisions of the German Copyright Law of September 9, 1965, in its current version, and permission for use must always be obtained from Springer. Violations are liable for prosecution under the German Copyright Law.

The use of general descriptive names, registered names, trademarks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

Cover design: Künkellopka, Heidelberg

Printed on acid-free paper
9 8 7 6 5 4 3 2 1

springer.com
To all Semantic Web and Semantic Web Services (SWS) researchers:
Let’s make it real!
Preface

Motivation

Computer science appears to be in a period of crisis. The globalization trend is moving programming jobs to low-labor countries. This appears to place computer science research and departments at risk of being considered as working on obsolete technology. However, the opposite is true. Computer science is on the verge of a new generation of computing that is leading to innovation not only in computing but also in business, science, and all other endeavors that depend on computing.

Times of crisis are also times of innovation and can lead to paradigm shifts. Computer science is entering a new generation. The previous generation was based on abstracting from hardware. The emerging generation comes from abstracting from software and sees all resources as services in a Service-Oriented Architecture (SOA). A SOA is essentially a collection of services and these services can communicate with each other. The communication can involve simple data passing or it could involve multiple services coordinating some activity. In a world of services, users are concerned only about the services and not about any software or hardware components that implement the service. To this end, service-oriented computing has become one of the predominant factors in current IT research and development efforts over the last few years.

Standardization in this area has already made its way out of the research laboratories into industrial-strength technologies and tools. Again, Web technologies prove to be a good starting point: Web Services seem to be the middleware solution of the future for enabling the development of highly interoperable, distributed software solutions: the new technologies subsumed under this common term promise easy application integration by means of languages such as XML, and a common communication platform by relying on widely used Web protocols.

A service-oriented world will have in the future an “uncountable” number of services. Computation will involve services searching for services based on functional and nonfunctional requirements and interoperating with those that they select. However, services will not be able to interact automatically and SOAs will not scale without signification mechanization of service discovery, negotiation, adaptation,
composition, invocation, and monitoring as well as service interaction which will require further data, protocol, and process mediation. Hence, machine processable semantics are critical for the next generation of computing – SOAs – to reach its full potential. Only with semantics can critical subtasks can be automated leaving humans to focus on problem solving.

This book presents a comprehensive Semantically Enabled Service-oriented Architecture (SESA) framework which aims to augment the worldwide movement to service orientation with semantics in the context of evolving industrial standards and technologies. Several promising results from numerous recent EU projects and efforts within standardization bodies such as OASIS and W3C show the direction for further developments and commercialization of semantic-based technologies.

Goals

The goal of this book is to provide an insight into and an understanding of the problems faced by Web Services and SOAs. Considering current Web service technologies, there is a large amount of human effort required in the process of finding and executing Web Services. This book lays the foundation for understanding the Semantic Web Services infrastructure, aimed at eliminating human intervention allowing for seamless integration of information system. It focuses on a particular infrastructure, which is currently the most advanced Semantic Web Services infrastructure, namely, SESA, and its related efforts such as the Web Services Execution Environment (WSMX) activities and the Semantic Execution Environment (OASIS SEE TC) standardization effort.

With the present book we want to give an overall understanding of SESA and show how it can be applied to the problems of SOAs. Industry, which plans to commercialize semantic solutions, is searching for examples and literature that guide it in the development of the end-to-end applications and systems that use semantics. This book targets professionals and researchers who want to improve their understanding of how semantics can be applied in execution engines to enable interoperability between distributed information systems. While such systems are already in the process of being developed and standardized in the open source community, the lack of appropriate literature prevents the wider popularization of these technologies. That is to say that while prototypes of such systems are already available, the commercialization of these technologies remains in its infancy. This book aims to bridge this gap and bring existing prototypes closer to commercial exploitation.

