12 Developer Support

12.1 Introduction

This chapter highlights a set of features that are included to maximize productivity by:

- Providing insight into how an application is behaving.
- Highlighting opportunities for optimization.
- Trapping errors at the point at which they occur.

12.2 configASSERT()

In C, the macro `assert()` is used to verify an *assertion* (an assumption) made by the program. The assertion is written as a C expression, and if the expression evaluates to false (0), then the assertion has deemed to have failed. For example, Listing 12.1 tests the assertion that the pointer `pxMyPointer` is not NULL.

```
/* Test the assertion that pxMyPointer is not NULL */
assert( pxMyPointer != NULL );
```

Listing 12.1 *Using the standard C assert() macro to check pxMyPointer is not NULL*

The application writer specifies the action to take if an assertion fails by providing an implementation of the `assert()` macro.

The FreeRTOS source code does not call `assert()`, because `assert()` is not available with all the compilers with which FreeRTOS is compiled. Instead, the FreeRTOS source code contains lots of calls to a macro called `configASSERT()`, which can be defined by the application writer in `FreeRTOSConfig.h`, and behaves exactly like the standard C `assert()`.

A failed assertion must be treated as a fatal error. Do not attempt to execute past a line that has failed an assertion.

> *Using `configASSERT()` improves productivity by immediately trapping and identifying many of the most common sources of error. It is strongly advised to have `configASSERT()` defined while developing or debugging a FreeRTOS application.*

Defining `configASSERT()` will greatly assist in run-time debugging, but will also increase the application code size, and therefore slow down its execution. If a definition of `configASSERT()` is not provided, then the default empty definition will be used, and all the calls to `configASSERT()` will be completely removed by the C pre-processor.

12.2.1 Example configASSERT() definitions

The definition of `configASSERT()` shown in Listing 12.2 is useful when an application is being executed under the control of a debugger. It will halt execution on any line that fails an assertion, so the line that failed the assertion will be the line displayed by the debugger when the debug session is paused.

```
/* Disable interrupts so the tick interrupt stops executing, then sit
   in a loop so execution does not move past the line that failed the
   assertion. If the hardware supports a debug break instruction, then the
   debug break instruction can be used in place of the for() loop. */

#define configASSERT( x ) if( ( x ) == 0 ) { taskDISABLE_INTERRUPTS(); for(;;); }
```

Listing 12.2 *A simple configASSERT() definition useful when executing under the control of a debugger*

The definition of `configASSERT()` shown in Listing 12.3 is useful when an application is not being executed under the control of a debugger. It prints out, or otherwise records, the source code line that failed an assertion. The line that failed the assertion is identified using the standard C `__FILE__` macro to obtain the name of the source file, and the standard C `__LINE__` macro to obtain the line number within the source file.

```
/* This function must be defined in a C source file, not the FreeRTOSConfig.h
   header file. */
void vAssertCalled( const char *pcFile, uint32_t ulLine )
{
    /* Inside this function, pcFile holds the name of the source file that
       contains the line that detected the error, and ulLine holds the line
       number in the source file. The pcFile and ulLine values can be printed
       out, or otherwise recorded, before the following infinite loop is
       entered. */
    RecordErrorInformationHere( pcFile, ulLine );

    /* Disable interrupts so the tick interrupt stops executing, then sit in a
       loop so execution does not move past the line that failed the assertion. */
    taskDISABLE_INTERRUPTS();
    for( ;; );
}
/*-----------------------------------------------------------*/

/* These following two lines must be placed in FreeRTOSConfig.h. */
extern void vAssertCalled( const char *pcFile, unsigned long ulLine );
#define configASSERT( x ) if( ( x ) == 0 ) vAssertCalled( __FILE__, __LINE__ )
```

Listing 12.3 *A configASSERT() definition that records the source code line that failed an assertion*

12.3 Tracealyzer for FreeRTOS

Tracealyzer for FreeRTOS is a run-time diagnostic and optimization tool provided by our partner company, Percepio.

Tracealyzer for FreeRTOS captures valuable dynamic behavior information, then presents the captured information in interconnected graphical views. The tool is also capable of displaying multiple synchronized views.

