Table of Contents

Chapter	1. See a Program Running	•••
1.1	Translate a C Program into a Machine Program	
1.2	Load a Machine Program into Memory	
1.2.	1 Harvard Architecture and Von Neumann Architecture	4
1.2.	2 Creating Runtime Memory Image	
1.3	Registers	. 1
1.3.	1 Reusing Registers to Improve Performance	. 1
1.3.	2 Processor Registers	. 1.
1.4	Executing a Machine Program	. 1
1.4.		
1.4.	2 Starting the Execution	. 1
1.4.	8	
1.5	Exercises	. 2
Chapter	2. Data Representation	. 2
2.1	Bit, Byte, Half-word, Word, and Double-word	. 2
2.2	Binary, Octal, Decimal, and Hexadecimal Numbers	
2.3	Unsigned Integers	. 2
2.4	Signed Integers	. 2
2.4.	1 Sign-and-Magnitude	. 3
2.4.	2 One's Complement	. 3
2.4.	3 Two's Complement	. 3
2.4.	4 Overflow Flag for Signed Addition or Subtraction	. 3
2.5	Character String	. 4
2.6	Exercises	. 5
Chapter	3. ARM Instruction Set Architecture	. 5
3.1	ARM Assembly Instruction Sets	. 5
3.2	ARM Cortex-M3 Organization	. 5
3.3	Going from C to Assembly	. 5
3.4	Assembly Instruction Format	. 6
3.5	Anatomy of an Assembly Program	
3.6	Assembly Directives	
3.7	Exercises	. 7
Chapter	4. Arithmetic and Logic	. 7
4.1	Program Status Register	.7
4.2	Updating Program Status Flags	
4.3	Shift and Rotate	. 7
4.4	Arithmetic Instructions	
4.5	Barrel Shifter	. 7

4.6	Bitwise Logic	80
4.7	Order of Bits and Bytes	
4.8	Sign and Zero Extension	
4.9	Data Comparison	
4.10	Data Movement Between Registers	
4.11	Exercises	
Chapte	er 5. Load and Store	91
5.1	Load Constant into Registers	91
	1.1 Data Movement Instruction MOV and MVN	
	1.2 Pseudo Instruction LDR and ADR	
5.	1.3 Comparison of LDR, ADR and MOV	
5.2	Big Endian and Little Endian	
5.3	Accessing Data in Memory	
5.4	Memory Addressing	95
5.4	4.1 Pre-index, Post-index, and Pre-index with Update	
5.4	4.2 Load and Store Instructions	97
5.4	4.3 PC-relative Addressing	98
5.4	4.4 Example of Accessing an Array	99
5.5	Exercises	100
Chapte	er 6. Branch and Conditional Execution	101
6.1	Condition Testing	101
6.1 6.2	Condition Testing Branch Instructions	
	e	104
6.2	Branch Instructions	104
6.2 6.3	Branch Instructions	
6.2 6.3 6.4	Branch Instructions	
6.2 6.3 6.4 6.5	Branch Instructions	
6.2 6.3 6.4 6.5 6.6	Branch Instructions	
6.2 6.3 6.4 6.5 6.6	Branch Instructions Conditional Execution If-then Statement For Loop While Loop Do While Loop Continue Statement	
6.2 6.3 6.4 6.5 6.6 6.7 6.8	Branch Instructions Conditional Execution If-then Statement If-then-else Statement For Loop While Loop Do While Loop Continue Statement Break Statement	
6.2 6.3 6.4 6.5 6.6 6.7 6.8 6.9 6.10 6.11	Branch Instructions Conditional Execution If-then Statement If-then-else Statement For Loop While Loop Do While Loop Continue Statement Break Statement Switch Statement	
6.2 6.3 6.4 6.5 6.6 6.7 6.8 6.9 6.10	Branch Instructions Conditional Execution If-then Statement If-then-else Statement For Loop While Loop Do While Loop Continue Statement Break Statement	
6.2 6.3 6.4 6.5 6.6 6.7 6.8 6.9 6.10 6.11	Branch Instructions Conditional Execution If-then Statement If-then-else Statement For Loop. While Loop Do While Loop. Continue Statement Break Statement Switch Statement Exercises	
6.2 6.3 6.4 6.5 6.6 6.7 6.8 6.9 6.10 6.11	Branch Instructions Conditional Execution If-then Statement If-then-else Statement For Loop While Loop Continue Statement Break Statement Switch Statement. Exercises	104 107 108 1108 111 112 113 114 115 116 117 119
6.2 6.3 6.4 6.5 6.6 6.7 6.8 6.9 6.10 6.11 6.12	Branch Instructions Conditional Execution If-then Statement If-then-else Statement For Loop While Loop Do While Loop Continue Statement Break Statement Switch Statement Exercises 27. Structured Programming	104 107 108 111 112 113 114 115 116 117 119 123
6.2 6.3 6.4 6.5 6.6 6.7 6.8 6.9 6.10 6.11 6.12 Chapte	Branch Instructions Conditional Execution If-then Statement If-then-else Statement For Loop While Loop Continue Statement Break Statement Switch Statement Exercises T. Structured Programming Basic Control Structures	104 107 108 111 112 113 114 115 116 117 119 123 123
6.2 6.3 6.4 6.5 6.6 6.7 6.8 6.9 6.10 6.11 6.12 Chapte 7.1 7.2	Branch Instructions Conditional Execution If-then Statement If-then-else Statement For Loop While Loop Continue Statement Break Statement Switch Statement Exercises T. Structured Programming Basic Control Structures Register Reuse	
6.2 6.3 6.4 6.5 6.6 6.7 6.8 6.9 6.10 6.11 6.12 Chapte 7.1 7.2 7.3	Branch Instructions	
6.2 6.3 6.4 6.5 6.6 6.7 6.8 6.9 6.10 6.11 6.12 Chapte 7.1 7.2 7.3 7.4	Branch Instructions	104 107 108 111 112 113 114 115 116 117 119 123 123 128 131 131 134 136

