Contents

Part I Context

| I | Intr | oauction | | 3 | |
|-------|--------------|---------------------------|--|----|--|
| | 1.1 | An Exa | ample of a Verification Problem | 3 | |
| | 1.2 | Busine | ss Rules Management Systems | 6 | |
| | | 1.2.1 | From Business Policies to Business Rules | 6 | |
| | | 1.2.2 | A Brief Genealogy of Business Rules | | |
| | | | Management Systems | 7 | |
| | | 1.2.3 | Industrial Context | 9 | |
| | 1.3 | Motiva | tion | 10 | |
| | 1.4 | 4 Summary of Contribution | | 12 | |
| | 1.5 | Structure of This Book | | | |
| | Refe | erences | | 15 | |
| 2 | Related Work | | | 19 | |
| | 2.1 | Rule-B | lased Paradigms: Model vs. State | 19 | |
| | | 2.1.1 | Model-Oriented Rules | 20 | |
| | | 2.1.2 | State-Oriented Rules | 20 | |
| | | 2.1.3 | Combining the Two Approaches | 21 | |
| | 2.2 | Forma | lization and Verification of Rule Programs | 22 | |
| | | 2.2.1 | Formalization | 22 | |
| | | 2.2.2 | Verification of Model-Oriented Rule Programs | 23 | |
| | | 2.2.3 | Verification of State-Oriented Rule Programs | 24 | |
| | 2.3 | Verific | ation of Pointer and Concurrent Programs | 25 | |
| | References | | | | |
| Par | t II | Rule Pro | ograms | | |
| - 447 | | | , g | | |
| 3 | Syn | tax of Ru | lles and Rule Programs | 33 | |
| | 3.1 | Signati | ure | 33 | |
| | 3.2 | Symbo | ols | 34 | |

хi

xii Contents

| | 3.3 | Expressions and Formulas | | |
|---|-------|------------------------------------|---|----------|
| | | 3.3.1 | Parameterized Languages of Expressions | 35 |
| | | | and Formulas | 35 |
| | | 3.3.2 | Well-Typed Expressions and Formulas | 37 |
| | | 3.3.3 | Formulas Are Flat | 38 |
| | | 3.3.4 | Theory Used in Examples | 38 |
| | 3.4 | Assign | ment | 39 |
| | 3.5 | | | 40 |
| | | 3.5.1 | Rule Variables | 4(|
| | | 3.5.2 | Rule Guard | 41 |
| | | 3.5.3 | Rule Action | 42 |
| | 3.6 | Rule P | rograms | 42 |
| | Refer | ences | | 43 |
| 1 | State | o and St | tata Assautions | 45 |
| 4 | 4.1 | | tate Assertions | 4. |
| | 4.1 | 4.1.1 | | 46 |
| | | 4.1.1 | DomainVariable Valuations | 47 |
| | | 4.1.3 | | 47 |
| | | 4.1.3 4.1.4 | Interpretation of Expressions. | 49 |
| | | 4.1.4 | Interpretation of Formulas | 52 |
| | 4.2 | | Assertions | 53 |
| | 4.2 | 4.2.1 | | 53 53 |
| | | 4.2.1 | Assertions | 53 |
| | | 4.2.2 | Global Assertions | 52 54 |
| | 4.2 | _ | Assertions Focused on a Rule | 54 54 |
| | 4.3 | | tion Assertions | 54 54 |
| | | 4.3.1 | Forward Transition Assertions | |
| | | 4.3.2 4.3.3 | Backward Transition Assertions | 56 |
| | 4.4 | Global Transition Assertions | 56 | |
| | 4.4 | | itics of Assignment | 57 |
| | | 4.4.1 | Update of an Attribute | 57 |
| | | 4.4.2 | Executing an Assignment | 58 |
| | 4.5 | 4.4.3 | Assignment as a Relation Between States | 59 |
| | 4.5 | | Guard and Action | 59 |
| | | 4.5.1 | Rule Guard | 59 |
| | n c | 4.5.2 | Rule Action | 59 |
| | Refe | rences | | 60 |
| 5 | Oper | rational | Semantics of Rule Programs | 6. |
| | 5.1 | Rule Program Execution, Informally | | |
| | 5.2 | Worki | ng Memory | 6 |
| | | 5.2.1 | Type-System Compliant States | 6 |
| | | 5.2.2 | Objects as Instances of Types | 68 |
| | | 5.2.3 | Preservation Properties | 69 |
| | 5.3 | Rule E | Execution | 7 |
| | | 5.3.1 | Rule Instance | 7. |

