# Design Patterns for Embedded Systems in C

An Embedded Software Engineering Toolkit

Bruce Powel Douglass, PhD





Preface	xv
Acknowledgements	xvii
About the Author	
Chapter 1 What Is Embedded Programming?	
1.1 What's Special About Embedded Systems?	
1.1.1 Embedded Design Constraints	
1.1.2 The Embedded Tool Chain	4
1.1.3 OS, RTOS, or Bareback?	
1.1.4 Embedded Middleware	
1.1.5 Codevelopment with Hardware	
1.1.6 Debugging and Testing	88
1.2 OO or Structured – It's Your Choice	
1.2.1 Classes	
1.2.3 Polymorphism and Virtual Functions	
1.2.4 Subclassing	
1.3 What Did We Learn?	
Chapter 2 Embedded Programming with The Harmony for Em	
RealTime Process	
2.1 Basic Elements of the Harmony Process	
2.1.1 A Quick Overview of the Development Workflow	
2.1.2 What Is a Design Pattern?	
2.1.3 Basic Structure of Design Patterns	
2.1.4 How to Read Design Patterns in This Book	
2.1.5 Using Design Patterns in Development	
2.1.6 Observer Pattern	
2.2 The Approach	
2.3 What's Coming Up	
Chapter 3 Design Patterns for Accessing Hardware	<i>79</i>
3.1 Basic Hardware Access Concepts	81

3.2 Hardware Proxy Pattern	85
3.2.1 Abstract	85
3.2.2 Problem	86
3.2.3 Pattern Structure	86
3.2.4 Collaboration Roles	87
3.2.5 Consequences	
3.2.6 Implementation Strategies	
3.2.7 Related Patterns	
3.2.8 Example	
3.3 Hardware Adapter Pattern	
3.3.1 Abstract	
3.3.2 Problem	
3.3.3 Pattern Structure	
3.3.4 Collaboration Roles	
3.3.5 Consequences	
3.3.6 Implementation Strategies	
3.3.7 Related Patterns	
3.3.8 Example	
3.4 Mediator Pattern	
3.4.1 Abstract	
3.4.2 Problem	
3.4.3 Pattern Structure	
3.4.4 Collaboration Roles	
3.4.5 Consequences	
3.4.6 Implementation Strategies	
3.4.7 Related Patterns.	
3.4.8 Example	
3.5 Observer Pattern	
3.5.1 Abstract	
3.5.2 Problem	
3.5.3 Pattern Structure	
3.5.4 Collaboration Roles	
3.5.5 Consequences	
3.5.6 Implementation Strategies	
3.5.7 Related Patterns	115
3.5.8 Example	
3.6 Debouncing Pattern	
3.6.1 Abstract	122
3.6.2 Problem	
3.6.3 Pottern Structure	123
3.6.3 Pattern Structure	123
3.6.4 Collaboration Roles	
3.6.5 Consequences	125

