Jacqueline Jarvis, Dennis Jarvis, Ralph Rönnquist and Lakhmi C. Jain

Holonic Execution: A BDI Approach

## Studies in Computational Intelligence, Volume 106

Editor-in-chief
Prof. Janusz Kacprzyk
Systems Research Institute
Polish Academy of Sciences
ul. Newelska 6
01-447 Warsaw
Poland
*E-mail:* kacprzyk@ibspan.waw.pl

Further volumes of this series can be found on our homepage: springer.com

Vol. 83. Bhanu Prasad and S.R.M. Prasanna (Eds.)
*Speech, Audio, Image and Biomedical Signal Processing using Neural Networks,* 2008
ISBN 978-3-540-75397-1

Vol. 84. Marek R. Ogiela and Ryszard Tadeusiewicz
*Modern Computational Intelligence Methods for the Interpretation of Medical Images,* 2008
ISBN 978-3-540-75399-5

Vol. 85. Arpad Kelemen, Ajith Abraham and Yulan Liang (Eds.)
*Computational Intelligence in Medical Informatics,* 2008
ISBN 978-3-540-75766-5

Vol. 86. Zbigniew Les and Mogdalena Les
*Shape Understanding Systems,* 2008
ISBN 978-3-540-75768-9

Vol. 87. Yuri Avramenko and Andrzej Kraslawski
*Case Based Design,* 2008
ISBN 978-3-540-75705-4

Vol. 88. Tina Yu, David Davis, Cem Baydar and Rajkumar Roy (Eds.)
*Evolutionary Computation in Practice,* 2008
ISBN 978-3-540-75770-2

Vol. 89. Ito Takayuki, Hattori Hiromitsu, Zhang Minjie and Matsuo Tokuro (Eds.)
*Rational, Robust, Secure,* 2008
ISBN 978-3-540-76281-2

Vol. 90. Simone Marinai and Hiromichi Fujisawa (Eds.)
*Machine Learning in Document Analysis and Recognition,* 2008
ISBN 978-3-540-76279-9

Vol. 91. Horst Bunke, Kandel Abraham and Last Mark (Eds.)
*Applied Pattern Recognition,* 2008
ISBN 978-3-540-76830-2

Vol. 92. Ang Yang, Yin Shan and Lam Thu Bui (Eds.)
*Success in Evolutionary Computation,* 2008
ISBN 978-3-540-76285-0

Vol. 93. Manolis Wallace, Marios Angelides and Phivos Mylonas (Eds.)
*Advances in Semantic Media Adaptation and Personalization,* 2008
ISBN 978-3-540-76359-8

Vol. 94. Arpad Kelemen, Ajith Abraham and Yuehui Chen (Eds.)
*Computational Intelligence in Bioinformatics,* 2008
ISBN 978-3-540-76802-9

Vol. 95. Radu Dogaru
*Systematic Design for Emergence in Cellular Nonlinear Networks,* 2008
ISBN 978-3-540-76800-5

Vol. 96. Aboul-Ella Hassanien, Ajith Abraham and Janusz Kacprzyk (Eds.)
*Computational Intelligence in Multimedia Processing: Recent Advances,* 2008
ISBN 978-3-540-76826-5

Vol. 97. Gloria Phillips-Wren, Nikhil Ichalkaranje and Lakhmi C. Jain (Eds.)
*Intelligent Decision Making: An AI-Based Approach,* 2008
ISBN 978-3-540-76829-9

Vol. 98. Ashish Ghosh, Satchidananda Dehuri and Susmita Ghosh (Eds.)
*Multi-Objective Evolutionary Algorithms for Knowledge Discovery from Databases,* 2008
ISBN 978-3-540-77466-2

Vol. 99. George Meghabghab and Abraham Kandel
*Search Engines, Link Analysis, and User's Web Behavior,* 2008
ISBN 978-3-540-77468-6

Vol. 100. Anthony Brabazon and Michael O'Neill (Eds.)
*Natural Computing in Computational Finance,* 2008
ISBN 978-3-540-77476-1

Vol. 101. Michael Granitzer, Mathias Lux and Marc Spaniol (Eds.)
*Multimedia Semantics - The Role of Metadata,* 2008
ISBN 978-3-540-77472-3