The captured information is invaluable when analyzing, troubleshooting, or simply optimizing a FreeRTOS application.

Tracealyzer for FreeRTOS can be used side-by-side with a traditional debugger, and complements the debugger's view with a higher level, time-based perspective.

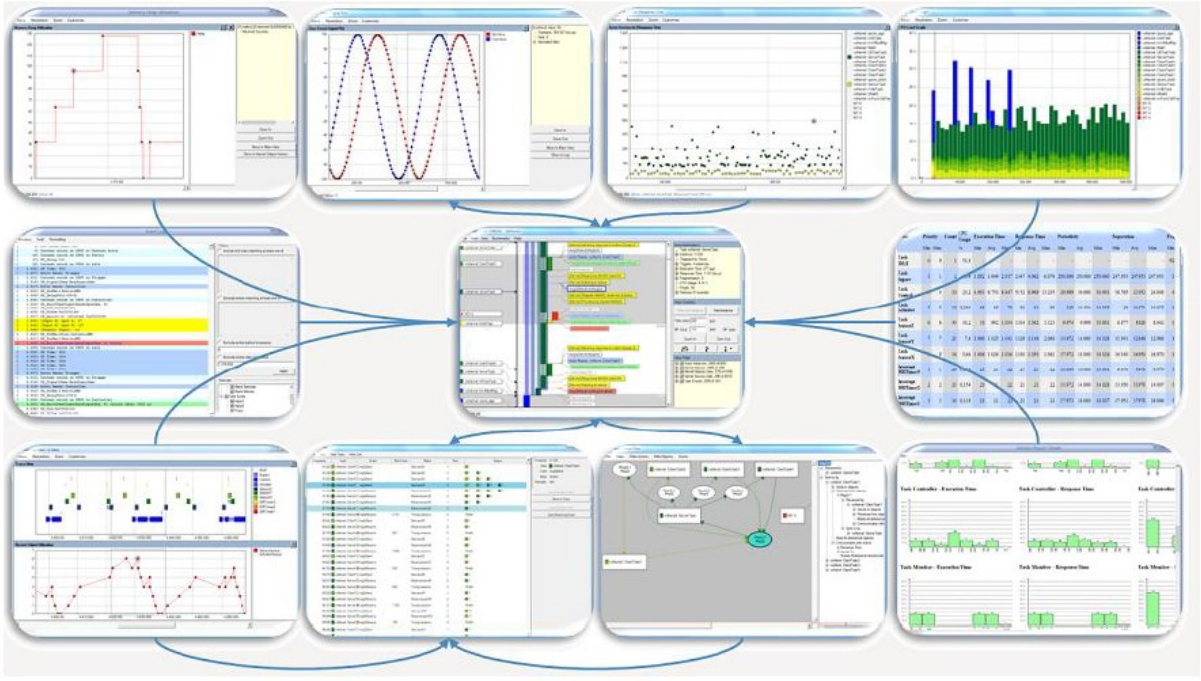


Figure 12.1 *FreeRTOS+Trace includes more than 20 interconnected views*

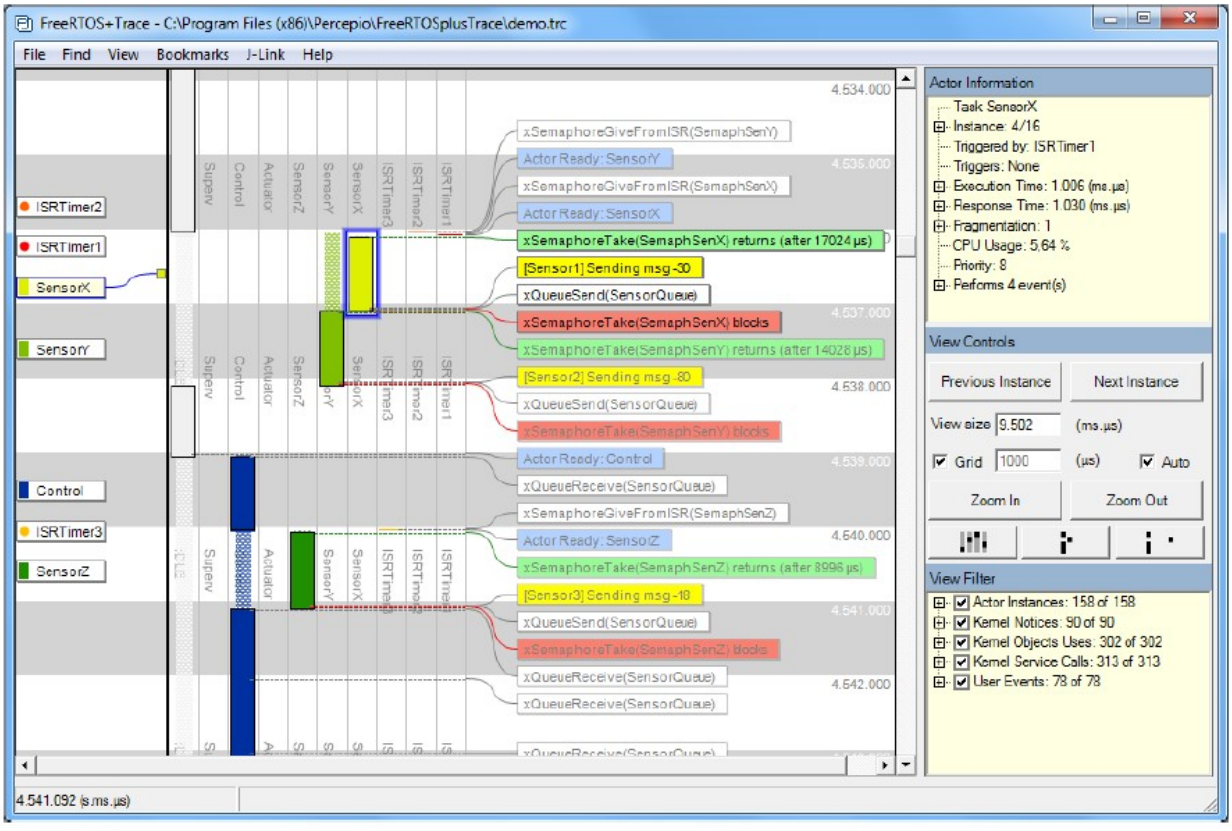


Figure 12.2 *FreeRTOS+Trace main trace view - one of more than 20 interconnected trace views*

