Using The FreeRTOS Real Time Kernel

NXP LPC17xx Edition

Richard Barry

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FreeRTOS™ is a portable, open source, royalty free, tiny footprint Real Time Kernel - a free to download and free to deploy RTOS that can be used in commercial applications. With downloads topping 75,000 last year alone, FreeRTOS is now a de facto standard for embedded microcontrollers.

"**Using the FreeRTOS Real Time Kernel – a Practical Guide LPC17xx Edition**" is a step by step hands on guide to using FreeRTOS on Cortex M3 microcontrollers from NXP. It presents and explains numerous examples that are written using the FreeRTOS API. Full source code for both the kernel and the examples is provided in an accompanying .zip file.

This document provides a summary of the full text. It includes the complete table of contents, the preface and the first section of each chapter. The complete document can be obtained by visiting http://www.FreeRTOS.org/Documentation.

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Contents

Complete copies of this text can be obtained from http://www.FreeRTOS.org/Documentation

Complete copies of this text can be obtained from http://www.FreeRTOS.org/Documentation

Complete copies of this text can be obtained from http://www.FreeRTOS.org/Documentation

Complete copies of this text can be obtained from http://www.FreeRTOS.org/Documentation

Complete copies of this text can be obtained from http://www.FreeRTOS.org/Documentation

List of Figures

Complete copies of this text can be obtained from http://www.FreeRTOS.org/Documentation

Complete copies of this text can be obtained from http://www.FreeRTOS.org/Documentation

List of Code Listings

Complete copies of this text can be obtained from http://www.FreeRTOS.org/Documentation

Complete copies of this text can be obtained from http://www.FreeRTOS.org/Documentation

Complete copies of this text can be obtained from http://www.FreeRTOS.org/Documentation

List of Tables

Complete copies of this text can be obtained from http://www.FreeRTOS.org/Documentation

List of Notation

API	Application Programming Interface
CMSIS	Cortex Microcontroller Software Interface Standard
FAQ	Frequently Asked Question
FIFO	First In First Out
HMI	Human Machine Interface
IDE	Integrated Development Environment
IRQ	Interrupt Request
ISR	Interrupt Service Routine
LCD	Liquid Crystal Display
MCU	Microcontroller
MPU	Memory Protection Unit
RMS	Rate Monotonic Scheduling
RTOS	Real-time Operating System
SIL	Safety Integrity Level
TCB	Task Control Block
UART	Universal Asynchronous Receiver/Transmitter

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Preface

FreeRTOS and the LPC17xx

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Multitasking on an LPC17xx Cortex M3 Microcontroller

An Introduction to Multitasking in Small Embedded Systems

The LPC17xx Cortex M3 microcontroller from NXP is ideally suited to deeply embedded real-time applications. Typically, applications of this type include a mix of both hard and soft real-time requirements.

Soft real-time requirements are those that state a time deadline—but breaching the deadline would not render the system useless. For example, responding to keystrokes too slowly may make a system seem annoyingly unresponsive without actually making it unusable.

Hard real-time requirements are those that state a time deadline—and breaching the deadline would result in absolute failure of the system. For example, a driver's airbag would be worse than useless if it responded to crash sensor inputs too slowly.

FreeRTOS is a real-time kernel (or real-time scheduler) on top of which LPC17xx applications can be built to meet their hard real-time requirements. It allows LPC17xx applications to be organized as a collection of independent threads of execution. As the LPC17xx has only one core, in reality only a single thread can be executing at any one time. The kernel decides which thread should be executing by examining the priority assigned to each thread by the application designer. In the simplest case, the application designer could assign higher priorities to threads that implement hard real-time requirements, and lower priorities to threads that implement soft real-time requirements. This would ensure that hard real-time threads are always executed ahead of soft real-time threads, but priority assignment decisions are not always that simplistic.

Do not be concerned if you do not fully understand the concepts in the previous paragraph yet. The following chapters provide a detailed explanation, with many examples, to help you understand how to use a real-time kernel, and how to use FreeRTOS, in particular.

A Note About Terminology

In FreeRTOS, each thread of execution is called a 'task'. There is no consensus on terminology within the embedded community, but I prefer 'task' to 'thread' as 'thread' can have a more specific meaning in some fields of application.

Why Use a Real-time Kernel?

There are many well established techniques for writing good embedded software without the use of a kernel, and, if the system being developed is simple, then these techniques might provide the most appropriate solution. In more complex cases, it is likely that using a kernel would be preferable, but where the crossover point occurs will always be subjective.

