

CONTENTS IN DETAIL

ACKNOWLEDGMENTS	xvii
------------------------	-------------

INTRODUCTION	xix
---------------------	------------

Who Is This Book For?	xx
How Much Math and Science Do I Need?	xx
How Much Programming Do I Need?	xxi
Book Overview	xxi
Teaching Modeling	xxii
Getting Started	xxii
Installing Python	xxiii
Running Jupyter	xxiii
Suggestions and Corrections	xxiv

PART I DISCRETE SYSTEMS

1	INTRODUCTION TO MODELING	3
----------	---------------------------------	----------

The Modeling Framework	3
Testing the Falling Penny Myth	5
Computation in Python	6
False Precision	7
Computation with Units	8
Summary	10
Exercises	11

2	MODELING A BIKE SHARE SYSTEM	15
----------	-------------------------------------	-----------

Our Bike Share Model	15
Defining Functions	17
Print Statements	18
if Statements	19
Parameters	21
for Loops	22
TimeSeries	22
Plotting	24

Summary	24
Exercises	25
Under the Hood	25

3 **ITERATIVE MODELING** **27**

Iterating on Our Bike Share Model	27
Using More Than One State Object	28
Documentation	29
Dealing with Negative Bikes	30
Comparison Operators.....	31
Introducing Metrics	32
Summary	33
Exercises	33

4 **PARAMETERS AND METRICS** **35**

Functions That Return Values	35
Loops and Arrays.....	37
Sweeping Parameters	38
Incremental Development.....	40
Summary	40
Exercises	41
Challenge Exercises	41
Under the Hood	42

5 **BUILDING A POPULATION MODEL** **43**

Exploring the Data	44
Absolute and Relative Errors	47
Modeling Population Growth	48
Simulating Population Growth	50
Summary	51
Exercise	52

6 **ITERATING THE POPULATION MODEL** **53**

System Objects.....	53
A Proportional Growth Model	56
Factoring Out the Update Function	57

Combining Birth and Death	58
Summary	59
Exercise	59
Under the Hood	59

7 LIMITS TO GROWTH 61

Quadratic Growth	62
Net Growth	63
Finding Equilibrium	65
Dysfunctions	65
Summary	68
Exercises	68

8 PROJECTING INTO THE FUTURE 69

Generating Projections	69
Comparing Projections	72
Summary	74
Exercise	74

9 ANALYSIS AND SYMBOLIC COMPUTATION 79

Difference Equations	79
Differential Equations	80
Analysis and Simulation	82
Analysis with WolframAlpha	83
Analysis with SymPy	83
Differential Equations in SymPy	84
Solving the Quadratic Growth Model	86
Summary	87
Exercises	88

10 CASE STUDIES PART I 89

Historical World Population	89
One Queue or Two?	90
Predicting Salmon Populations	91
Tree Growth	91

PART II **FIRST-ORDER SYSTEMS**

11	EPIDEMIOLOGY AND SIR MODELS	95
The Freshman Plague	95	
The Kermack-McKendrick Model	96	
The KM Equations	97	
Implementing the KM Model	98	
The Update Function	99	
Running the Simulation	100	
Collecting the Results	101	
Now with a TimeFrame	103	
Summary	104	
Exercise	104	
12	QUANTIFYING INTERVENTIONS	105
The Effects of Immunization	105	
Choosing Metrics	107	
Sweeping Immunization	108	
Summary	110	
Exercise	110	
13	SWEEPING PARAMETERS	111
Sweeping Beta	111	
Sweeping Gamma	113	
Using a SweepFrame	114	
Summary	117	
Exercise	118	
14	NONDIMENSIONALIZATION	119
Beta and Gamma	119	
Exploring the Results	120	
Contact Number	122	
Comparing Analysis and Simulation	123	
Estimating the Contact Number	124	
Summary	125	
Exercises	125	
Under the Hood	126	

15 127

Thermal Systems	127
The Coffee Cooling Problem	127
Temperature and Heat	128
Heat Transfer	129
Newton's Law of Cooling	129
Implementing Newtonian Cooling	130
Finding Roots	134
Estimating r	135
Summary	136
Exercises	136

16 137

SOLVING THE COFFEE PROBLEM

Mixing Liquids	138
Mix First or Last?	139
Optimal Timing	140
The Analytic Solution	141
Summary	143
Exercises	143

17 145

MODELING BLOOD SUGAR

The Minimal Model	146
The Glucose Minimal Model	146
Getting the Data	148
Interpolation	149
Summary	150
Exercises	151

18 153

IMPLEMENTING THE MINIMAL MODEL

Implementing the Model	154
The Update Function	154
Running the Simulation	156
Solving Differential Equations	158
Summary	162
Exercise	162

19 163

CASE STUDIES PART II

Revisiting the Minimal Model	163
The Insulin Minimal Model	164

Low-Pass Filter	164
Thermal Behavior of a Wall	166
HIV	167

PART III SECOND-ORDER SYSTEMS

20 THE FALLING PENNY REVISITED 171

Newton's Second Law of Motion	171
Dropping Pennies	172
Event Functions	175
Summary	176
Exercise	176

21 DRAG 177

Calculating Drag Force	177
The Params Object	179
Simulating the Penny Drop	180
Summary	183
Exercises	183

22 TWO-DIMENSIONAL MOTION 185

Assumptions and Decisions	185
Vectors	186
Simulating Baseball Flight	189
Drag Force	191
Adding an Event Function	192
Visualizing Trajectories	194
Animating the Baseball	196
Summary	196
Exercises	196

23 OPTIMIZATION 199

The Manny Ramirez Problem	200
Finding the Range	201
Summary	203
Exercise	204
Under the Hood	204

24		
ROTATION		205
The Physics of Toilet Paper	206	
Setting Parameters	207	
Simulating the System	208	
Plotting the Results	210	
The Analytic Solution	212	
Summary	213	
Exercise	214	
25		
TORQUE		215
Angular Acceleration	215	
Moment of Inertia	216	
Teapots and Turntables	216	
Two-Phase Simulation	219	
Phase 1	220	
Phase 2	220	
Combining the Results	221	
Estimating Friction	223	
Animating the Turntable	225	
Summary	226	
Exercise	226	
26		
CASE STUDIES PART III		227
Bungee Jumping	227	
Bungee Dunk Revisited	228	
Orbiting the Sun	229	
Spider-Man	229	
Kittens	230	
Simulating a Yo-Yo	231	
Congratulations	233	
APPENDIX: UNDER THE HOOD		235
How <code>run_solve_ivp</code> Works	236	
How <code>root_scalar</code> Works	239	
How <code>maximize_scalar</code> Works	240	
INDEX		243