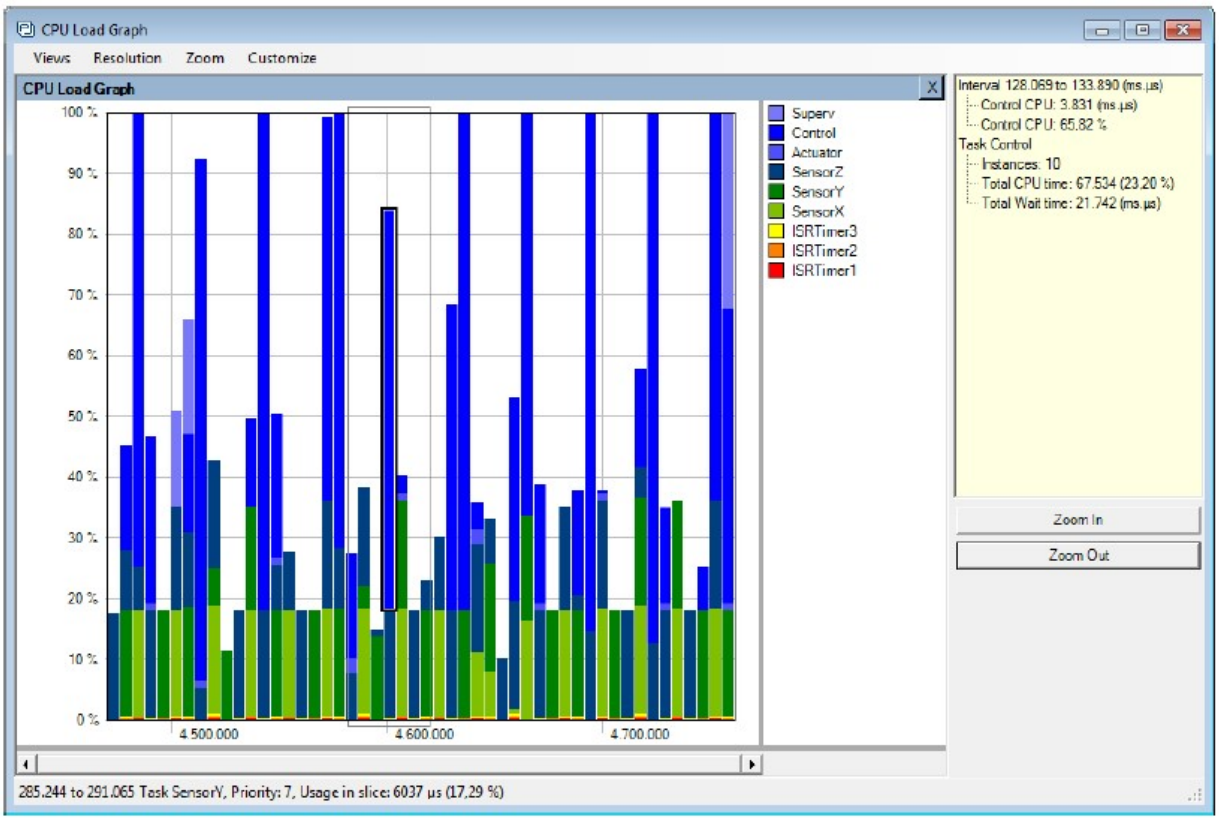


Figure 12.3 *FreeRTOS+Trace CPU load view - one of more than 20 interconnected trace views*

