

## Contents

|                                                          |           |
|----------------------------------------------------------|-----------|
| List of Figures                                          | xi        |
| List of Research Corners                                 | xiv       |
| List of Technology Corners                               | xiv       |
| Acknowledgments                                          | xv        |
| <b>1 Introduction</b>                                    | <b>1</b>  |
| 1.1 Objectives                                           | 2         |
| 1.2 Challenges                                           | 2         |
| 1.3 Approach                                             | 4         |
| 1.4 Intended Readership                                  | 5         |
| 1.5 Book Structure and Reading Guide                     | 5         |
| <b>2 An Overview of Multi-Agent Oriented Programming</b> | <b>9</b>  |
| 2.1 Multi-Agent Systems                                  | 9         |
| 2.2 Multi-Agent Oriented Programming                     | 12        |
| 2.3 Main Abstractions                                    | 14        |
| 2.4 Integrated View                                      | 16        |
| 2.5 Overcoming Challenges                                | 18        |
| 2.6 Wrap-Up                                              | 22        |
| 2.7 Bibliographical Notes                                | 23        |
| <b>3 Getting Started</b>                                 | <b>25</b> |
| 3.1 Single-Agent Hello-World                             | 26        |
| 3.2 Multi-Agent Hello-World                              | 27        |
| 3.3 Hello-World Environment                              | 28        |
| 3.4 Hello-World Organization                             | 30        |
| 3.5 Bibliographical Notes                                | 34        |
| Exercises                                                | 36        |

|          |                                                                  |            |
|----------|------------------------------------------------------------------|------------|
| <b>4</b> | <b>The Agent Dimension</b>                                       | <b>37</b>  |
| 4.1      | Overview                                                         | 37         |
| 4.2      | Agent Abstractions                                               | 39         |
| 4.3      | Agent Execution                                                  | 45         |
| 4.4      | Bibliographical Notes                                            | 49         |
|          | Exercises                                                        | 50         |
| <b>5</b> | <b>The Environment Dimension</b>                                 | <b>51</b>  |
| 5.1      | Overview                                                         | 51         |
| 5.2      | Environment Abstractions                                         | 53         |
| 5.3      | Environment Execution                                            | 66         |
| 5.4      | Bibliographical Notes                                            | 68         |
|          | Exercises                                                        | 69         |
| <b>6</b> | <b>Programming an Agent and Its Environment</b>                  | <b>71</b>  |
| 6.1      | Programming a Proactive Smart Room                               | 71         |
| 6.2      | Adding Reactivity to the Smart Room                              | 81         |
| 6.3      | Adding Fault Tolerance to the Smart Room                         | 84         |
| 6.4      | Making the Smart Room Adaptive                                   | 85         |
| 6.5      | What We Have Learned                                             | 89         |
|          | Exercises                                                        | 89         |
| <b>7</b> | <b>Programming Multiple Agents Interacting in an Environment</b> | <b>91</b>  |
| 7.1      | Programming a Smart Room with Multiple Agents                    | 91         |
| 7.2      | Decentralizing the Coordination with Interaction Protocols       | 98         |
| 7.3      | Environment-Mediated Coordination                                | 103        |
| 7.4      | From Decentralization to Distribution                            | 110        |
| 7.5      | What We Have Learned                                             | 116        |
|          | Exercises                                                        | 117        |
| <b>8</b> | <b>The Organization Dimension</b>                                | <b>119</b> |
| 8.1      | Overview                                                         | 119        |
| 8.2      | Organization Abstractions                                        | 125        |
| 8.3      | Organization Execution                                           | 133        |
| 8.4      | Bibliographical Notes                                            | 141        |
|          | Exercises                                                        | 142        |
| <b>9</b> | <b>Programming Organizations of Situated Agents</b>              | <b>143</b> |
| 9.1      | Programming an Organized Smart Room                              | 143        |

|           |                                                     |            |
|-----------|-----------------------------------------------------|------------|
| 9.2       | Changing the Organization                           | 156        |
| 9.3       | Agents Deploying Their Organization                 | 158        |
| 9.4       | Agents Reasoning about Their Organization           | 160        |
| 9.5       | What We Have Learned                                | 163        |
|           | Exercises                                           | 163        |
| <b>10</b> | <b>Integration with Other Technologies</b>          | <b>165</b> |
| 10.1      | Libraries, Frameworks, and Platforms                | 165        |
| 10.2      | Mainstream Application Domains and Technologies     | 174        |
| 10.3      | Integration with Other Multi-Agent System Platforms | 185        |
| <b>11</b> | <b>Wrap-Up and Perspectives</b>                     | <b>189</b> |
| 11.1      | The MAOP Viewpoint—Wrap-Up                          | 189        |
| 11.2      | MAOP and Artificial Intelligence                    | 191        |
| 11.3      | MAOP and Software Engineering                       | 197        |
| 11.4      | The Road Ahead                                      | 203        |
|           | Solutions to Exercises                              | 205        |
|           | References                                          | 219        |
|           | Index                                               | 235        |