

# Contents

1. Introduction . . . . .	1
1.1 Formal Methods . . . . .	2
1.2 Developing and Acquiring Formal Methods . . . . .	5
1.3 Using Formal Methods . . . . .	7
1.4 Applying Formal Methods . . . . .	9
1.5 Overview of the Book . . . . .	11
2. Preliminaries . . . . .	13
2.1 Set Notation . . . . .	13
2.2 Strings and Languages . . . . .	15
2.3 Graphs . . . . .	16
2.4 Computational Complexity and Computability . . . . .	20
2.5 Further Reading . . . . .	27
3. Logic and Theorem Proving . . . . .	29
3.1 First Order Logic . . . . .	29
3.2 Terms . . . . .	30
3.3 First Order Formulas . . . . .	33
3.4 Propositional Logic . . . . .	39
3.5 Proving First Order Logic Formulas . . . . .	39
3.6 Properties of Proof Systems . . . . .	43
3.7 Proving Propositional Logic Properties . . . . .	46
3.8 A Practical Proof System . . . . .	47
3.9 Example Proofs . . . . .	50
3.10 Machine Assisted Proofs . . . . .	59
3.11 Mechanized Theorem Provers . . . . .	61
3.12 Further Reading . . . . .	61
4. Modeling Software Systems . . . . .	63
4.1 Sequential, Concurrent and Reactive Systems . . . . .	64
4.2 States . . . . .	67
4.3 State Spaces . . . . .	68
4.4 Transition Systems . . . . .	71
4.5 Granularity of Transitions . . . . .	75

4.6 Examples of Modeling Programs .....	77
4.7 Nondeterministic Transitions .....	85
4.8 Assigning Propositional Variables to States .....	86
4.9 Combining State Spaces .....	88
4.10 The Linear View .....	90
4.11 The Branching View .....	91
4.12 Fairness .....	92
4.13 The Partial Order View .....	98
4.14 Modeling Formalisms .....	107
4.15 A Modeling Project .....	109
4.16 Further Reading .....	110
<b>5. Formal Specification .....</b>	<b>113</b>
5.1 Properties of Specification Formalisms .....	114
5.2 Linear Temporal Logic .....	116
5.3 Axiomatizing LTL .....	121
5.4 Examples of LTL Specification .....	123
5.5 Automata on Infinite Words .....	127
5.6 Specification using Büchi-automata .....	129
5.7 Deterministic Büchi Automata .....	132
5.8 Alternative Specification Formalisms .....	133
5.9 Complicated Specifications .....	136
5.10 Completeness of Specification .....	136
5.11 Further Reading .....	138
<b>6. Automatic Verification .....</b>	<b>139</b>
6.1 State Space Search .....	140
6.2 Representing States .....	143
6.3 The Automata Framework .....	143
6.4 Combining Büchi Automata .....	145
6.5 Complementing a Büchi Automaton .....	151
6.6 Checking Emptiness .....	152
6.7 A Model Checking Example .....	154
6.8 Translating LTL into Automata .....	156
6.9 The Complexity of Model Checking .....	164
6.10 Representing Fairness .....	169
6.11 Checking the LTL Specifications .....	170
6.12 Safety Properties .....	171
6.13 The State Space Explosion Problem .....	172
6.14 Advantages of Model Checking .....	174
6.15 Weaknesses of Model Checking .....	174
6.16 Selecting Automatic Verification Tools .....	175
6.17 Model Checking Projects .....	175
6.18 Model Checking Tools .....	176
6.19 Further Reading .....	177

<b>7. Deductive Software Verification . . . . .</b>	179
7.1 Verification of Flow Chart Programs . . . . .	180
7.2 Verification with Array Variables . . . . .	187
7.3 Total Correctness . . . . .	190
7.4 Axiomatic Program Verification . . . . .	195
7.5 Verification of Concurrent Programs . . . . .	202
7.6 Advantages of Deductive Verification . . . . .	207
7.7 Weaknesses of Deductive verification . . . . .	208
7.8 Soundness and Completeness of Proof Systems . . . . .	210
7.9 Compositionality . . . . .	212
7.10 Deductive Verification Tools . . . . .	213
7.11 Further Reading . . . . .	213
<b>8. Process Algebra and Equivalences . . . . .</b>	215
8.1 Process Algebras . . . . .	217
8.2 A Calculus of Communicating Systems . . . . .	218
8.3 An Example: Dekker's Algorithm . . . . .	225
8.4 Modeling Issues . . . . .	229
8.5 Equivalences between Agents . . . . .	230
8.5.1 Trace equivalence . . . . .	231
8.5.2 Failure equivalence . . . . .	232
8.5.3 Simulation Equivalence . . . . .	233
8.5.4 Bisimulation and Weak Bisimulation equivalence . . . . .	235
8.6 A Hierarchy of Equivalence Relations . . . . .	237
8.7 Studying Concurrency using Process Algebra . . . . .	238
8.8 Calculating Bisimulation Equivalence . . . . .	242
8.9 LOTOS . . . . .	245
8.10 Process Algebra Tools . . . . .	247
8.11 Further Reading . . . . .	247
<b>9. Software Testing . . . . .</b>	249
9.1 Inspections and Walkthroughs . . . . .	251
9.2 Control Flow Coverage Criteria . . . . .	253
9.3 Dataflow Coverage Criteria . . . . .	259
9.4 Propagating path conditions . . . . .	261
9.5 Equivalence Partition . . . . .	267
9.6 Preparing the Code for Testing . . . . .	267
9.7 Checking the Test Suite . . . . .	269
9.8 Compositionality . . . . .	270
9.9 Black Box Testing . . . . .	272
9.10 Probabilistic Testing . . . . .	275
9.11 Advantages of Testing . . . . .	276
9.12 Disadvantages of Testing . . . . .	277
9.13 Testing Tools . . . . .	278
9.14 Further Reading . . . . .	278

<b>10. Combining Formal Methods</b>	279
10.1 Abstraction	279
10.2 Combining Testing and Model Checking	286
10.2.1 Direct Checking	286
10.2.2 Black Box Systems	287
10.2.3 Combination Lock Automata	288
10.2.4 Black Box Deadlock Detection	289
10.2.5 Conformance Testing	290
10.2.6 Checking the Reliability of Resets	294
10.2.7 Black Box Checking	294
10.3 The Cleanroom Method	297
<b>11. Visualization</b>	299
11.1 Using Visualizations for Formal Methods	300
11.2 Message Sequence Charts	300
11.3 Visualizing Flowcharts and State Machines	305
11.4 Hierarchical State Graphs	308
11.5 Visualizing Program Text	312
11.6 Petri Nets	312
11.7 Visualization Tools	314
11.8 Further Reading	316
<b>12. Conclusions</b>	317
<b>References</b>	321
<b>Index</b>	329