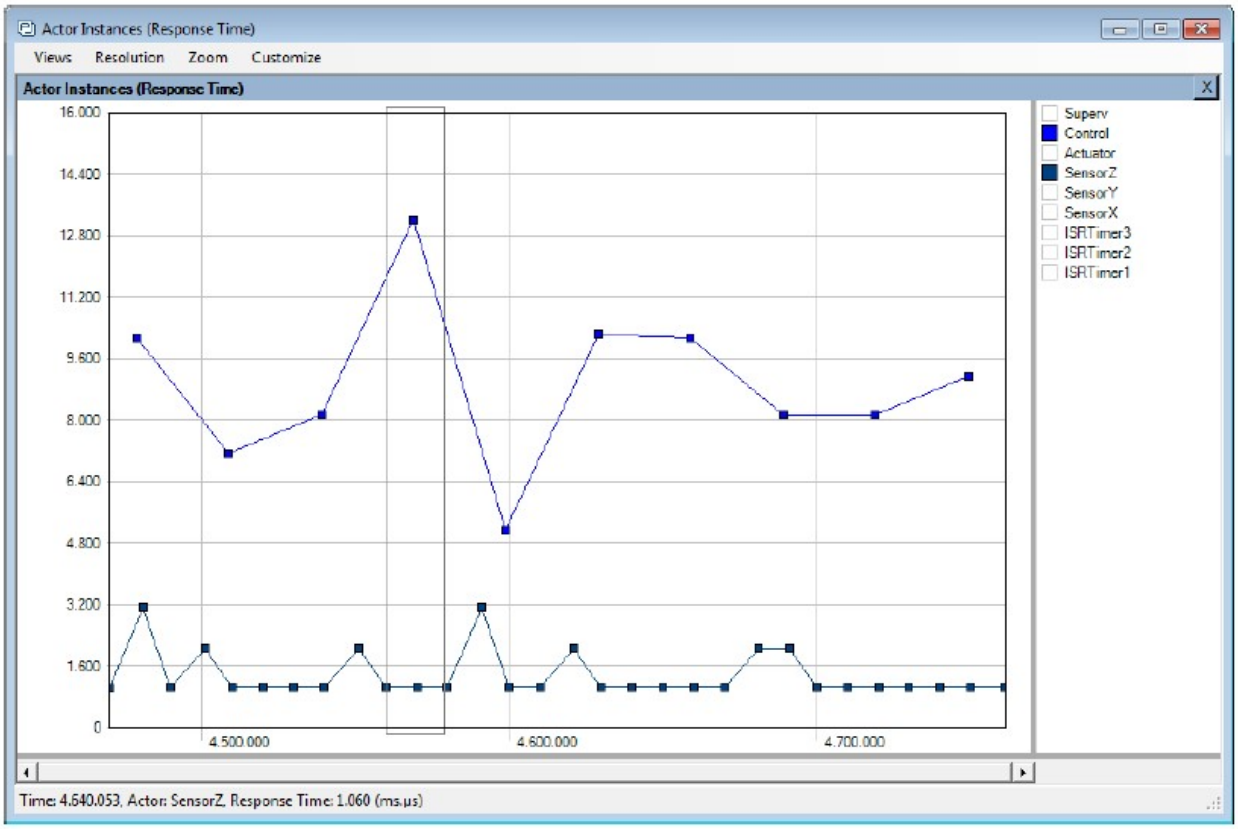


Figure 12.4 *FreeRTOS+Trace response time view - one of more than 20 interconnected trace views*