As already described, task prioritization can help ensure an application meets its processing deadlines, but a kernel can bring other less obvious benefits, too. Some of these are listed very briefly below:

- Abstracting away timing information

  The kernel is responsible for execution timing and provides a time-related API to the application. This allows the structure of the application code to be simpler and the overall code size to be smaller.

- Maintainability/Extensibility

  Abstracting away timing details results in fewer interdependencies between modules and allows the software to evolve in a controlled and predictable way. Also, the kernel is responsible for timing, so application performance is less susceptible to changes in the underlying hardware.

- Modularity

  Tasks are independent modules, each of which should have a well-defined purpose.

- Team development

  Tasks should also have well-defined interfaces, allowing easier development by teams.

- Easier testing

  If tasks are well-defined independent modules with clean interfaces, they can be tested in isolation.

- Code reuse

  Greater modularity and fewer interdependencies can result in code that can be re-used with less effort.

- Improved efficiency

Using a kernel allows software to be completely event-driven, so no processing time is wasted by polling for events that have not occurred. Code executes only when there is something that must be done.

Counter to the efficiency saving is the need to process the RTOS tick interrupt and to switch execution from one task to another.

- Idle time

The Idle task is created automatically when the kernel is started. It executes whenever there are no application tasks wishing to execute. The idle task can be used to measure spare processing capacity, to perform background checks, or simply to place the processor into a low-power mode.

- Flexible interrupt handling

Interrupt handlers can be kept very short by deferring most of the required processing to handler tasks.

- Mixed processing requirements

Simple design patterns can achieve a mix of periodic, continuous, and event-driven processing within an application. In addition, hard and soft real-time requirements can be met by selecting appropriate task and interrupt priorities.

- Easier control over peripherals

Gatekeeper tasks can be used to serialize access to peripherals.

The LPC17xx Port of FreeRTOS

The LPC17xx port includes all the standard FreeRTOS features:

- Pre-emptive or co-operative operation
- Very flexible task priority assignment
- Queues
- Binary semaphores
- Counting semaphores

- Recursive semaphores
- Mutexes
- Tick hook functions
- Idle hook functions
- Stack overflow checking
- Trace hook macros
- Optional commercial licensing and support

FreeRTOS also manages interrupt nesting, and allows interrupts above a user-definable priority level to remain unaffected by the activity of the kernel. Using FreeRTOS will not introduce any additional timing jitter or latency for these interrupts.

There are two separate FreeRTOS ports for the LPC17xx:

1. FreeRTOS-MPU

   FreeRTOS-MPU includes full Memory Protection Unit (MPU) support. In this version, tasks can execute in either User mode or Privileged mode. Also, access to Flash, RAM, and peripheral memory regions can be tightly controlled, on a task-by-task basis.

2. FreeRTOS (the original port)

   This does not include any MPU support. All tasks execute in the Privileged mode and can access the entire memory map.

The examples that accompany this text use the original FreeRTOS version without MPU support, but a chapter describing FreeRTOS-MPU is included for completeness (see Chapter 7).

Resources Used By FreeRTOS

FreeRTOS makes use of the LPC17xx SysTick, PendSV, and SVC interrupts. These interrupts are not available for use by the application.

FreeRTOS has a very small footprint. A typical kernel build will consume approximately 6K bytes of Flash space and a few hundred bytes of RAM. Each task also requires RAM to be allocated for use as the task stack.

The FreeRTOS, OpenRTOS, and SafeRTOS Family

FreeRTOS uses a modified GPL license. The modification is included to ensure:

1. FreeRTOS can be used in commercial applications.
2. FreeRTOS itself remains open source.
3. FreeRTOS users retain ownership of their intellectual property.

When you link FreeRTOS into an application, you are obliged to open source only the kernel, including any additions or modifications you may have made. Components that merely use FreeRTOS through its published API can remain closed source and proprietary. Appendix 1: contains the modification text.

OpenRTOS shares the same code base as FreeRTOS, but is provided under standard commercial license terms. The commercial license removes the requirement to open source any code at all and provides IP infringement protection.

OpenRTOS can be purchased with a professional support contract and a selection of other useful components such as TCP/IP stacks and drivers, USB stacks and drivers, and various different file systems. Evaluation versions can be downloaded from http://www.OpenRTOS.com.

Table 1 provides an overview of the differences between the FreeRTOS and OpenRTOS license models.

SafeRTOS has been developed in accordance with the practices, procedures, and processes necessary to claim compliance with various internationally recognized safety related standards.