Vol. 102. Carlos Cotta, Simeon Reich, Robert Schaefer and Antoni Ligeza (Eds.)
*Knowledge-Driven Computing,* 2008
ISBN 978-3-540-77474-7

Vol. 103. Devendra K. Chaturvedi
*Soft Computing Techniques and its Applications in Electrical Engineering,* 2008
ISBN 978-3-540-77480-8

Vol. 104. Maria Virvou and Lakhmi C. Jain (Eds.)
*Intelligent Interactive Systems in Knowledge-Based Environments,* 2008
ISBN 978-3-540-77470-9

Vol. 105. Wolfgang Guenthner
*Enhancing Cognitive Assistance Systems with Inertial Measurement Units,* 2008
ISBN 978-3-540-76996-5

Vol. 106. Jacqueline Jarvis, Dennis Jarvis, Ralph Rönnquist and Lakhmi C. Jain
*Holonic Execution: A BDI Approach,* 2008
ISBN 978-3-540-77478-5

Jacqueline Jarvis
Dennis Jarvis
Ralph Rönnquist
Lakhmi C. Jain

# Holonic Execution: A BDI Approach

With 15 Figures and 12 Tables

Springer

Dr. Jacqueline Jarvis
School of Management
and Information Systems
Central Queensland University
Rockhampton
Queensland 4702
Australia

Dr. Dennis Jarvis
School of Computing Sciences
Central Queensland University
Rockhampton
Queensland 4702
Australia

Dr. Ralph Rönnquist
Director, Intendico Pty. Ltd.
Suite 40, 85 Grattan St
Carlton
Victoria 3053
Australia

Dr. Lakhmi C. Jain
SCT-Building
Professor of Knowledge-Based Engineering
University of South Australia
Adelaide
Mawson Lakes Campus
South Australia SA 5095
Australia

ISBN 978-3-540-77478-5 e-ISBN 978-3-540-77479-2

Studies in Computational Intelligence ISSN 1860-949X

Library of Congress Control Number: 2008920056



Cover design: Deblik, Berlin, Germany

Printed on acid-free paper

9 8 7 6 5 4 3 2 1

springer.com

# Preface

The term "holon" was first introduced by Koestler (Koestler, 1967) to capture the idea that both biological and social structures consisted of entities that were part of a larger whole, while being self-contained entities in their own right. These entities were called holons and the structures that they form were called holarchies. In this book, we present a conceptual model for holonic manufacturing execution and then use this model to develop two implementations for an execution system for an industrial strength robotic assembly cell. The model is based on the experience that we have gained in developing a number of agent-based execution systems over the past 10 years.

Manufacturing execution is that activity which is concerned with the management of actual manufacturing tasks. It involves interaction with device controllers, but it is conceptually separate from manufacturing control. The applicability of the holonic concept to manufacturing was first noted by Suda (Suda, 1990) and this led to the formation of the Holonic Manufacturing Systems project in 1993 (HMS Consortium, 2001). The HMS project was conducted under the auspices of the Intelligent Manufacturing Systems (IMS) program (IMS, 2005) and remains of the largest of the IMS projects to have been undertaken. The HMS project spanned three separate phases, ending in 2004. In addition, a significant amount of work (including the work described in this book) was conducted outside the HMS project. Conceptually, holons are similar to agents. The key distinguishing feature, according to the HMS Consortium is that a holon can have both an information processing part and a physical part, whereas an agent has only an information processing part (Brennan and Norrie, 2003). While this distinction is present in our model, we choose to emphasise the notion of holarchy as being the key distinguishing feature between a holonic system and a traditional multi-agent system.

In our conceptual model, holon behaviour draws on the BDI (Belief, Desire, Intention) model of agency. A BDI agent makes rational commitments to particular courses of action (intentions) that it believes will enable it to achieve its goals (desires) (Bratman, 1987; Rao and Georgeff, 1995). As the agent is situated in a dynamically changing environment, its beliefs and goals will change over time. By and large, the HMS community has forgone the BDI model in favour of bespoke behaviour models. They have also adopted the individual agent focus of the multi-agent systems community whereby group behaviour arises bottom up through the reasoned interaction of individual agents. In this book, we advocate a top down approach, whereby organizational structure and coordinated group behaviour are explicitly modelled.