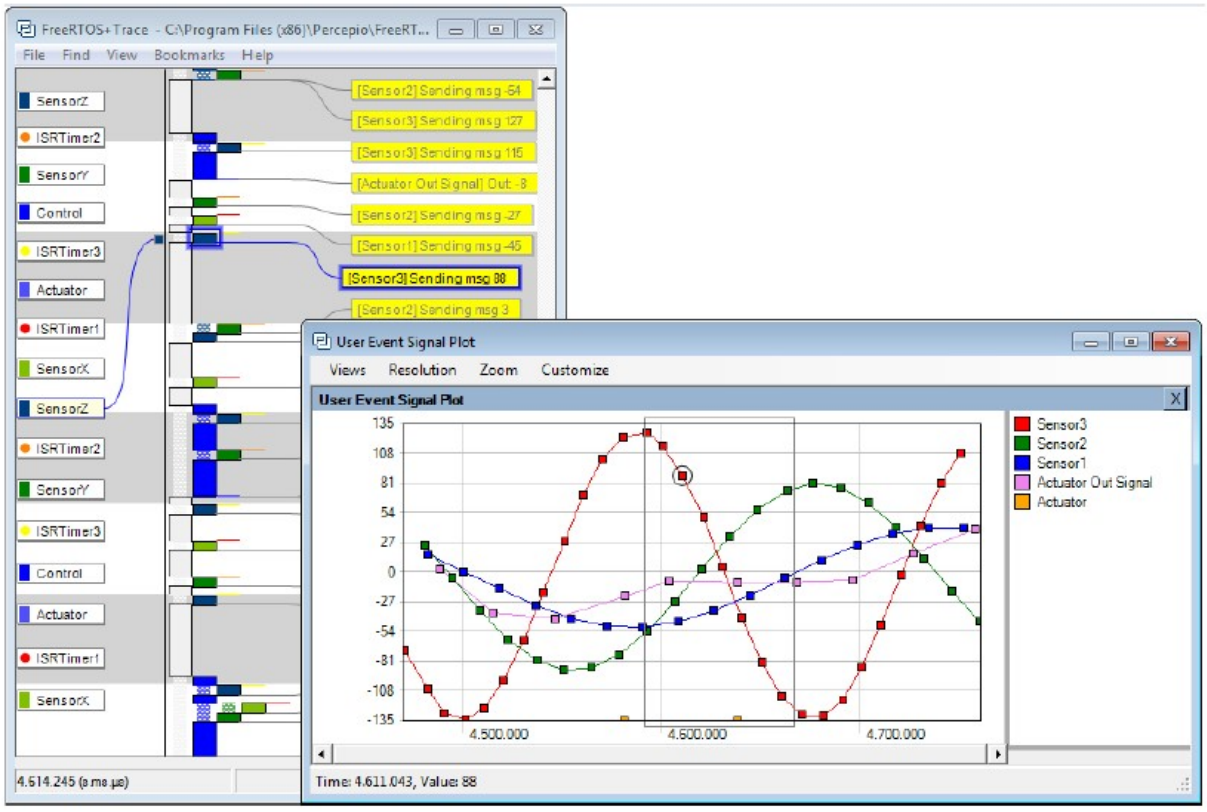


Figure 12.5 *FreeRTOS+Trace user event plot view - one of more than 20 interconnected trace views*