IEC 61508 is an international standard covering the development and use of electrical, electronic, and programmable electronic safety-related systems. The standard defines the analysis, design, implementation, production, and test requirements for safety-related systems, in accordance with the Safety Integrity Level (SIL) assigned to the system. The SIL is assigned according to the risks associated with the use of the system under development, with a maximum SIL of 4 being assigned to systems with the highest perceived risk. The SafeRTOS development process has been independently certified by TÜV SÜD as being in compliance with that required by IEC 61508 for SIL 3 applications. SafeRTOS is supplied with

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complete lifecycle compliance evidence and has itself been certified for use in IEC 61508, IEC 62304 and FDA 510(K) applications.

SafeRTOS was originally derived from FreeRTOS and retains a similar usage model. Visit http://www.SafeRTOS.com for additional information.

Table 1. Comparing the FreeRTOS license with the OpenRTOS license

	FreeRTOS License	**OpenRTOS License**
Is it Free?	Yes	No
Can I use it in a commercial application?	Yes	Yes
Is it royalty free?	Yes	Yes
Do I have to open source my application code that makes use of FreeRTOS services?	No, as long as the code provides functionality that is distinct from that provided by FreeRTOS	No
Do I have to open source my changes to the kernel?	Yes	No
Do I have to document that my product uses FreeRTOS?	Yes	No
Do I have to offer to provide the FreeRTOS code to users of my application?	Yes	No
Can I buy an annual support contract?	No	Yes
Is a warranty provided?	No	Yes
Is legal protection provided?	No	Yes, IP infringement protection is provided

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Using the Examples that Accompany this Book

Required Tools and Hardware

The examples described in this book are included in an accompanying .zip file. You can download the .zip file from http://www.FreeRTOS.org/Documentation/code if you did not receive a copy with this book.

To build and execute the examples you will need:

1. The LPCXpresso IDE.

   This is a free tool but requires registration to obtain a license. Instructions are provided on the download page: http://www.code-red-tech.com/lpcxpresso.

2. LPC17xx or LPC13xx based hardware.

   The only output device used by the examples is the console that is accessed through the debugger. This means that the examples should execute on any LPC17xx or LPC13xx based hardware with sufficient RAM. As supplied, the projects are configured to use an LPC1768 (see Figure 2), but can be re-targeted using the 'Change Target MCU' speed button in the LPCXpresso IDE (see Figure 1). Each project within the workspace must be re-targeted individually.

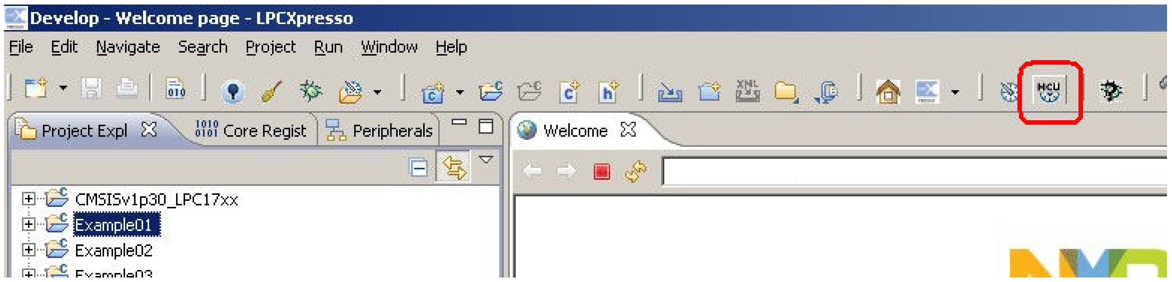


Figure 1. Locating the 'Change Target MCU' speed button within the LPCXpresso IDE (highlighted by the red square)

