

# CONTENTS IN DETAIL

## INTRODUCTION

xvii

## PART I: EMBEDDED PROGRAMMING

1

### 1

#### HELLO WORLD

3

Installing GCC . . . . .	4
Downloading System Workbench for STM32 . . . . .	4
Our First Program . . . . .	5
Compiling the Program . . . . .	5
Making Mistakes . . . . .	6
Understanding the Program . . . . .	7
Adding Comments . . . . .	8
Improving the Program and Build Process . . . . .	9
The make Program . . . . .	9
Compiler Flags . . . . .	10
How the Compiler Works Behind the Scenes . . . . .	10
The Preprocessor . . . . .	12
The Compiler . . . . .	12
The Assembler . . . . .	12
The Linker . . . . .	14
Adding to Your Makefile . . . . .	15
Summary . . . . .	16
Questions . . . . .	17

### 2

#### INTRODUCTION TO THE INTEGRATED DEVELOPMENT ENVIRONMENT

19

Using System Workbench for STM32 . . . . .	20
Starting the IDE . . . . .	20
Creating Hello World . . . . .	21
Debugging the Program . . . . .	26
What the IDE Did for Us . . . . .	30
Importing the Book's Programming Examples . . . . .	31
Summary . . . . .	31

Programming Problems . . . . .	32
Questions . . . . .	32

### **3 PROGRAMMING THE MICROCONTROLLER 33**

The NUCLEO-F030R8 Development Board . . . . .	34
Programming and Debugging the Board . . . . .	34
Setting Up the Board . . . . .	35
Setting Up an Embedded Project . . . . .	37
Your First Embedded Program . . . . .	40
Initializing the Hardware . . . . .	41
Programming a GPIO Pin . . . . .	41
Toggling the LED . . . . .	42
Building the Completed Program . . . . .	43
Exploring the Build Process . . . . .	44
Exploring the Project Files . . . . .	46
Debugging the Application . . . . .	47
Stepping Through the Program . . . . .	50
Summary . . . . .	51
Programming Problems . . . . .	52
Questions . . . . .	52

### **4 NUMBERS AND VARIABLES 53**

Working with Integers . . . . .	54
Declaring Variables to Hold Integers . . . . .	55
Assigning Values to Variables . . . . .	56
Initializing Variables . . . . .	56
Integer Sizes and Representations . . . . .	57
Number Representations . . . . .	59
Standard Integers . . . . .	61
Unsigned Integer Types . . . . .	62
Overflow . . . . .	63
Two's Complement Representation in Signed Integer Types . . . . .	64
Shorthand Operators . . . . .	65
Controlling Memory-Mapped I/O Registers Using Bit Operations . . . . .	67
OR . . . . .	67
AND . . . . .	68
NOT . . . . .	68
Exclusive OR . . . . .	69
Shifting . . . . .	69
Defining the Meaning of Bits . . . . .	70
Setting the Values of Two Bits at Once . . . . .	72
Turning Off a Bit . . . . .	72
Checking the Values of Bits . . . . .	72
Summary . . . . .	75
Programming Problems . . . . .	75

**5** **DECISION AND CONTROL STATEMENTS** **77**

The if Statement . . . . . 77  
The if/else Statement . . . . . 79  
Looping Statements . . . . . 80  
    The while Loop . . . . . 80  
    The for Loop . . . . . 82  
Using the Button . . . . . 83  
    Initialization . . . . . 84  
    Choosing a Pulldown Circuit . . . . . 85  
    Getting the State of the Button. . . . . 86  
    Running the Program . . . . . 87  
Loop Control . . . . . 87  
    The break Statement . . . . . 87  
    The continue Statement . . . . . 88  
Anti-patterns . . . . . 88  
    The Empty while Loop . . . . . 89  
    Assignment in while. . . . . 89  
Summary . . . . . 90  
Programming Problems . . . . . 90

**6** **ARRAYS, POINTERS, AND STRINGS** **91**

Arrays . . . . . 92  
    Under the Hood: Pointers . . . . . 94  
    Array and Pointer Arithmetic. . . . . 97  
    Array Overflow. . . . . 98  
Characters and Strings . . . . . 100  
Summary . . . . . 102  
Programming Problems . . . . . 103

**7** **LOCAL VARIABLES AND PROCEDURES** **105**

Local Variables . . . . . 106  
Hidden Variables . . . . . 107  
Procedures . . . . . 108  
Stack Frames . . . . . 109  
Recursion . . . . . 112  
Programming Style . . . . . 114  
Summary . . . . . 114  
Programming Problems . . . . . 115

**8** **COMPLEX DATA TYPES** **117**

Enums. . . . . 118  
Preprocessor Tricks and Enums. . . . . 119  
Structures . . . . . 121  
    Structures in Memory. . . . . 122  
    Accessing Unaligned Data . . . . . 125

Structure Initialization . . . . .	127
Structure Assignment . . . . .	128
Structure Pointers . . . . .	128
Structure Naming . . . . .	129
Unions . . . . .	130
Creating a Custom Type . . . . .	132
Structures and Embedded Programming . . . . .	133
typedef . . . . .	135
Function Pointers and typedef . . . . .	136
typedef and struct . . . . .	137
Summary . . . . .	137
Programming Problems . . . . .	138