	3.6.6	Implementation Strategies	125
	3.6.7	Related Patterns	126
	3.6.8	Example	126
3.7	Interru	pt Pattern	130
	3.7.1	Abstract	130
	3.7.2	Problem	130
	3.7.3	Pattern Structure	131
	3.7.4	Collaboration Roles	131
	3.7.5	Consequences	132
	3.7.6	Implementation Strategies	134
	3.7.7	Related Patterns	135
	3.7.8	Example	135
3.8	Polling	g Pattern	138
	3.8.1	Abstract	138
		Problem	
		Pattern Structure	
	3.8.4	Collaboration Roles	138
	3.8.5	Consequences	141
	3.8.6	Implementation Strategies	141
	3.8.7	Related Patterns	142
		Example	
3.9	So, Wl	nat Did We Learn?	147
Manag	r 4 De	esign Patterns for Embedding Concurrency and Resource	40
	emeni .		710
4.1			
	Basic (	Concurrency Concepts	152
	4.1.1	Concurrency Concepts	152 160
	4.1.1 4.1.2	Concurrency Concepts	152 160 161
	4.1.1 4.1.2 4.1.3	Concurrency Concepts Identifying Tasks Concurrency in the UML Real-Time Operating Systems	152 160 161 163
S	4.1.1 4.1.2 4.1.3 cheduli	Concurrency Concepts Identifying Tasks Concurrency in the UML Real-Time Operating Systems ng Patterns	152 160 161 163 164
S	4.1.1 4.1.2 4.1.3 cheduli Cyclic	Concurrency Concepts Identifying Tasks Concurrency in the UML Real-Time Operating Systems ng Patterns Executive Pattern	152 160 161 163 164 164
S	4.1.1 4.1.2 4.1.3 cheduli Cyclic 4.2.1	Concurrency Concepts Identifying Tasks Concurrency in the UML Real-Time Operating Systems ng Patterns Executive Pattern Abstract	152 160 161 163 164 164 165
S	4.1.1 4.1.2 4.1.3 cheduli Cyclic 4.2.1 4.2.2	Concurrency Concepts Identifying Tasks Concurrency in the UML Real-Time Operating Systems ng Patterns Executive Pattern Abstract Problem	152 160 161 163 164 164 165 165
S	4.1.1 4.1.2 4.1.3 cheduli Cyclic 4.2.1 4.2.2 4.2.3	Concurrency Concepts Identifying Tasks Concurrency in the UML Real-Time Operating Systems ng Patterns Executive Pattern Abstract Problem Pattern Structure	152 160 161 163 164 164 165 165
S	4.1.1 4.1.2 4.1.3 cheduli Cyclic 4.2.1 4.2.2 4.2.3 4.2.4	Concurrency Concepts Identifying Tasks Concurrency in the UML Real-Time Operating Systems ng Patterns Executive Pattern Abstract Problem Pattern Structure Collaboration Roles	152 160 161 163 164 165 165 165
S	4.1.1 4.1.2 4.1.3 cheduli Cyclic 4.2.1 4.2.2 4.2.3 4.2.4 4.2.5	Concurrency Concepts Identifying Tasks Concurrency in the UML Real-Time Operating Systems ng Patterns Executive Pattern Abstract Problem Pattern Structure Collaboration Roles ConcreteCEThread	152 160 161 163 164 165 165 165
S	4.1.1 4.1.2 4.1.3 cheduli Cyclic 4.2.1 4.2.2 4.2.3 4.2.4 4.2.5 4.2.6	Concurrency Concepts Identifying Tasks Concurrency in the UML Real-Time Operating Systems ng Patterns Executive Pattern Abstract Problem Pattern Structure Collaboration Roles ConcreteCEThread Consequences	152 160 161 163 164 165 165 165 165
S	4.1.1 4.1.2 4.1.3 cheduli Cyclic 4.2.1 4.2.2 4.2.3 4.2.4 4.2.5 4.2.6 4.2.7	Concurrency Concepts Identifying Tasks Concurrency in the UML Real-Time Operating Systems ng Patterns Executive Pattern Abstract Problem Pattern Structure Collaboration Roles ConcreteCEThread Consequences Implementation Strategies	152 160 161 163 164 165 165 165 165 167
S	4.1.1 4.1.2 4.1.3 cheduli Cyclic 4.2.1 4.2.2 4.2.3 4.2.4 4.2.5 4.2.6 4.2.7 4.2.8	Concurrency Concepts Identifying Tasks Concurrency in the UML Real-Time Operating Systems Ing Patterns Executive Pattern Abstract Problem Pattern Structure Collaboration Roles ConcreteCEThread Consequences Implementation Strategies	152 160 161 163 164 165 165 165 166 167
S 4.2	4.1.1 4.1.2 4.1.3 cheduli Cyclic 4.2.1 4.2.2 4.2.3 4.2.4 4.2.5 4.2.6 4.2.7 4.2.8 4.2.9	Concurrency Concepts Identifying Tasks Concurrency in the UML Real-Time Operating Systems ng Patterns Executive Pattern Abstract Problem Pattern Structure Collaboration Roles ConcreteCEThread Consequences Implementation Strategies Related Patterns.  Example	152 160 161 163 164 165 165 165 166 167 167
S 4.2	4.1.1 4.1.2 4.1.3 cheduli Cyclic 4.2.1 4.2.2 4.2.3 4.2.4 4.2.5 4.2.6 4.2.7 4.2.8 4.2.9 Static F	Concurrency Concepts Identifying Tasks Concurrency in the UML Real-Time Operating Systems ng Patterns Executive Pattern Abstract Problem Pattern Structure Collaboration Roles ConcreteCEThread Consequences Implementation Strategies Related Patterns Example Priority Pattern	152 160 161 163 164 165 165 165 167 167 167
S 4.2	4.1.1 4.1.2 4.1.3 cheduli Cyclic 4.2.1 4.2.2 4.2.3 4.2.4 4.2.5 4.2.6 4.2.7 4.2.8 4.2.9 Static F 4.3.1	Concurrency Concepts Identifying Tasks Concurrency in the UML Real-Time Operating Systems ng Patterns Executive Pattern Abstract Problem Pattern Structure Collaboration Roles ConcreteCEThread Consequences Implementation Strategies Related Patterns.  Example	152 160 161 163 164 165 165 165 167 167 167

