Contents

Prologue 1

1 Can a computer have a mind? 3
- Introduction 3
- The Turing test 5
- Artificial intelligence 11
- An AI approach to 'pleasure' and 'pain' 14
- Strong AI and Searle's Chinese room 17
- Hardware and software 23

2 Algorithms and Turing machines 30
- Background to the algorithm concept 30
- Turing's concept 35
- Binary coding of numerical data 42
- The Church–Turing Thesis 47
- Numbers other than natural numbers 49
- The universal Turing machine 51
- The insolubility of Hilbert's problem 57
- How to outdo an algorithm 64
- Church's lambda calculus 66

3 Mathematics and reality 74
- The land of Tor'Bled-Nam 74
- Real numbers 80
- How many real numbers are there? 82
- 'Reality' of real numbers 86
- Complex numbers 87
- Construction of the Mandelbrot set 92
- Platonic reality of mathematical concepts? 94

4 Truth, proof, and insight 99
- Hilbert's programme for mathematics 99
- Formal mathematical systems 102
- Gödel's theorem 105
- Mathematical insight 108
- Platonism or intuitionism? 112
- Gödel-type theorems from Turing's result 116
- Recursively enumerable sets 118
- Is the Mandelbrot set recursive? 124
- Some examples of non-recursive mathematics 129
- Is the Mandelbrot set like non-recursive mathematics? 138
- Complexity theory 140
- Complexity and computability in physical things 145

5 The classical world 149
The status of physical theory 149
Euclidean geometry 156
The dynamics of Galileo and Newton 162
The mechanistic world of Newtonian dynamics 167
Is life in the billiard-ball world computable? 170
Hamiltonian mechanics 174
Phase space 176
Maxwell's electromagnetic theory 184
Computability and the wave equation 187
The Lorentz equation of motion; runaway particles 188
The special relativity of Einstein and Poincaré 191
Einstein's general relativity 202
Relativistic causality and determinism 211
Computability in classical physics: where do we stand? 216
Mass, matter, and reality 217

6 Quantum magic and quantum mystery 225
Do philosophers need quantum theory? 225
Problems with classical theory 228
The beginnings of quantum theory 230
The two-slit experiment 231
Probability amplitudes 236
The quantum state of a particle 243
The uncertainty principle 248
The evolution procedures **U** and **R** 250
Particles in two places at once? 251
Hilbert space 257
Measurements 260
Spin and the Riemann sphere of states 264
Objectivity and measurability of quantum states 268
Copying a quantum state 269
Photon spin 270
Objects with large spin 273
Many-particle systems 275
The 'paradox' of Einstein, Podolsky, and Rosen 279
Experiments with photons: a problem for relativity? 286
Schrödinger's equation; Dirac's equation 288
Quantum field theory 289
Schrödinger's cat 290
Various attitudes in existing quantum theory 293
Where does all this leave us? 296

7 Cosmology and the arrow of time 302
The flow of time 302
The inexorable increase of entropy 304
What is entropy? 309
The second law in action 314
The origin of low entropy in the universe 317
Cosmology and the big bang 322

The primordial fireball 326
Does the big bang explain the second law? 328
Black holes 330
The structure of space–time singularities 335
How special was the big bang? 339

8 In search of quantum gravity 348
Why quantum gravity? 348
What lies behind the Weyl curvature hypothesis? 350
Time-asymmetry in state-vector reduction 354
Hawking's box: a link with the Weyl curvature hypothesis? 359
When does the state-vector reduce? 367

9 Real brains and model brains 374
What are brains actually like? 374
Where is the seat of consciousness? 381
Split-brain experiments 384
Blindsight 386
Information processing in the visual cortex 387
How do nerve signals work? 389
Computer models 392
Brain plasticity 396
Parallel computers and the 'oneness' of consciousness 398
Is there a role for quantum mechanics in brain activity? 400
Quantum computers 401
Beyond quantum theory? 402

10 Where lies the physics of mind? 405
What are minds for? 405
What does consciousness actually do? 409
Natural selection of algorithms? 414
The non-algorithmic nature of mathematical insight 416
Inspiration, insight, and originality 418
Non-verbality of thought 423
Animal consciousness? 425
Contact with Plato's world 426
A view of physical reality 429
Determinism and strong determinism 431
The anthropic principle 433
Tilings and quasicrystals 434
Possible relevance to brain plasticity 437
The time-delays of consciousness 439
The strange role of time in conscious perception 442
Conclusion: a child's view 447

Epilogue 451

References 452

Index 461