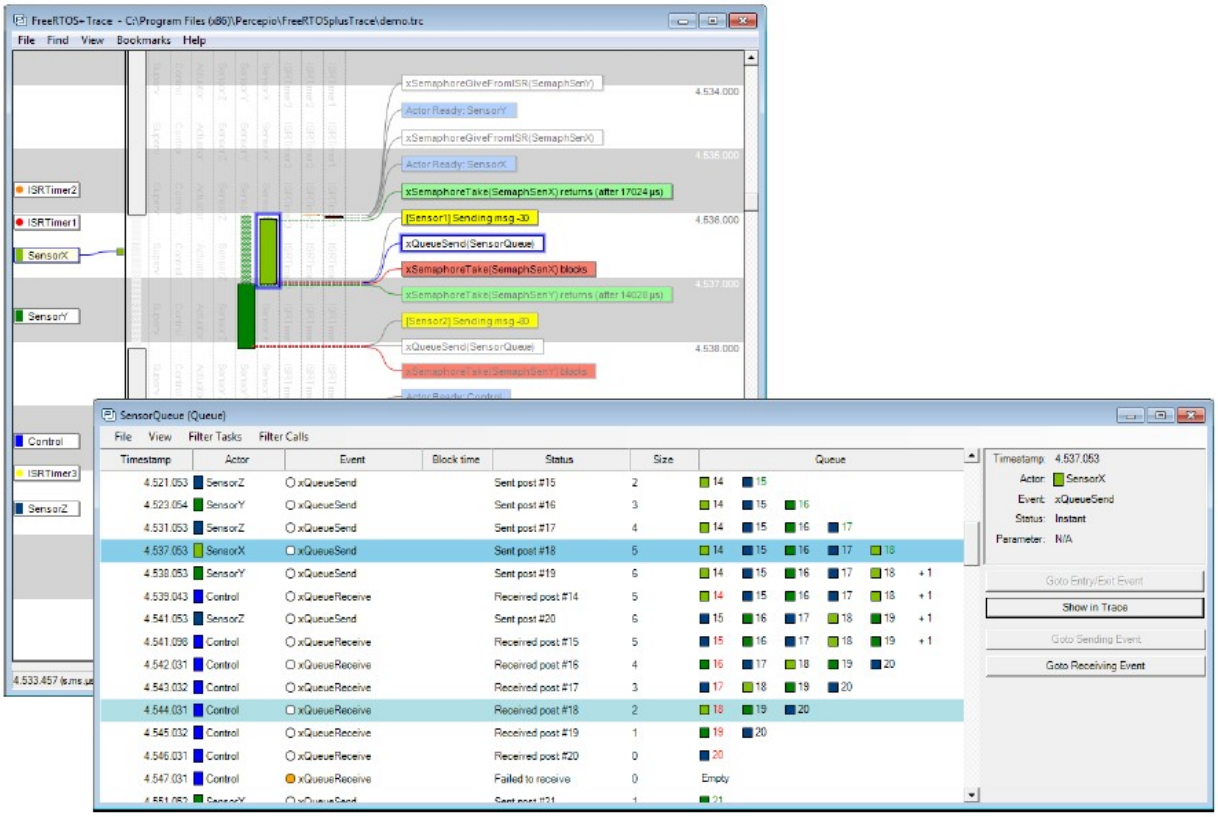


Figure 12.6 *FreeRTOS+Trace kernel object history view - one of more than 20 interconnected trace views*

12.4 Debug Related Hook (Callback) Functions

12.4.1 Malloc failed hook

The malloc failed hook (or callback) was described in Chapter 3, Heap Memory Management.

Defining a malloc failed hook ensures the application developer is notified immediately if an attempt to create a task, queue, semaphore or event group fails.

12.4.2 Stack overflow hook

Details of the stack overflow hook are provided in section 13.3, Stack Overflow.

Defining a stack overflow hook ensures the application developer is notified if the amount of stack used by a task exceeds the stack space allocated to the task.

12.5 Viewing Run-time and Task State Information

12.5.1 Task Run-Time Statistics

Task run-time statistics provide information on the amount of processing time each task has received. A task's *run time* is the total time the task has been in the Running state since the application booted.