4.3.3	Pattern Structure	171
4.3.4	Collaboration Roles	172
4.3.5	Consequences	173
4.3.6	Implementation Strategies	173
	Related Patterns	
4.3.8	Example	175
Task Co	ordination Patterns	182
4.4 Critica	l Region Pattern	182
4.4.1	Abstract	182
4.4.2	Problem	182
4.4.3	Pattern Structure	182
4.4.4	Collaboration Roles	183
4.4.5	Consequences	184
4.4.6	Implementation Strategies	184
4.4.7	Related Patterns	184
4.4.8	Example	184
4.5 Guardo	ed Call Pattern	190
4.5.1	Abstract	190
4.5.2	Problem	190
4.5.3	Pattern Structure	190
4.5.4	Collaboration Roles	191
4.5.5	Consequences	192
4.5.6	Implementation Strategies	192
4.5.7	Related Patterns	193
4.5.8	Example	194
4.6 Queuir	ng Pattern	207
4.6.1	Abstract	207
4.6.2	Problem	207
4.6.3	Pattern Structure	208
4.6.4	Collaboration Roles	208
4.6.5	Consequences	209
	Implementation Strategies	
4.6.7	Related Patterns	210
	Example	
	zvous Pattern	
	Abstract	
	Problem	
	Pattern Structure	
	Collaboration Roles	
	Consequences	
4.7.6	Implementation Strategies	228

	4.7.7 Related Patterns	228
	4.7.8 Example	228
	Deadlock Avoidance Patterns	231
4.8	Simultaneous Locking Pattern	232
	4.8.1 Abstract	232
	4.8.2 Problem	233
	4.8.3 Pattern Structure	
	4.8.4 Collaboration Roles	234
	4.8.5 Consequences	236
	4.8.6 Implementation Strategies	236
	4.8.7 Related Patterns	236
	4.8.8 Example	236
4.9	Ordered Locking	
	4.9.1 Abstract	
	4.9.2 Problem	
	4.9.3 Pattern Structure	
	4.9.4 Collaboration Roles	244
	4.9.5 Consequences	247
	4.9.6 Implementation Strategies	248
	4.9.7 Related Patterns	
	4.9.8 Example	
4.1	O So, What Have We Learned?	255
Chatte	er 5 Design Patterns for State Machines	257
•	Oh Behave!	
	Basic State Machine Concepts	
3.2	5.2.1 OR-States	
	5.2.2 AND-States	
	5.2.3 Special Stuff: Timeouts, Conditionals, and More	267
5.3	5.2.3 Special Stuff: Timeouts, Conditionals, and More	267 270
5.3	5.2.3 Special Stuff: Timeouts, Conditionals, and More	267 270 274
5.3	5.2.3 Special Stuff: Timeouts, Conditionals, and More 5.2.4 Synchronous versus Asynchronous? Single Event Receptor Pattern 5.3.1 Abstract	267 270 274
5.3	5.2.3 Special Stuff: Timeouts, Conditionals, and More 5.2.4 Synchronous versus Asynchronous?  Single Event Receptor Pattern 5.3.1 Abstract 5.3.2 Problem	
5.3	5.2.3 Special Stuff: Timeouts, Conditionals, and More 5.2.4 Synchronous versus Asynchronous? Single Event Receptor Pattern 5.3.1 Abstract 5.3.2 Problem 5.3.3 Pattern Structure	
5.3	5.2.3 Special Stuff: Timeouts, Conditionals, and More 5.2.4 Synchronous versus Asynchronous? Single Event Receptor Pattern 5.3.1 Abstract 5.3.2 Problem 5.3.3 Pattern Structure 5.3.4 Collaboration Roles	
5.3	5.2.3 Special Stuff: Timeouts, Conditionals, and More 5.2.4 Synchronous versus Asynchronous?  Single Event Receptor Pattern 5.3.1 Abstract 5.3.2 Problem 5.3.3 Pattern Structure 5.3.4 Collaboration Roles 5.3.5 Consequences	
5.3	5.2.3 Special Stuff: Timeouts, Conditionals, and More 5.2.4 Synchronous versus Asynchronous?  Single Event Receptor Pattern 5.3.1 Abstract 5.3.2 Problem 5.3.3 Pattern Structure 5.3.4 Collaboration Roles 5.3.5 Consequences 5.3.6 Implementation Strategies	
5.3	5.2.3 Special Stuff: Timeouts, Conditionals, and More. 5.2.4 Synchronous versus Asynchronous? Single Event Receptor Pattern 5.3.1 Abstract. 5.3.2 Problem. 5.3.3 Pattern Structure. 5.3.4 Collaboration Roles 5.3.5 Consequences. 5.3.6 Implementation Strategies 5.3.7 Related Patterns.	
	5.2.3 Special Stuff: Timeouts, Conditionals, and More. 5.2.4 Synchronous versus Asynchronous? Single Event Receptor Pattern 5.3.1 Abstract. 5.3.2 Problem. 5.3.3 Pattern Structure. 5.3.4 Collaboration Roles. 5.3.5 Consequences. 5.3.6 Implementation Strategies. 5.3.7 Related Patterns. 5.3.8 Example.	
	5.2.3 Special Stuff: Timeouts, Conditionals, and More. 5.2.4 Synchronous versus Asynchronous? Single Event Receptor Pattern 5.3.1 Abstract. 5.3.2 Problem. 5.3.3 Pattern Structure. 5.3.4 Collaboration Roles 5.3.5 Consequences. 5.3.6 Implementation Strategies 5.3.7 Related Patterns.	