Contents xiii

| | | 5.3.2 | Applicability of a Rule Instance | | |
|----|--------|---------------------------------------|---|-----|--|
| | | 5.3.3 | Application of a Rule Instance | 72 | |
| | | 5.3.4 | Execution of a Rule Instance | | |
| | | 5.3.5 | Executions of a Rule | 74 | |
| | 5.4 | Rule Pr | rogram Execution | 76 | |
| | | 5.4.1 | Configurations | 76 | |
| | | 5.4.2 | Initial Configuration | | |
| | | 5.4.3 | Transition Between Configurations | 77 | |
| | | 5.4.4 | Executions of a Rule Program | | |
| | 5.5 | Selection | on Strategies | 81 | |
| | 5.6 | Eligibi | lity Strategies | 82 | |
| | | 5.6.1 | Identity Eligibility Strategy | 83 | |
| | | 5.6.2 | Refraction Eligibility Strategy | | |
| | | 5.6.3 | Sequential Execution Strategy | | |
| | | 5.6.4 | One-Shot Eligibility Strategy | 87 | |
| | Refe | rences | | 89 | |
| | | | | | |
| Pa | rt III | A Hoar | re Logic for Rule Programs | | |
| 6 | Corr | roctnoss i | of Rule Programs | 93 | |
| U | 6.1 | | inaries | | |
| | 0.1 | 6.1.1 | Fixing the Execution Strategy | | |
| | | 6.1.2 | Correctness Formulas, Proofs, Proof Systems | | |
| | 6.2 | | etness Formula for a Single Rule | | |
| | 6.3 | | Compared to Conditional Statements | | |
| | 0.5 | 6.3.1 | Loop-Free Programs | | |
| | | 6.3.2 | Rules vs. Conditional Statements | | |
| | 6.4 | | etness Formula for a Rule Program | | |
| | 0.4 | 6.4.1 | Syntax and Semantics | | |
| | | 6.4.2 | From Rules to Rule Programs | | |
| | Dofo | | From Rules to Rule Frograms. | | |
| | Kere | rences | | 100 | |
| 7 | Cor | Correctness of Programs: A Comparison | | | |
| | 7.1 | Correc | ctness of Loop-Free Parallel Programs | 107 | |
| | | 7.1.1 | Loop-Free Parallel Programs | 108 | |
| | | 7.1.2 | Loop-Free Parallel Program Derived | | |
| | | | from a Rule Program | 110 | |
| | | 7.1.3 | Rule Programs vs. Loop-Free Parallel Programs | 112 | |
| | 7.2 | Correc | ctness of Parallel Programs | 113 | |
| | | 7.2.1 | Ghost Variables | 113 | |
| | | 7.2.2 | while Programs | 115 | |
| | | 7.2.3 | Parallel Programs | | |
| | | 7.2.4 | Parallel Program Derived from a Rule Program | | |
| | | 7.2.5 | Rule Programs vs. Parallel Programs | | |