Intended Audience

The book is suitable for professionals, academic and industry researchers working on various aspects of semantics, who have knowledge of integration aspects gained from their past experiences using traditional integration technologies. Through this book they will learn how to apply the Semantic Web Services infrastructure to automate
and semiautomate tasks, which until now have required a lot of human intervention, while using existing integration technologies. This book is also suitable for novice readers, such as advanced graduate students enrolled in courses covering knowledge management, the Semantic Web, and engineering and semantics in information systems. This book will educate them about grounding technologies for Semantic Web Services, but will also explain the more generic issues related to integration of information systems.

Organization of This Book

We have divided the book into four main parts.

Part I provides an introduction to the field and its history. We cover basic Web technologies, Web Services and their predecessors, and the state of research and standardization in the Semantic Web field.

Part II presents SESA – the architecture aiming to enable the execution of Semantic Web Services. We describe the building blocks and show how they are consolidated into a coherent software architecture that can be used as a blueprint for implementation.

Part III gives more insight into middleware services. The architecture defines the necessary conceptual functionality that is imposed on the architecture through the underlying principles. Each such functionality is realized (totally or partially) by a number of so-called middleware services.

Part IV shows how SESA can be applied to real-world scenarios and provides an overview of compatible and related systems.

Acknowledgements

The work presented in this book has been funded by the European Commission under SWWS (IST-2001-37134), DIP (FP6-507483), Knowledge Web (FP6-507482), TRIPCOM (FP6-027324), and SUPER (FP6-026850) projects. In addition, contributions came from several Austrian-based projects, namely, SEMBIZ (812525), GRISINO (810805/5512), RW2 (809250), and TSC (809249). The work presented in this book was funded as well through the Lion project supported by Science Foundation Ireland under grant no. SFI/02/CE1/I131. Additionally we would like to acknowledge US National Science Foundation grants CCR-0311512 and IIS-0534419.

The majority of the research that is described in this publication must be accredited to the tireless efforts of the SEE, WSMO, WSML, WSMX, and WSMT working groups, to whom we remain gratefully indebted for their valuable discussion and helpful advice.

The editors, January 2008
## Contents

### Part I Foundations

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1 From Web to Semantic Web</strong></td>
<td>3</td>
</tr>
<tr>
<td>1.1 The Web – A Familiar Starting Point</td>
<td>3</td>
</tr>
<tr>
<td>1.2 Architectural Principles of the World Wide Web</td>
<td>5</td>
</tr>
<tr>
<td>1.3 The World Wide Web Consortium – W3C</td>
<td>7</td>
</tr>
<tr>
<td>1.4 Spawning the Semantic Web</td>
<td>9</td>
</tr>
<tr>
<td>1.5 The Semantic Web</td>
<td>14</td>
</tr>
<tr>
<td>1.6 The Semantic Web – Future Prospects</td>
<td>24</td>
</tr>
<tr>
<td>1.7 Summary</td>
<td>25</td>
</tr>
<tr>
<td><strong>2 Semantic Web Services</strong></td>
<td>27</td>
</tr>
<tr>
<td>2.1 Behavioral Perspective of the World Wide Web</td>
<td>27</td>
</tr>
<tr>
<td>2.2 Web Services</td>
<td>34</td>
</tr>
<tr>
<td>2.3 Semantic Web Services: The Future of Integration!</td>
<td>37</td>
</tr>
<tr>
<td>2.4 The Ideal World</td>
<td>40</td>
</tr>
<tr>
<td>2.5 Summary</td>
<td>41</td>
</tr>
<tr>
<td><strong>3 WSMO and WSML</strong></td>
<td>43</td>
</tr>
<tr>
<td>3.1 The Web Service Modeling Ontology</td>
<td>43</td>
</tr>
<tr>
<td>3.2 The Web Service Modeling Language</td>
<td>53</td>
</tr>
<tr>
<td>3.3 Summary</td>
<td>65</td>
</tr>
</tbody>
</table>

### Part II SESA Environment

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>4 Introduction to Semantically Enabled Service-oriented Architectures</strong></td>
<td>69</td>
</tr>
<tr>
<td>4.1 SESA Background</td>
<td>69</td>
</tr>
<tr>
<td>4.2 Service Orientation</td>
<td>70</td>
</tr>
<tr>
<td>4.3 Execution Environment for Semantic Web Services</td>
<td>74</td>
</tr>
<tr>
<td>4.4 Governing Principles</td>
<td>76</td>
</tr>
</tbody>
</table>
### Contents