		5.4.3 Pattern Structure	288
		5.4.4 Collaboration Roles	
		5.4.5 Consequences	
		5.4.6 Implementation Strategies	
		5.4.7 Related Patterns.	
		5.4.8 Example	
	5.5	State Table Pattern	
		5.5.1 Abstract	
		5.5.2 Problem	
		5.5.3 Pattern Structure	
		5.5.4 Collaboration Roles	
		5.5.5 Consequences	
		5.5.6 Implementation Strategies	299
		5.5.7 Related Patterns.	
		5.5.8 Example	
	5.6	State Pattern	
		5.6.1 Abstract	
		5.6.2 Problem	
		5.6.3 Pattern Structure	,
		5.6.4 Collaboration Roles	
		5.6.5 Consequences	
		5.6.6 Implementation Strategies	
		5.6.7 Related Patterns	
		5.6.8 Example	
	5.7	AND-States	
		Decomposed AND-State Pattern	
		5.8.1 Abstract	
		5.8.2 Problem	
		5.8.3 Pattern Structure	
		5.8.4 Collaboration Roles	
		5.8.5 Consequences	
		5.8.6 Implementation Strategies	
		5.8.7 Related Patterns	
		5.8.8 Example	
	5.9	OK, What Have We Learned?	356
Ch		r 6 Safety and Reliability Patterns	
		A Little Bit About Safety and Reliability	
	0.1	6.1.1 Safety and Reliability Related Faults	360
		6.1.2 Achieving Safety and Reliability	261
	62	One's Complement Pattern	
	بيدرن	6.2.1 Abstract	
		A	362 362
		U	ากว

	6.2.3	Pattern Structure	. 362
	6.2.4	Collaboration Roles	. 362
	6.2.5	Consequences	. 363
	6.2.6	Implementation Strategies	. 363
	6.2.7	Related Patterns	. 363
	6.2.8	Example	363
6.3	CRC I	Pattern	. 367
	6.3.1	Abstract	367
	6.3.2	Problem	367
	6.3.3	Pattern Structure	368
	6.3.4	Collaboration Roles	368
	6.3.5	Consequences	369
	6.3.6	Implementation Strategies	369
	6.3.7	Related Patterns	369
	6.3.8	Example	369
6.4	Smart	Data Pattern	380
		Abstract	
	6.4.2	Problem	381
		Pattern Structure	
	6.4.4	Collaboration Roles	382
	6.4.5	Consequences	382
		Implementation Strategies	
	6.4.7	Related Patterns	383
		Example	
6.5		el Pattern	
		Abstract	
		Problem	
		Pattern Structure	
	6.5.4	Collaboration Roles	395
		Consequences	
		Implementation Strategies	
	6.5.7	Related Patterns	397
		Example	
6.6	Protect	ted Single Channel Pattern	402
	6.6.1	Abstract	402
	6.6.2	Problem	402
		Pattern Structure	
	6.6.4	Collaboration Roles	404
	6.6.5	Implementation Strategies	405
		Related Patterns	
		Example	

413
413
414
414
414
417
417
417
421
422
425
425
425
429
429
430
430
437