Embedded Systems with ARM Cortex-M3 Microcontrollers in Assembly Language and C

Dr. Yifeng Zhu

542 pages, Copyright 2014

ISBN-10: 0982692625

7.8	E	xample of Perfect Numbers	139
7.9	E	xample of Armstrong Numbers	141
7.10	E:	xample of Palindrome String	142
7.11	E:	xample of Converting String to Integer (atoi)	144
7.12	E:	xample of Binary Search	145
7.13	E	xample of Bubble Sort	147
7.14	E:	xercises	149
Chapt	er 8.	Subroutines	151
8.1	С	alling a Subroutine	152
8.2		ack	
8.3	P	reserving Runtime Environment via Stack	155
8.4	Pa	assing Arguments to Subroutine via Registers	157
8.	.4.1	Pass a Variable by Value and by Reference	158
8.	.4.2	Example of Passing by Value	161
8.	.4.3	Write a Subroutine in Different Files	163
8.	.4.4	Example of Passing by Reference	164
8.	.4.5	Example of Greatest Common Divisor	165
8.	.4.6	Example of Concatenating Two Strings	167
8.	.4.7	Example of Comparing Two Strings	
8.	.4.8	Example of Inserting an Integer into a Sorted Array	
	.4.9	Example of Converting Integer to String (itoa)	
		Example of Matrix Transpose	
		Example of Removing a Character from a String	
8.		Example of Finding Unique Numbers in an Array	
8.5		assing Arguments Through Stack	
8.6		ecursive Functions	
8.	.6.1	Example of Factorial Numbers	
	.6.2	Example of Reversing a String	
8.	.6.3	Example of String Permutation	
8.7	E:	xercises	187
Chapt	er 9.	64-bit Data Processing	189
9.1	64	1-bit Addition	189
9.2	64	4-bit Subtraction	190
9.3		1-bit Counting Leading Zeroes	
9.4	64	4-bit Sign Extension	191
9.5	64	4-bit Logic Shift Left	192
9.6	64	4-bit Logic Shift Right	193
9.7	64	1-bit Multiplication	194
9.8	64	1-bit Unsigned Division	194
9.9		4-bit Signed Division	
9.10	E	xercises	198