The implementations are realized using two different software systems – JACK$^{TM}$ Intelligent Agents (JACK), a commercially supported intelligent agent framework (Agent Oriented Software, 2008a) and GORITE, a framework that provides team programming support for Java developers (Rönnquist, 2008). Both support team-based organizational models and behaviour models that employ BDI reasoning, but they provide two quite different perspectives on holonic application development. JACK follows the path of conventional BDI implementations with the expectation that a major aspect of a holonic application will be the attribution of reasoned behaviour to individual situated agents. This reasoned behaviour will then guide both autonomous and cooperative behaviour. JACK supports the notion of explicitly modeling team behaviour and ascribing it to team agents; however, these agents are also expected to exhibit reasoned behaviour. The nett result is a perspective in which situated agent behaviour drives system behaviour. GORITE provides a different perspective in which system behaviour is specified in terms of the coordinated behaviour of situated agents. Coordination is at the level of goals, so autonomy is still preserved – agents have control over both goal realisation and goal progression. However, agent behaviour is now driven by the needs of system behaviour. To emphasise this distinction and the central role that coordinated behaviour plays, we refer to the approach as Team Programming. Our experience has indicated that complex manufacturing applications, such as execution are well suited to this approach. Our expectation is that applications other than manufacturing that require the engineering of large, complex systems, such as sensor network management, UAV mission management, business process management and military behaviour modeling would benefit from this approach.

The book will be of interest to both researchers and practitioners in the holonic systems, manufacturing systems and multi-agent systems communities. It will also be of interest to the wider complex systems community, as it introduces what may become a new paradigm for complex systems development in the form of Team Programming.

# Contents

**Preface** .... V

**1 Introduction** .... 1

**2 Holonic Manufacturing Systems** .... 7
2.1 The Holonic Concept .... 7
2.2 The HMS Project .... 7
2.3 Holonic Manufacturing Execution .... 9
2.3.1 Part-Oriented Approaches .... 10
2.3.2 Resource Oriented Approaches .... 13
2.3.3 Combined Approaches .... 15
2.3.4 Discussion .... 15

**3 Rational Agency** .... 17
3.1 Models .... 17
3.1.1 Soar .... 17
3.1.2 The BDI Model .... 18
3.1.3 Team Reasoning .... 20
3.2 Frameworks .... 22
3.2.1 JACK .... 22
3.2.2 JACK Teams .... 26
3.2.3 GORITE .... 28

**4 A Conceptual Model for Holonic Manufacturing Execution** 33
4.1 The HMS Perspective .... 34
4.2 The Conceptual Model .... 35
4.2.1 The Structural Model .... 35
4.2.2 The Behavioural Model .... 38

4.3 Conceptual Model Mappings ..... 39
4.3.1 JACK Teams ..... 39
4.3.2 GORITE ..... 40

**5 The Meter Box Cell** ..... 43
5.1 Description ..... 43
5.2 Design ..... 45
5.2.1 Holarchy Design ..... 46
5.2.2 Holon Design ..... 46
5.3 JACK Teams Implementation ..... 49
5.3.1 Cell Structure ..... 49
5.3.2 Cell Behaviour ..... 51
5.3.3 Machine Behaviour ..... 56
5.4 GORITE Implementation ..... 56
5.4.1 Cell Structure ..... 57
5.4.2 Cell Behaviour ..... 59
5.4.3 Machine Behaviour ..... 63

**6 Future Work** ..... 69

**7 Conclusion** ..... 73

**Appendices** ..... 75

**A. The Pilot Systems** ..... 75
A.1 Model Based Diagnosis ..... 76
A.1.1 VQ Shuttle ..... 76
A.2 HMS WP3 ..... 77
A.2.1 Huller-Hille Machine ..... 77
A.2.2 Wilson Line ..... 78
A.2.3 Sorting Conveyor ..... 79
A.3 Holonic Manufacturing Execution ..... 79
A.3.1 Meter Box Cell ..... 79
A.3.2 Packing Cell ..... 79

**B. GORITE** ..... 83
B.1 Process Modeling Classes ..... 83
B.2 Belief Modelling Classes ..... 87

**References** ..... 91

**Glossary** ..... 97