

# From Mathematics to Generic Programming

# From Mathematics to Generic Programming

# **Table of Contents**

Cover

Title Page

Copyright Page

Contents

Acknowledgments

About the Authors

Authors' Note

- 1 What This Book Is About
  - 1.1 Programming and Mathematics
  - 1.2 A Historical Perspective
  - 1.3 Prerequisites
  - 1.4 Roadmap
- 2 The First Algorithm
  - 2.1 Egyptian Multiplication
  - 2.2 Improving the Algorithm
  - 2.3 Thoughts on the Chapter
- 3 Ancient Greek Number Theory
  - 3.1 Geometric Properties of Integers
  - 3.2 Sifting Primes
  - 3.3 Implementing and Optimizing the Code



- 3.4 Perfect Numbers
- 3.5 The Pythagorean Program
- 3.6 A Fatal Flaw in the Program
- 3.7 Thoughts on the Chapter

### 4 Euclid's Algorithm

- 4.1 Athens and Alexandria
- 4.2 Euclid's Greatest Common Measure Algorithm
- 4.3 A Millennium without Mathematics
- 4.4 The Strange History of Zero
- 4.5 Remainder and Quotient Algorithms
- 4.6 Sharing the Code
- 4.7 Validating the Algorithm
- 4.8 Thoughts on the Chapter

# 5 The Emergence of Modern Number Theory

- 5.1 Mersenne Primes and Fermat Primes
- 5.2 Fermat's Little Theorem
- 5.3 Cancellation
- 5.4 Proving Fermat's Little Theorem
- 5.5 Euler's Theorem
- 5.6 Applying Modular Arithmetic
- 5.7 Thoughts on the Chapter

#### 6 Abstraction in Mathematics

- 6.1 Groups
- 6.2 Monoids and Semigroups
- 6.3 Some Theorems about Groups
- 6.4 Subgroups and Cyclic Groups



- 6.5 Lagrange's Theorem
- 6.6 Theories and Models
- 6.7 Examples of Categorical and Non-categorical Theories
- 6.8 Thoughts on the Chapter

# 7 Deriving a Generic Algorithm

- 7.1 Untangling Algorithm Requirements
- 7.2 Requirements on A
- 7.3 Requirements on N
- 7.4 New Requirements
- 7.5 Turning Multiply into Power
- 7.6 Generalizing the Operation
- 7.7 Computing Fibonacci Numbers
- 7.8 Thoughts on the Chapter

# 8 More Algebraic Structures

- 8.1 Stevin, Polynomials, and GCD
- 8.2 Göttingen and German Mathematics
- 8.3 Noether and the Birth of Abstract Algebra
- 8.4 Rings
- 8.5 Matrix Multiplication and Semirings
- 8.6 Application: Social Networks and Shortest Paths
- 8.7 Euclidean Domains
- 8.8 Fields and Other Algebraic Structures
- 8.9 Thoughts on the Chapter

# 9 Organizing Mathematical Knowledge

9.1 Proofs



- 9.2 The First Theorem
- 9.3 Euclid and the Axiomatic Method
- 9.4 Alternatives to Euclidean Geometry
- 9.5 Hilbert's Formalist Approach
- 9.6 Peano and His Axioms
- 9.7 Building Arithmetic
- 9.8 Thoughts on the Chapter

# 10 Fundamental Programming Concepts

- 10.1 Aristotle and Abstraction
- 10.2 Values and Types
- 10.3 Concepts
- 10.4 Iterators
- 10.5 Iterator Categories, Operations, and Traits
- 10.6 Ranges
- 10.7 Linear Search
- 10.8 Binary Search
- 10.9 Thoughts on the Chapter

# 11 Permutation Algorithms

- 11.1 Permutations and Transpositions
- 11.2 Swapping Ranges
- 11.3 Rotation
- 11.4 Using Cycles
- 11.5 Reverse
- 11.6 Space Complexity
- 11.7 Memory-Adaptive Algorithms
- 11.8 Thoughts on the Chapter



#### 12 Extensions of GCD

- 12.1 Hardware Constraints and a More Efficient Algorithm
- 12.2 Generalizing Stein's Algorithm
- 12.3 Bézout's Identity
- 12.4 Extended GCD
- 12.5 Applications of GCD
- 12.6 Thoughts on the Chapter

### 13 A Real-World Application

- 13.1 Cryptology
- 13.2 Primality Testing
- 13.3 The Miller-Rabin Test
- 13.4 The RSA Algorithm: How and Why It Works
- 13.5 Thoughts on the Chapter

#### 14 Conclusions

Further Reading

A: Notation

### **B:** Common Proof Techniques

- **B.1 Proof by Contradiction**
- **B.2 Proof by Induction**
- B.3 The Pigeonhole Principle

### C: C++ for Non-C++ Programmers

- C.1 Template Functions
- C.2 Concepts
- C.3 Declaration Syntax and Typed Constants
- C.4 Function Objects



- C.5 Preconditions, Postconditions, and Assertions
- C.6 STL Algorithms and Data Structures
- C.7 Iterators and Ranges
- C.8 Type Aliases and Type Functions with using in C++11
- C.9 Initializer Lists in C++11
- C.10 Lambda Functions in C++11
- C.11 A Note about inline

Bibliography

Index