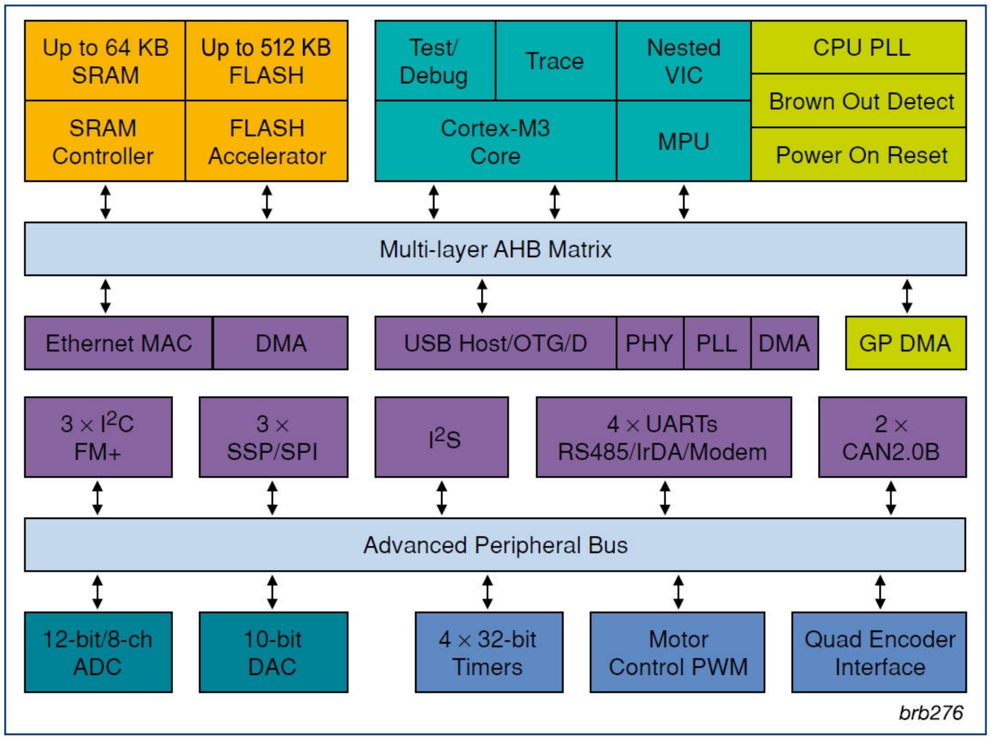


Figure 2. Block diagram of the LPC17xx

Opening the Example Workspaces

All the example projects are provided in a single .zip file archive. Do not extract the files manually from the archive. Instead, follow the procedure defined below.

1. Start the LPCXpresso IDE. You will be prompted to select a workspace.
2. Select an existing workspace (if you have one) or create a new one by entering the path to where you would like the new workspace to be created.
3. Select 'Import' from the 'File' menu. The dialog box shown in Figure 3 will open.

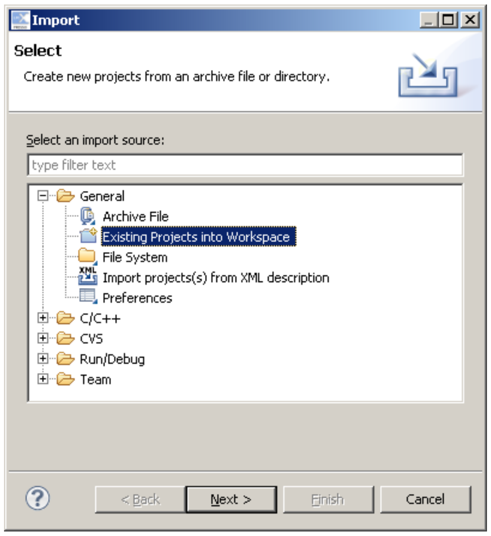
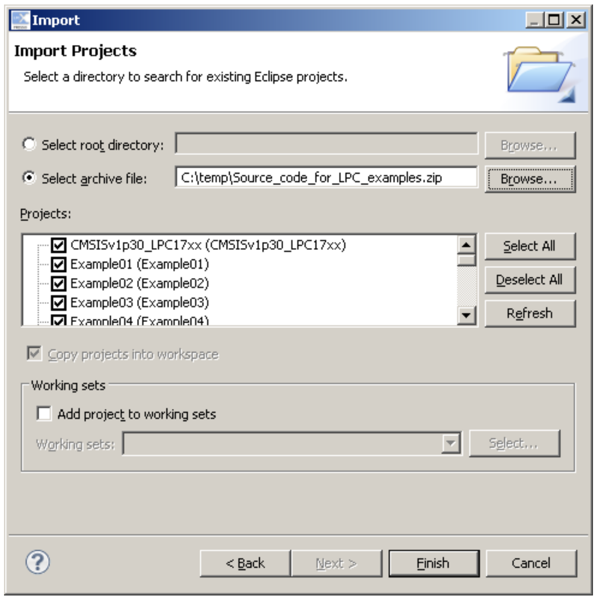


Figure 3. Selecting the option to import existing projects into the workspace

4. Select 'Existing Projects into Workspace' and click 'Next'. The dialog box shown in Figure 4 will open.



Select archive file: C:\temp\Source_code_for_LPC_examples.zip

Projects:
- [✓] CMSISv1p30_LPC17xx (CMSISv1p30_LPC17xx)
- [✓] Example01 (Example01)
- [✓] Example02 (Example02)
- [✓] Example03 (Example03)
- [✓] Example04 (Example04)

[✓] Copy projects into workspace

Figure 4. Selecting the .zip archive

5. Choose the 'Select archive file' option, then browse to and select the .zip file that contains the projects.

6. Click 'Finish'.

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Building the Examples

The Project Explorer window in the LPCXpresso IDE will list sixteen example projects (named Example01 to Example16) and two library projects (named CMSISv1p30_LPC17xx and FreeRTOS_Library). This arrangement is shown in Figure 5.