4.5 SESA Vision – Global View ................................................. 76
4.6 SESA Roadmap ............................................................... 82
4.7 SESA Research Areas and Goals ........................................ 83
4.8 Summary ................................................................. 97

5 **SESA Middleware** ............................................................ 99
5.1 Services Viewpoint .......................................................... 100
5.2 Technology Viewpoint ..................................................... 112
5.3 Summary ................................................................. 117

6 **SESA Execution Semantics** ................................................ 119
6.1 Motivation ................................................................. 120
6.2 Proposed Description Formalism ....................................... 121
6.3 Mandatory Execution Semantics ....................................... 122
6.4 Case Study Example of SESA Execution Semantics ............ 126
6.5 Technical Perspective on Execution Semantics .................. 131
6.6 Summary ................................................................. 134

### Part III SESA Services

7 **Reasoning** ................................................................. 137
7.1 Reasoning Requirements ................................................ 137
7.2 Logical Background ...................................................... 140
7.3 Reasoning Tasks ........................................................... 144
7.4 Reasoning Within SESA .................................................. 155
7.5 A Generic Framework for Reasoning with WSML ............... 156
7.6 Rule Interchange Format ................................................ 162
7.7 Conclusion ............................................................... 164

8 **Discovery** ................................................................. 167
8.1 A Conceptual Model for Discovery .................................... 167
8.2 Web Services at Various Levels of Abstraction .................. 168
8.3 Keyword-Based Discovery .............................................. 169
8.4 Discovery Based on Simple Semantic Descriptions ............ 174
8.5 Discovery Based on Rich Semantic Descriptions ............... 182
8.6 Summary ............................................................... 191

9 **Selection** ................................................................. 193
9.1 Introduction ............................................................. 193
9.2 Nonfunctional Properties ............................................... 194
9.3 Selecting Services ...................................................... 201
9.4 Related Work ........................................................... 207
9.5 Summary ............................................................... 208
10 Mediation ................................................................. 211
10.1 Preliminaries ......................................................... 211
10.2 Ontology-Based Data Mediation ................................. 214
10.3 Behavioral Mediation .............................................. 223
10.4 Summary ............................................................. 231

11 Storage and Internal Communication .............................. 233
11.1 Introduction to Triple Space Computing ......................... 234
11.2 Triple Space Kernel ................................................ 237
11.3 Role of Triple Space Computing in SESA ....................... 247
11.4 Evaluation .......................................................... 255
11.5 Summary ............................................................ 256

Part IV SESA Application and Compatible Systems

12 SESA Application ..................................................... 261
12.1 Case Scenario: B2B Integration .................................... 261
12.2 Case Scenario: Voice and Data Integration ..................... 270
12.3 Summary ............................................................. 284

13 Compatible and Related Systems ................................. 285
13.1 The Internet Reasoning Service .................................... 285
13.2 Other WSMO-Compatible Tools .................................. 293
13.3 Tools Based on OWL-S ............................................ 294
13.4 METEOR-S ......................................................... 296

14 Conclusions and Outlook ............................................. 303
14.1 Why SOA? .......................................................... 303
14.2 Future Work ........................................................ 305
14.3 Commercialization ............................................... 306

References ............................................................... 307

Index ................................................................. 319
List of Contributors

Jos de Bruijn – Chapter 3
Faculty of Computer Science, Free University of Bozen-Bolzano,
Piazza Domenicali 3, 39100 Bolzano, Italy
debuijn@inf.unibz.it

Christoph Bussler – Chapter 2
Cisco Systems, Inc., San Jose, CA, USA
ChBussler@aol.com

Emilia Cimpian – Chapter 10
STI Innsbruck, Leopold Franzens Universität Innsbruck, ICT – Technologie Park, Technikerstrasse 21a, 6020 Innsbruck, Austria
emilia.cimpian@sti2.at