**9 SERIAL OUTPUT ON THE STM 141**

Writing a String One Character at a Time . . . . .	142
Defining Our Own putchar . . . . .	142
Serial Output . . . . .	143
A Brief History of Serial Communications . . . . .	145
Serial Hello World! . . . . .	147
UART Initialization . . . . .	147
Transmitting a Character . . . . .	150
Communicating with the Device . . . . .	156
Windows . . . . .	156
Linux and macOS . . . . .	158
Summary . . . . .	158
Programming Problems . . . . .	159

**10 INTERRUPTS 161**

Polling vs. Interrupts . . . . .	161
Interrupts for Serial I/O . . . . .	162
Interrupt Routines . . . . .	163
Writing a String with Interrupts . . . . .	164
Program Details . . . . .	167
Interrupt Hell . . . . .	171
Using a Buffer to Increase Speed . . . . .	172
Sending Function . . . . .	173
Interrupt Routine . . . . .	174
Full Program . . . . .	174
The Problem . . . . .	177
Summary . . . . .	182
Programming Problems . . . . .	182

**11 THE LINKER 183**

The Linker's Job . . . . .	184
Compilation and Linking Memory Models . . . . .	185
The Ideal C Model . . . . .	185
Nonstandard Sections . . . . .	190

The Linking Process . . . . .	191
Symbols Defined by the Linker . . . . .	192
Relocation and Linking Object Files . . . . .	192
The Linker Map . . . . .	193
Advanced Linker Usage . . . . .	195
Flash Memory for “Permanent” Storage . . . . .	195
Multiple Configuration Items . . . . .	202
Field Customization Example . . . . .	203
Firmware Upgrade . . . . .	204
Summary . . . . .	204
Programming Problems . . . . .	205

## **12 THE PREPROCESSOR 207**

Simple Macros . . . . .	208
Parameterized Macros . . . . .	210
Code Macros . . . . .	211
Conditional Compilation . . . . .	214
Where Symbols Get Defined . . . . .	216
Command Line Symbols . . . . .	216
Predefined Symbols . . . . .	217
Include Files . . . . .	217
Other Preprocessor Directives . . . . .	217
Preprocessor Tricks . . . . .	218
Summary . . . . .	219
Programming Problems . . . . .	220

## **PART II: C FOR BIG MACHINES 221**

### **13 DYNAMIC MEMORY 223**

Basic Heap Allocation and Deallocation . . . . .	224
Linked Lists . . . . .	226
Adding a Node . . . . .	227
Printing the Linked List . . . . .	229
Deleting a Node . . . . .	230
Putting It All Together . . . . .	231
Dynamic Memory Problems . . . . .	233
Valgrind and the GCC Address Sanitizer . . . . .	234
Summary . . . . .	236
Programming Problems . . . . .	236

### **14 BUFFERED FILE I/O 237**

The printf Function . . . . .	238
Writing the ASCII Table . . . . .	239
Writing to Predefined Files . . . . .	240

Reading Data . . . . .	240
The Evil gets Function . . . . .	241
Opening Files . . . . .	242
Binary I/O . . . . .	244
Copying a File. . . . .	244
Buffering and Flushing . . . . .	246
Closing Files . . . . .	247
Summary . . . . .	247
Programming Problems. . . . .	248

**15**  
**COMMAND LINE ARGUMENTS AND RAW I/O** **249**

Command Line Arguments. . . . .	249
Raw I/O. . . . .	250
Using Raw I/O. . . . .	251
Using Binary Mode . . . . .	254
ioctl . . . . .	255
Summary . . . . .	255
Programming Problems. . . . .	256

**16**  
**FLOATING-POINT NUMBERS** **257**

What Is a Floating-Point Number? . . . . .	258
Floating-Point Types . . . . .	258
Automatic Conversions . . . . .	258
Problems with Floating-Point Numbers. . . . .	259
Rounding Errors . . . . .	259
Digits of Precision . . . . .	260
Infinity, NaN, and Subnormal Numbers . . . . .	260
Implementation . . . . .	262
Alternatives . . . . .	262
Summary . . . . .	265
Programming Problems. . . . .	266

**17**  
**MODULAR PROGRAMMING** **267**

Simple Modules . . . . .	268
Problems with the Simple Module . . . . .	269
Making the Module . . . . .	271
What Makes Good Modules . . . . .	272
Namespaces . . . . .	272
Libraries . . . . .	273
ranlib and Library Linking . . . . .	276
Deterministic vs. Nondeterministic Libraries . . . . .	278
Weak Symbols. . . . .	278
Summary . . . . .	280
Programming Problems. . . . .	280

<b>AFTERWORD</b>	<b>281</b>
Learn How to Write . . . . .	281
Learn How to Read. . . . .	282
Collaboration and Creative Theft . . . . .	282
Useful Open Source Tools . . . . .	282
Cppcheck . . . . .	283
Doxygen . . . . .	283
Valgrind. . . . .	283
SQLite . . . . .	284
Never Stop Learning. . . . .	284
 <b>APPENDIX: PROJECT CREATION CHECKLIST</b>	 <b>285</b>
Native C Project . . . . .	285
STM32 Workbench Embedded Project . . . . .	287
 <b>INDEX</b>	 <b>289</b>