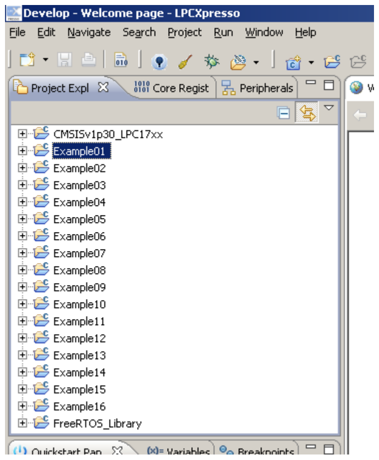

Figure 5. The projects listed in the Project Explorer window of the LPCXpresso IDE

To build an example, highlight the project in the Project Explorer, then select 'Build Project' from the IDE 'Project' menu. Figure 5 shows Example01 highlighted.

The example projects depend on the library projects; therefore, the libraries will build automatically the first time an example is built. The FreeRTOS code itself is contained in the FreeRTOS_Library project. As a consequence of this arrangement, only a single FreeRTOSConfig.h configuration file exists— this is located in the FreeRTOS_Library directory tree. All the example projects reference this single configuration file.

Starting a Debug Session

Highlight the required project in the Project Explorer window, then click the 'Debug' speed button. Figure 6 shows the location of the debug speed button.

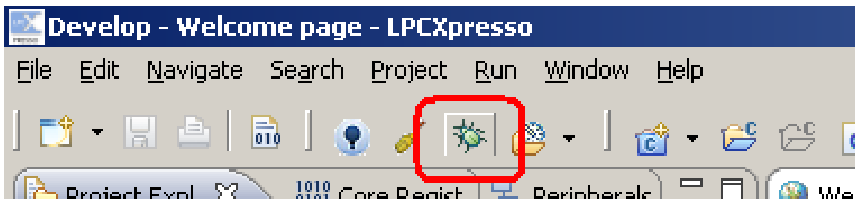
Develop - Welcome page - LPCXpresso
File Edit Navigate Search Project Run Window Help

Figure 6. Locating the 'Debug' speed button within the LPCXpresso IDE (highlighted by the red square)

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Chapter 1

Task Management

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1.1 Chapter Introduction and Scope

Scope

This chapter aims to give readers a good understanding of:

- How FreeRTOS allocates processing time to each task within an application.
- How FreeRTOS chooses which task should execute at any given time.
- How the relative priority of each task affects system behavior.
- The states that a task can exist in.

Readers should also gain a good understanding of:

- How to implement tasks.
- How to create one or more instances of a task.
- How to use the task parameter.
- How to change the priority of a task that has already been created.
- How to delete a task.
- How to implement periodic processing.
- When the idle task will execute and how it can be used.

The concepts presented in this chapter are fundamental to understanding how to use FreeRTOS and how FreeRTOS applications behave. This is, therefore, the most detailed chapter in the book.

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Chapter 2

Queue Management

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2.1 Chapter Introduction and Scope

Applications that use FreeRTOS are structured as a set of independent tasks—each task is effectively a mini program in its own right. It is likely that these autonomous tasks will have to communicate with each other so that, collectively, they can provide useful system functionality. The 'queue' is the underlying primitive used by all FreeRTOS communication and synchronization mechanisms.

Scope

This chapter aims to give readers a good understanding of:

- How to create a queue.
- How a queue manages the data it contains.
- How to send data to a queue.
- How to receive data from a queue.
- What it means to block on a queue.
- The effect of task priorities when writing to and reading from a queue.

Only task-to-task communication is covered in this chapter. Task-to-interrupt and interrupt-to-task communication is covered in Chapter 3.