Dieter Fensel – Chapters 1–14
STI Innsbruck, Leopold Franzens Universität Innsbruck, ICT – Technologie Park, Technikerstrasse 21a, 6020 Innsbruck, Austria
dieter.fensel@sti2.at

Graham Hench – Chapter 1
STI Innsbruck, Leopold Franzens Universität Innsbruck, ICT – Technologie Park, Technikerstrasse 21a, 6020 Innsbruck, Austria
graham.hench@sti2.at

Uwe Keller – Chapter 7
STI Innsbruck, Leopold Franzens Universität Innsbruck, ICT – Technologie Park, Technikerstrasse 21a, 6020 Innsbruck, Austria
uwe.keller@sti2.at

Mick Kerrigan – Chapter 3
STI Innsbruck, Leopold Franzens Universität Innsbruck, ICT – Technologie Park, Technikerstrasse 21a, 6020 Innsbruck, Austria
mick.kerrigan@sti2.at

Michael Kifer
Department of Computer Science, State University of New York at Stony Brook, Stony Brook, NY 11794-4400, USA
kifer@cs.sunysb.edu

Holger Lausen – Chapter 8
STI Innsbruck, Leopold Franzens Universität Innsbruck, ICT – Technologie Park, Technikerstrasse 21a, 6020 Innsbruck, Austria
holger.lausen@sti2.at

Adrian Mocan – Chapter 10
STI Innsbruck, Leopold Franzens Universität Innsbruck, ICT – Technologie Park, Technikerstrasse 21a, 6020 Innsbruck, Austria
adrian.mocan@sti2.at
XVI    List of Contributors

Matthew Moran – Chapter 5
DERI Galway, National University of Ireland Galway, IDA Business
Park, Lower Dangan, Galway, Ireland
mattew.moran@deri.org

Barry Norton – Chapter 13
Knowledge Media Institute, Open University, Walton Hall, Milton Keynes MK7 6AA, UK
b.j.norton@open.ac.uk

Carlos Pedrinaci – Chapter 13
Knowledge Media Institute, Open University, Walton Hall, Milton Keynes MK7 6AA, UK

Dumitru Roman – Chapter 9
STI Innsbruck, Leopold Franzens Universität Innsbruck, ICT – Technologie Park, Technikerstrasse 21a, 6020 Innsbruck, Austria
dumitru.roman@sti2.at

Ioan Toma – Chapter 9
STI Innsbruck, Leopold Franzens Universität Innsbruck, ICT – Technologie Park, Technikerstrasse 21a, 6020 Innsbruck, Austria
ioan.toma@sti2.at

Jana Viskova – Chapter 12
Department of Information Networks, University of Zilina, Zilina, Slovakia
viskova@kis.fri.utc.sk

Tomas Vitvar – Chapters 5, 12
DERI Galway, National University of Ireland Galway, IDA Business
Park, Lower Dangan, Galway, Ireland
tomas.vitvar@deri.org

Zhixian Yan – Chapter 5
STI Innsbruck, Leopold Franzens Universität Innsbruck, ICT – Technologie Park, Technikerstrasse 21a, 6020 Innsbruck, Austria
zhixian.yan@sti2.at

Maciej Zaremba – Chapter 6
DERI Galway, National University of Ireland Galway, IDA Business
Park, Lower Dangan, Galway, Ireland
maciej.zaremba@deri.org

Michal Zaremba – Chapter 5
STI Innsbruck, Leopold Franzens Universität Innsbruck, ICT – Technologie Park, Technikerstrasse 21a, 6020 Innsbruck, Austria
michal.zaremba@sti2.at

Omair Shafiq – Chapter 11
STI Innsbruck, Leopold Franzens Universität Innsbruck, ICT - Technologie Park, Technikerstrasse 21a, 6020 Innsbruck, Austria
adrian.mocan@sti2.at

Nathalie Steinmetz – Chapter 7
STI Innsbruck, Leopold Franzens Universität Innsbruck, ICT – Technologie Park, Technikerstrasse 21a, 6020 Innsbruck, Austria
nathalie.steinmetz@sti2.at