

# **On the Foundations of Computing**

GIUSEPPE PRIMIERO

**OXFORD**  
UNIVERSITY PRESS

# Contents

<b>1</b>	<b>Introduction</b>	<b>1</b>
<b>Part I The Mathematical Foundation</b>		<b>5</b>
<b>2</b>	<b>A Fundamental Crisis</b>	<b>7</b>
2.1	The Foundations of Mathematics Debated	7
2.2	Logical Roots	8
2.3	Logicism	10
2.4	Finitism	15
2.5	Intuitionism	17
	<i>Exercises</i>	19
<b>3</b>	<b>Computing and Deciding</b>	<b>21</b>
3.1	Enumerability	21
3.2	Encoding	24
3.3	Diagonalization	25
3.4	The Decision Problem	27
	<i>Exercises</i>	28
<b>4</b>	<b>What is Computable?</b>	<b>31</b>
4.1	Mathematical Induction	31
4.2	Primitive Recursion	34
4.3	Partial Recursion	36
4.4	Church's Thesis	38
	<i>Exercises</i>	40
<b>5</b>	<b>Mechanical Computation</b>	<b>43</b>
5.1	Turing Computability	43
5.2	The Universal Machine	51
5.3	The Halting Problem	54
5.4	Turing's Thesis	56
	<i>Exercises</i>	63

<b>6</b>	<b>On the Nature of Algorithms</b>	<b>65</b>
6.1	Fast Backwards	65
6.2	Intuitive Explanation	69
6.3	Algorithms as Specifications	72
6.4	Algorithms as Procedures	73
6.5	Algorithms as Abstract Machines	74
6.6	Equivalent Algorithms	76
	<i>Exercises</i>	80
<b>7</b>	<b>Computing as a Mathematical Discipline</b>	<b>81</b>
7.1	Proofs as Programs	81
7.2	Program Correctness	88
7.3	The Debate	100
7.4	Formal Computational Validity	107
	<i>Exercises</i>	114
<b>Part II The Engineering Foundation</b>		<b>115</b>
<b>8</b>	<b>The First Generation of Computers</b>	<b>117</b>
8.1	Shannon's Circuits	117
8.2	Early Memories	122
8.3	von Neumann Design	130
8.4	Universality and All-purposefulness	136
	<i>Exercises</i>	140
<b>9</b>	<b>The Laws of Evolution</b>	<b>143</b>
9.1	Computing grows	143
9.2	New Memories	144
9.3	Miniaturization, Parallelism, and Compatibility	151
9.4	The First Law	156
9.5	Computational Growth	161
	<i>Exercises</i>	170
<b>10</b>	<b>Properties of Implemented Computations</b>	<b>171</b>
10.1	Physical Computing	171
10.2	Functionality	176
10.3	Usability	181
10.4	Efficiency	184
10.5	Limits of the Church-Turing Thesis	186
	<i>Exercises</i>	187
<b>11</b>	<b>Specification and Implementation</b>	<b>189</b>
11.1	The Debate on Implementation	189
11.2	Correct Implementations	193
11.3	Miscomputation	196
	<i>Exercises</i>	198

<b>12</b>	<b>Computing as an Engineering Discipline</b>	199
12.1	Software Engineering	199
12.2	The Debate	206
12.3	Physical Computational Validity	209
	<i>Exercises</i>	213
<b>Part III The Experimental Foundation</b>		<b>215</b>
<b>13</b>	<b>Elements of Experimental Computing</b>	217
13.1	Experimental Computer Science	217
13.2	On Computational Hypotheses	222
13.3	On Computational Experiments	226
	<i>Exercises</i>	230
<b>14</b>	<b>Models and Simulations</b>	231
14.1	On Models	231
14.2	On Computer Simulations	235
14.3	Epistemic Role of Computer Simulations	238
	<i>Exercises</i>	240
<b>15</b>	<b>Formal Relations</b>	241
15.1	Identity and Dependence	241
15.2	Isomorphism	244
15.3	Analogy and Similarity	246
15.4	Variants of Simulationism	248
	<i>Exercises</i>	254
<b>16</b>	<b>Computing as an Experimental Discipline</b>	255
16.1	A Balanced Approach	255
16.2	Evaluation	256
16.3	Maximal Criteria: Robustness and Reliability	262
16.4	Minimal Criteria: Usability and Fitness	265
16.5	Experimental Computational Validity	267
	<i>Exercises</i>	269
<b>17</b>	<b>Conclusion</b>	271
	<i>Bibliography</i>	273
	<i>Index</i>	293