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Chapter 3

Interrupt Management

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3.1 Chapter Introduction and Scope

Events

Embedded real-time systems have to take actions in response to events that originate from the environment. For example, a packet arriving on an Ethernet peripheral (the event) might require passing to a TCP/IP stack for processing (the action). Non-trivial systems will have to service events that originate from multiple sources, all of which will have different processing overhead and response time requirements. In each case, a judgment has to be made as to the best event processing implementation strategy:

1. How should the event be detected? Interrupts are normally used, but inputs can also be polled.

2. When interrupts are used, how much processing should be performed inside the interrupt service routine (ISR), and how much outside? It is normally desirable to keep each ISR as short as possible.

3. How can events be communicated to the main (non-ISR) code, and how can this code be structured to best accommodate processing of potentially asynchronous occurrences?

FreeRTOS does not impose any specific event processing strategy on the application designer, but does provide features that allow the chosen strategy to be implemented in a simple and maintainable way.

Note that only API functions and macros ending in 'FromISR' or 'FROM_ISR' should be used within an interrupt service routine.

Scope

This chapter aims to give readers a good understanding of:

- Which FreeRTOS API functions can be used from within an interrupt service routine.

- How a deferred interrupt scheme can be implemented.

- How to create and use binary semaphores and counting semaphores.

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- The differences between binary and counting semaphores.
- How to use a queue to pass data into and out of an interrupt service routine.
- The interrupt nesting model of the Cortex M3 FreeRTOS port.

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Chapter 4

Resource Management

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4.1 Chapter Introduction and Scope

In a multitasking system, there is potential for conflict if one task starts to access a resource, but does not complete its access before being transitioned out of the Running state. If the task leaves the resource in an inconsistent state, then access to the same resource by any other task or interrupt could result in data corruption or other similar error.

Following are some examples:

1. Accessing Peripherals

   Consider the following scenario where two tasks attempt to write to an LCD.

   1. Task A executes and starts to write the string “Hello world” to the LCD.

   2. Task A is pre-empted by Task B after outputting just the beginning of the string—“Hello w”.

   3. Task B writes “Abort, Retry, Fail?” to the LCD before entering the Blocked state.

   4. Task A continues from the point at which it was pre-empted and completes outputting the remaining characters—“orld”.

   The LCD now displays the corrupted string “Hello wAbort, Retry, Fail?orld”.

2. Read, Modify, Write Operations

   Listing 1 shows a line of C code and its resultant assembly output. It can be seen that the value of GlobalVar is first read from memory into a register, modified within the register, and then written back to memory. This is called a read, modify, write operation.

```
/* The C code being compiled. */
GlobalVar |= 0x01;

/* The assembly code produced. */
LDR      r4,[pc,#284]
LDR      r0,[r4,#0x08] /* Load the value of GlobalVar into r0. */
ORR      r0,r0,#0x01   /* Set bit 0 of r0. */
STR      r0,[r4,#0x08] /* Write the new r0 value back to GlobalVar. */
```

Listing 1. An example read, modify, write sequence

This is a ‘non-atomic’ operation because it takes more than one instruction to complete and can be interrupted. Consider the following scenario where two tasks attempt to update a variable called GlobalVar:

1. Task A loads the value of GlobalVar into a register—the read portion of the operation.

2. Task A is pre-empted by Task B before it completes the modify and write portions of the same operation.

3. Task B updates the value of GlobalVar, then enters the Blocked state.

4. Task A continues from the point at which it was pre-empted. It modifies the copy of the GlobalVar value that it already holds in a register before writing the updated value back to GlobalVar.

In this scenario, Task A updates and writes back an out-of-date value for GlobalVar. Task B modifies GlobalVar after Task A takes a copy of the GlobalVar value and before Task A writes its modified value back to the GlobalVar variable. When Task A writes to GlobalVar, it overwrites the modification that has already been performed by Task B, effectively corrupting the GlobalVar variable value.

3. Non-atomic Access to Variables

Updating multiple members of a structure, or updating a variable that is larger than the natural word size of the architecture (for example, updating a 64-bit variable on a 32-bit machine), are examples of non-atomic operations. If they are interrupted, they can result in data loss or corruption.

4. Function Reentrancy

A function is reentrant if it is safe to call the function from more than one task, or from both tasks and interrupts.

Each task maintains its own stack and its own set of core register values. If a function does not access any data other than data stored on the stack or held in a register, then the function is reentrant. Listing 2 is an example of a reentrant function. Listing 3 is an example of a function that is not reentrant.