Chapter 10.	Mixing C and Assembly	199
10.1 Da	ta Types and Access	200
	Signed or Unsigned Integers	
	Data Alignment	
10.1.3	Data Structure Padding	203
10.2 Sp	ecial Variables	206
10.2.1	Static Variables	206
10.2.2	Volatile Variables	210
10.3 Inl	ine Assembly	212
10.3.1	Assembly Functions in a C Program	212
10.3.2	Inline Assembly Instructions in a C Program	213
10.4 Ca	lling Assembly Subroutines from a C Program	214
10.4.1	Example of Calling an Assembly Subroutine	214
10.4.2	Example of Accessing C Variables in Assembly	215
10.5 Ca	lling C Functions from Assembly Programs	216
10.5.1	Example of Calling a C Function.	216
10.5.2	Example of Accessing Assembly Data in a C Program	217
10.6 Ex	ercises	218
Chapter 11.	Fixed-point and Floating-point Arithmetic	221
11.1 Fix	ed-point Arithmetic	222
	Fixed-point Representation	
11.1.2	Fixed-point Range and Resolution Tradeoff	224
	Fixed-point Addition and Subtraction	
11.1.4	Fixed-point Multiplication	226
11.1.5	Fixed-point Division	227
11.2 Flo	pating-point Arithmetic	228
11.2.1	Floating-point Representation	229
11.2.2	Special Values	233
11.2.3	Overflow and Underflow	234
	Subnormal Numbers	
11.2.5	Tradeoff between Numeric Range and Resolution	236
11.2.6	Rounding Rules	238
	Floating-point Addition	
	Floating-point Multiplication	
11.3 Ex	ercises	247
Chapter 12.	Interrupt	249
12.1 Int	roduction to Interrupt	249
	errupt Service Routine (ISR)	
12.3 Ne	ested Vectored Interrupt Controller (NVIC)	254
	Enable and Disable Peripheral Interrupts	
12.3.2	Interrupt Priority	257

Embedded Systems with ARM Cortex-M3 Microcontrollers in Assembly Language and ${\tt C}$

Dr. Yifeng Zhu

542 pages, Copyright 2014

ISBN-10: 0982692625

12.3.3 Global Interrupt Enable and Disable	260
12.4 System Timer	261
12.5 External Interrupt	269
12.6 Software Interrupt	271
12.7 Exercises	273
Chapter 13. Instruction Encoding and Decoding	g275
13.1 Tradeoff between Code Density and Perfo	rmance
	ructions
13.3 Encoding 16-bit Thumb Instructions	278
13.4 Encoding 32-bit Instructions	279
13.5 Calculating Target Memory Address	280
13.6 Instruction Decoding Example 1	282
13.7 Instruction Decoding Example 2	286
13.8 Exercises	291
Chapter 14. Generic-purpose I/O	293
14.1 Introduction to Generic Purpose I/O (GPIC	D)293
	rn
	ı-Drain295
14.3.1 GPIO Push-Pull Output	
14.3.2 GPIO Open-Drain Output	
	298
	299
~ ~ .	304
	308
	312
Chapter 15. General-purpose Timers	313
15.1 Timer Organization and Counting Modes.	313
	316
15.2.1 Setting Output Mode	
15.2.2 Example of Toggling LED	
15.3 PWM Output	
15.3.1 PWM Output Events	
15.3.2 PWM Programming Flowchart	325
15.4 Input Capture	329
15.4.1 Input Capture Timer Diagram	331
15.4.2 Configuring Input Capture	
15.4.3 Interfacing to Ultrasonic Distance Sensor.	
15.5 Exercises	341
Chapter 16. Stepper Motor Control	343
16.1 Bipolar and Unipolar Stepper Motor	343