xiv Contents

| | 7.3 | Correct | tness of Nondeterministic Programs | 122 |
|-----|----------|------------|--|-----|
| | | 7.3.1 | Nondeterministic Programs | 123 |
| | | 7.3.2 | Nondeterministic Program Derived | |
| | | | from a Rule Program | 125 |
| | Refe | rences | | 127 |
| Par | t IV | Proof R | tules for Rule Programs | |
| | | | - | 131 |
| 8 | 8.1 | _ | n Rule Program Verification rence Cases in Rule Programs | 131 |
| | 0.1 | 8.1.1 | Cross-Rule Interference | 132 |
| | | 8.1.2 | Interference Due to Aliasing | 133 |
| | 8.2 | - | Rules | 135 |
| | 8.3 | | Proof Rule | 136 |
| | 8.4 | | | 141 |
| | 0.7 | 8.4.1 | Use the Proof Rule Bottom-Up | 141 |
| | | 8.4.2 | What to Look for | 142 |
| | | 8.4.3 | Application of the Verification Method | 143 |
| | 8.5 | | pleteness | 145 |
| | | | | 148 |
| 9 | A V | rificatio | n Method for Rule Programs | 149 |
| | 9.1 | | Eligibility into Account | 149 |
| | , | 9.1.1 | Eligibility Ghost Variables | 149 |
| | | 9.1.2 | Eligibility-Aware Assertions | 151 |
| | | 9.1.3 | Eligibility-Aware Execution | 152 |
| | | 9.1.4 | Eligibility-Aware Correctness Formulas | 156 |
| | 9.2 | | rence Freedom | 158 |
| | | 9.2.1 | Cross-Rule Interference | 158 |
| | | 9.2.2 | Interference Due to Aliasing | 159 |
| | 9.3 | Genera | al Proof Rule | 160 |
| | 9.4 | Relativ | ve Completeness | 165 |
| | 9.5 | | cation of the Verification Method | 173 |
| | | 9.5.1 | Approach | 173 |
| | | 9.5.2 | Example | 175 |
| | Refe | erences | | 183 |
| 10 | Spe | cialized I | Proof Rules | 185 |
| | 10.1 | Eligib | ility-Aware Unary Rules | 185 |
| | | 10.1.1 | Proof Rule | 186 |
| | | 10.1.2 | Example | 189 |
| | 10.2 | Aliasii | ng-Free n-ary Rule Programs | 194 |
| | 10.3 | | ntness in Rule Programs | |
| | | 10.3.1 | · · · · · · · · · · · · · · · · · · · | |
| | | 10.3.2 | Disjoint Rule Programs | 200 |
| | Refe | erences | | 201 |

Contents xv

| 11 | Conc | lusion | | 203 |
|-----|---------|---|-------------------|-----|
| | 11.1 | Modeling an Industrial Product | | 204 |
| | 11.2 | Local vs. Global: What Is a State? | | 204 |
| | 11.3 | Are Rule Programs Magical? | | 205 |
| | 11.4 | From Local to Global | | 206 |
| | 11.5 | Possible Directions of Extension | | 207 |
| | | 11.5.1 Propose an Algorithm | | 207 |
| | | 11.5.2 Study More General Rule Prog | rams | 207 |
| | | 11.5.3 Study Other Properties | | 208 |
| | | 11.5.4 Leverage Program Analysis an | | |
| | | Techniques | | 209 |
| | Refer | rences | | 209 |
| A | Verif | ication in an Industrial Business Rules | Management System | 211 |
| А | A.1 | Preliminaries | - | 211 |
| | 7 1. 1 | A.1.1 Rule Static Analysis Features . | | 211 |
| | | A.1.2 Notations | | 212 |
| | A.2 | Rule Applicability | | 214 |
| | 11.2 | A.2.1 Rule May Apply When | | 214 |
| | | A.2.2 Rule Is Never Applicable | | 216 |
| | A.3 | Impact Analysis | | 216 |
| | 11.5 | A.3.1 Rule May Lead to a State Whe | | 217 |
| | | A.3.2 Rule May Enable | | 218 |
| | | A.3.3 Rule May Become Applicable | | 220 |
| | A.4 | Redundancy | | 221 |
| | 7 | A.4.1 Equivalent Rules | | 221 |
| | | A.4.2 Redundant Rules | | 221 |
| | A.5 | Confluence and Completeness | | 222 |
| | 11.0 | A.5.1 Conflicting Rules | | 222 |
| | | A.5.2 Completeness Analysis | | 224 |
| | A.6 | Safety | | 225 |
| | | A.6.1 Rule May Have an Unsafe Exe | | 225 |
| | A.7 | Discussion | | 226 |
| | | rences | | 227 |
| | | | | |
| Lis | t of Pr | oof Rules | | 229 |
| Inc | lex | | | 231 |
| | | | | |