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```
/* A parameter is passed into the function.  This will either be
passed on the stack or in a CPU register.  Either way is safe as
each task maintains its own stack and its own set of register
values. */
long lAddOneHundered( long lVar1 )
{
/* This function scope variable will also be allocated to the stack
or a register, depending on the compiler and optimization level.  Each
task or interrupt that calls this function will have its own copy
of lVar2. */
long lVar2;

    lVar2 = lVar1 + 100;

    /* Most likely the return value will be placed in a CPU register,
    although it too could be placed on the stack. */
    return lVar2;
}
```

Listing 2. An example of a reentrant function

```
/* In this case lVar1 is a global variable so every task that calls
the function will be accessing the same single copy of the variable. */
long lVar1;

long lNonsenseFunction( void )
{
/* This variable is static so is not allocated on the stack.  Each task
that calls the function will be accessing the same single copy of the
variable. */
static long lState = 0;
long lReturn;

    switch( lState )
    {
        case 0 : lReturn = lVar1 + 10;
                 lState = 1;
                 break;

        case 1 : lReturn = lVar1 + 20;
                 lState = 0;
                 break;
    }
}
```

Listing 3. An example of a function that is not reentrant

Mutual Exclusion

Access to a resource that is shared between tasks, or between tasks and interrupts, must be managed using a 'mutual exclusion' technique, to ensure that data consistency is maintained at all times. The goal is to ensure that, once a task starts to access a shared resource, the same task has exclusive access until the resource has been returned to a consistent state.

FreeRTOS provides several features that can be used to implement mutual exclusion, but the best mutual exclusion method is to (whenever possible) design the application in such a way that resources are not shared and each resource is accessed only from a single task.

Scope

This chapter aims to give readers a good understanding of:

- When and why resource management and control is necessary.
- What a critical section is.
- What mutual exclusion means.
- What it means to suspend the scheduler.
- How to use a mutex.
- How to create and use a gatekeeper task.
- What priority inversion is, and how priority inheritance can reduce (but not remove) its impact.

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Chapter 5

Memory Management

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5.1 Chapter Introduction and Scope

The kernel has to allocate RAM dynamically each time a task, queue, or semaphore is created. The standard malloc() and free() library functions can be used, but they may not be suitable or appropriate for one or more of the following reasons:

- They are not always available on small embedded systems.
- Their implementation can be relatively large, taking up valuable code space.
- They are rarely thread-safe.
- They are not deterministic; the amount of time taken to execute the functions will differ from call to call.
- They can suffer from memory fragmentation.
- They can complicate the linker configuration.

Different embedded systems have varying RAM allocation and timing requirements, so a single RAM allocation algorithm will only ever be appropriate for a subset of applications. Therefore, FreeRTOS treats memory allocation as part of the portable layer (as opposed to part of the core code base). This enables individual applications to provide their own specific implementations, when appropriate.

When the kernel requires RAM, instead of calling malloc() directly it calls pvPortMalloc(). When RAM is being freed, instead of calling free() directly, the kernel calls vPortFree(). pvPortMalloc() has the same prototype as malloc(), and vPortFree() has the same prototype as free().

FreeRTOS comes with three example implementations of both pvPortMalloc() and vPortFree(); these examples are all documented in this chapter. Users of FreeRTOS can use one of the example implementations, or provide their own.

The three examples are defined in the files heap_1.c, heap_2.c, and heap_3.c—all of which are located in the FreeRTOS\Source\portable\MemMang directory. The original memory pool and block allocation scheme used by very early versions of FreeRTOS have been removed because of the effort and understanding required to dimension the blocks and pools.

It is common for small embedded systems only to create tasks, queues, and semaphores before the scheduler has been started. When this is the case, memory only gets dynamically allocated by the kernel before the application starts to perform any real-time functionality, and the memory remains allocated for the lifetime of the application. This means that the chosen allocation scheme does not have to consider any of the more complex issues such as determinism and fragmentation, and can instead consider only attributes such as code size and simplicity.

Scope

This chapter aims to give readers a good understanding of:

- When FreeRTOS allocates RAM.
- The three example memory allocation schemes supplied with FreeRTOS.

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Chapter 6

Trouble Shooting

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6.1 Chapter Introduction and Scope

This chapter aims to highlight the most common issues encountered by users who are new to FreeRTOS. It focuses mainly on stack overflow and stack overflow detection, because stack issues have proven to be the most frequent source of support requests over the years. It then briefly, and in an FAQ style, touches on other common errors, their possible cause, and their solutions.

printf-stdarg.c