16.2	Step Angle	345
16.3	Wave Stepping	346
16.4	Full Stepping	347
16.5	Half Stepping	349
16.6	Micro-stepping	351
16.7	Driving Stepper Motor	
16.8	Exercises	354
Chapte	r 17. Liquid-crystal Display (LCD)	355
17.1	Static Drive	356
17.2	Multiplexed Drive	357
17.3	LCD Software Driver	
17.4	Generic LCD Driver to Display Strings	366
17.5	Exercises	370
Chapte	r 18. Real-time Clock (RTC)	371
18.1	UNIX Epoch Time	371
18.2	RTC Frequency Setting	
18.3	Binary Coded Decimal (BCD) Encoding	
18.4	RTC Initialization	
18.5	RTC Alarm	
18.6	Exercises	
Chapte	r 19. Direct Memory Access (DMA)	381
Chapte		
19.1	DMA Bus Matrix	381
	DMA Bus Matrix Programming DMA	381
19.1 19.2 19.3	DMA Bus Matrix Programming DMA Exercises	381 383 385
19.1 19.2 19.3 Chapte	DMA Bus Matrix Programming DMA Exercises r 20. Analog-to-Digital Converter	381 383 385 387
19.1 19.2 19.3 Chapte 20.1	DMA Bus Matrix Programming DMA Exercises r 20. Analog-to-Digital Converter ADC Architecture	381 383 385 387
19.1 19.2 19.3 Chapte 20.1	DMA Bus Matrix Programming DMA Exercises r 20. Analog-to-Digital Converter ADC Architecture	381 383 385 387 388
19.1 19.2 19.3 Chapte 20.1 20	DMA Bus Matrix Programming DMA Exercises r 20. Analog-to-Digital Converter ADC Architecture 1.1 Digital Quantization 1.2 Sampling and Hold	381 383 385 387 388 390
19.1 19.2 19.3 Chapte 20.1 20 20 20.2	DMA Bus Matrix Programming DMA Exercises 7 20. Analog-to-Digital Converter ADC Architecture 1.1.1 Digital Quantization 1.2 Sampling and Hold ADC Sampling Error	
19.1 19.2 19.3 Chapte 20.1 20 20.2 20.2	DMA Bus Matrix Programming DMA Exercises r 20. Analog-to-Digital Converter ADC Architecture 1.1 Digital Quantization 1.2 Sampling and Hold ADC Sampling Error ADC Conversion Modes	
19.1 19.2 19.3 Chapte 20.1 20 20.2 20.3 20.4	DMA Bus Matrix Programming DMA Exercises r 20. Analog-to-Digital Converter ADC Architecture 1.1 Digital Quantization 1.2 Sampling and Hold ADC Sampling Error ADC Conversion Modes ADC Data Alignment	
19.1 19.2 19.3 Chapte 20.1 20 20.2 20.3 20.4 20.5	DMA Bus Matrix Programming DMA Exercises r 20. Analog-to-Digital Converter ADC Architecture 1.1 Digital Quantization 1.2 Sampling and Hold ADC Sampling Error ADC Conversion Modes ADC Data Alignment ADC Triggers	
19.1 19.2 19.3 Chapte 20.1 20.2 20.2 20.3 20.4 20.5 20.6	DMA Bus Matrix Programming DMA Exercises r 20. Analog-to-Digital Converter ADC Architecture 1.1 Digital Quantization 1.2 Sampling and Hold ADC Sampling Error ADC Conversion Modes ADC Data Alignment ADC Triggers Measuring the Input Voltage	
19.1 19.2 19.3 Chapte 20.1 20 20.2 20.3 20.4 20.5	DMA Bus Matrix Programming DMA Exercises r 20. Analog-to-Digital Converter ADC Architecture 1.1 Digital Quantization 1.2 Sampling and Hold ADC Sampling Error ADC Conversion Modes ADC Data Alignment ADC Triggers Measuring the Input Voltage ADC Configuration Flowchart	
19.1 19.2 19.3 Chapte 20.1 20.2 20.2 20.3 20.4 20.5 20.6 20.7	DMA Bus Matrix Programming DMA Exercises r 20. Analog-to-Digital Converter ADC Architecture 1.1 Digital Quantization 1.2 Sampling and Hold ADC Sampling Error ADC Conversion Modes ADC Data Alignment ADC Triggers Measuring the Input Voltage	
19.1 19.2 19.3 Chapte 20.1 20.2 20.3 20.4 20.5 20.6 20.7 20.8	DMA Bus Matrix Programming DMA Exercises r 20. Analog-to-Digital Converter ADC Architecture 1.1 Digital Quantization 1.2 Sampling and Hold ADC Sampling Error ADC Conversion Modes ADC Data Alignment ADC Triggers Measuring the Input Voltage ADC Configuration Flowchart ADC with DMA Exercises	381 383 385 387 387 388 390 391 393 395 396 399 403 405
19.1 19.2 19.3 Chapte 20.1 20 20.2 20.3 20.4 20.5 20.6 20.7 20.8 20.9 Chapte	DMA Bus Matrix Programming DMA Exercises r 20. Analog-to-Digital Converter ADC Architecture 1.1 Digital Quantization 1.2 Sampling and Hold ADC Sampling Error ADC Conversion Modes ADC Data Alignment ADC Triggers Measuring the Input Voltage ADC Configuration Flowchart ADC with DMA Exercises r 21. Digital-to-Analog Converter	381 383 385 387 387 388 390 391 393 395 396 399 403 405
19.1 19.2 19.3 Chapte 20.1 20.2 20.3 20.4 20.5 20.6 20.7 20.8	DMA Bus Matrix Programming DMA Exercises r 20. Analog-to-Digital Converter ADC Architecture 1.1 Digital Quantization 1.2 Sampling and Hold ADC Sampling Error ADC Conversion Modes ADC Data Alignment ADC Triggers Measuring the Input Voltage ADC Configuration Flowchart ADC with DMA Exercises r 21. Digital-to-Analog Converter DAC Architecture	381 383 385 387 387 388 390 391 393 395 396 399 403 405 407