Stack usage can get particularly high when standard C library functions are used, especially IO and string handling functions such as sprintf(). The FreeRTOS download includes a file called printf-stdarg.c that contains a minimal and stack-efficient version of sprintf(), which can be used in place of the standard library version. In most cases, this will permit a much smaller stack to be allocated to each task that calls sprintf() and related functions.

Printf-stdarg.c is open source but is owned by a third party. Therefore, it is licensed separately from FreeRTOS. The license terms are contained at the top of the source file.

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Chapter 7

FreeRTOS-MPU

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7.1 Chapter Introduction and Scope

The LPC17xx includes a Memory Protection Unit (MPU). This allows the entire memory map (including Flash, RAM, and peripherals) to be sub-divided into a number of regions, and access permissions to be assigned to each region, individually. A region is an address range consisting of a start address and a size.

FreeRTOS-MPU is a FreeRTOS Cortex M3 port that includes integrated MPU support. It permits additional functionality and includes a slightly extended API, but is otherwise backward compatible with the standard Cortex M3 port.

Using FreeRTOS-MPU will always:

- Protect the kernel from invalid execution by tasks.
- Protect the data used by the kernel from invalid access by tasks.
- Protect the configuration of Cortex M3 core resources, such as the SysTick timer.
- Guarantee that all task stack overflows are detected as soon as they occur.

Also, at the application level, it is possible to ensure that tasks are isolated in their own memory space and that peripherals are protected from unintended modification.

FreeRTOS-MPU provides a simple interface to the MPU by hiding the register level MPU configuration from the user. However, writing an application for an environment that does not permit free access to all data can be challenging.

Scope

This chapter aims to give readers a good understanding of:

- The constraints the MPU hardware places on how memory regions can be defined.
- The access permissions that can be assigned to each memory region.
- The difference between User Mode tasks and Privileged Mode tasks.
- The FreeRTOS-MPU specific API.

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Chapter 8

The FreeRTOS Download

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8.1 Chapter Introduction and Scope

FreeRTOS is distributed as a single .zip file archive containing all the official FreeRTOS ports and a large number of pre-configured demo applications. The large number of files can seem overwhelming, but only a subset will actually be required.

Scope

This chapter aims to help users orientate themselves with the FreeRTOS files and directories by:

- Providing a top level view of the FreeRTOS directory structure.
- Describing which files are actually required by LPC17xx projects.
- Introducing the demo applications.
- Providing information on how a new project can be created.

The description here relates only to the main FreeRTOS .zip file distribution. The examples that come with this book use a slightly different organization.

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Appendix 1: Licensing Information

FreeRTOS is licensed under a modified version of the GNU General Public License (GPL) and *can* be used in commercial applications under that license. An alternative and optional commercial license is also available if:

- You cannot fulfill the requirements stated in the 'Open source modified GPL license' column of Table 2.
- You wish to receive direct technical support.
- You wish to have assistance with your development.
- You require guarantees and indemnification.

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Table 2. Comparing the open source license with the commercial license

	Open source modified GPL license	**Commercial license**
Is it free?	Yes	No
Can I use it in a commercial application?	Yes	Yes
Is it royalty free?	Yes	Yes
Do I have to open source my application code?	No	No
Do I have to open source my changes to the FreeRTOS kernel?	Yes	No
Do I have to document that my product uses FreeRTOS.	Yes	No
Do I have to offer to provide the FreeRTOS source code to users of my application?	Yes (a WEB link to the FreeRTOS.org site is normally sufficient)	No
Can I receive support on a commercial basis?	No	Yes
Are any legal guarantees provided?	No	Yes

Open Source License Details

The FreeRTOS source code is licensed under version 2 of the GNU General Public License (GPL) *with an exception*.

The full text of the GPL is available at http://www.freertos.org/license.txt. The text of the exception is provided below.

The exception permits the source code of applications that use FreeRTOS solely through the API published on the FreeRTOS.org website to remain closed source, thus permitting the use of FreeRTOS in commercial applications without necessitating that the entire application be open sourced. The exception can be used only if you wish to combine FreeRTOS with a proprietary product and you comply with the terms stated in the exception itself.

GPL Exception Text

Note that the exception text is subject to change. Consult the FreeRTOS.org website for the most recent version.

Clause 1

Linking FreeRTOS statically or dynamically with other modules is making a combined work based on FreeRTOS. Thus, the terms and conditions of the GNU General Public License cover the whole combination.

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2. *The combined work is not itself an RTOS, scheduler, kernel or related product.*

3. *The independent modules add significant and primary functionality to FreeRTOS and do not merely extend the existing functionality already present in FreeRTOS.*

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INDEX

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