Embedded Systems with ARM Cortex-M3 Microcontrollers in Assembly Language and C

Dr. Yifeng Zhu

542 pages, Copyright 2014

ISBN-10: 0982692625

XIII XIV

21.3 Conversion Trigger	410
21.4 Buffered Output	
21.5 Generating a Sinusoidal Wave via Table Lookup	
21.6 Using Timer as a Trigger to DAC	
21.7 Musical Synthesizing	
21.7.1 Musical Pitch	
21.7.2 Musical Duration	421
21.7.3 Amplitude Modulation of Tones	421
21.8 Exercises	
Chapter 22. Serial Communication Protocols	427
22.1 Universal Asynchronous Receiver and Transmitter	427
22.1.1 Communication Frame	
22.1.2 Baud Rate	429
22.1.3 Example Program Code in C	
22.1.4 Serial Communication to Bluetooth Module	436
22.2 Inter-Integrated Circuit (I ² C)	
22.2.1 Interfacing Serial Digital Thermal Sensors via I ² C	
22.2.2 I ² C Clock Control	445
22.2.3 I ² C Maximum Rising Time	446
22.2.4 Sending Data to I ² C Slave	447
22.2.5 Receiving Data from I ² C Slave	448
22.2.6 Example Program Code in C	451
22.3 Serial Peripheral Interface Bus (SPI)	457
22.3.1 Data Exchange	458
22.3.2 Clock Configuration	460
22.3.3 Example Program Code in C	
22.4 Universal Serial Bus (USB)	465
22.4.1 USB Bus Layer	466
22.4.2 USB Device Layer	468
22.4.3 USB Function Layer	471
22.4.4 USB Class Layer	479
22.4.5 Human Interface Device (HID)	480
22.5 Exercises	485
Chapter 23. Multitasking	487
23.1 Cortex-M3 Processor Mode and Privilege	487
23.2 Supervisor Call (SVC)	
23.3 CPU Scheduling	
23.4 Exercises	
Appendix A: Cortex-M3 16-bit Thumb-2 Instruction Encoding	503
Appendix B: Cortex-M3 32-bit Thumb-2 Instruction Encoding	505

Appendix C: HID Codes of a Keyboard	512
Bibliography	514
Index	517

Embedded Systems with ARM Cortex-M3 Microcontrollers in Assembly Language and ${\tt C}$

Dr. Yifeng Zhu

542 pages, Copyright 2014

ISBN-10: 0982692625