Run-time statistics are intended to be used as a profiling and debugging aid during the development phase of a project. The information they provide is only valid until the counter used as the run-time statistics clock overflows. Collecting run-time statistics will increase the task context switch time.

To obtain binary run-time statistics information, call the `uxTaskGetSystemState()` API function. To obtain run-time statistics information as a human readable ASCII table, call the `vTaskGetRunTimeStatistics()` helper function.

12.5.2 The Run-Time Statistics Clock

Run-time statistics need to measure fractions of a tick period. Therefore, the RTOS tick count is not used as the run-time statistics clock, and the clock is instead provided by the application code. It is recommended to make the frequency of the run-time statistics clock between 10 and 100 times faster than the frequency of the tick interrupt. The faster the run-time statistics clock, the more accurate the statistics will be, but also the sooner the time value will overflow.

Ideally, the time value will be generated by a free-running 32-bit peripheral timer/counter, the value of which can be read with no other processing overhead. If the available peripherals and clock speeds do not make that technique possible, then alternative, but less efficient, techniques include:

- Configure a peripheral to generate a periodic interrupt at the desired run-time statistics clock frequency, and then use a count of the number of interrupts generated as the run-time statistics clock.

  This method is very inefficient if the periodic interrupt is only used for the purpose of providing a run-time statistics clock. However, if the application already uses a periodic interrupt with a suitable frequency, then it is simple and efficient to add a count of the number of interrupts generated into the existing interrupt service routine.

- Generate a 32-bit value by using the current value of a free running 16-bit peripheral timer as the 32-bit value's least significant 16-bits, and the number of times the timer has overflowed as the 32-bit value's most significant 16-bits.

It is possible, with appropriate and somewhat complex manipulation, to generate a run-time statistics clock by combining the RTOS tick count with the current value of an ARM Cortex-M SysTick timer. Some of the demo projects in the FreeRTOS download demonstrate how this is achieved.

12.5.3 Configuring an Application to Collect Run-Time Statistics

Below are details on the macros necessary to collect task run-time statistics. Originally, the macros were intended to be included in the RTOS port layer, which is why the macros are prefixed 'port', but it has proven more practical to define them in `FreeRTOSConfig.h`.

Macros used in the collection of run-time statistics

- `configGENERATE_RUN_TIME_STATS`

  This macro must be set to 1 in FreeRTOSConfig.h. When this macro is set to 1 the scheduler will call the other macros detailed in this section at the appropriate times.

- `portCONFIGURE_TIMER_FOR_RUN_TIME_STATS()`

  This macro must be provided to initialize whichever peripheral is used to provide the run-time statistics clock.

- `portGET_RUN_TIME_COUNTER_VALUE()`, or `portALT_GET_RUN_TIME_COUNTER_VALUE(Time)`

  One of these two macros must be provided to return the current run-time statistics clock value. This is the total time the application has been running, in run-time statistics clock units, since the application first booted.

  If the first macro is used, it must be defined to evaluate to the current clock value. If the second macro is used, it must be defined to set its 'Time' parameter to the current clock value.

12.5.4 The uxTaskGetSystemState() API Function

`uxTaskGetSystemState()` provides a snapshot of status information for each task under the control of the FreeRTOS scheduler. The information is provided as an array of `TaskStatus_t` structures, with one index in the array for each task. `TaskStatus_t` is described by Listing 12.5 and below.

```
UBaseType_t uxTaskGetSystemState( TaskStatus_t * const pxTaskStatusArray,
                                  const UBaseType_t uxArraySize,
                                  configRUN_TIME_COUNTER_TYPE * const
pulTotalRunTime );
```

Listing 12.4 *The uxTaskGetSystemState() API function prototype*

> Note: `configRUN_TIME_COUNTER_TYPE` defaults to `uint32_t` for backward compatibility, but can be overridden in FreeRTOSConfig.h if `uint32_t` is too restrictive.

uxTaskGetSystemState() parameters and return value

- `pxTaskStatusArray`

  A pointer to an array of `TaskStatus_t` structures.

  The array must contain at least one `TaskStatus_t` structure for each task. The number of tasks can be determined using the `uxTaskGetNumberOfTasks()` API function.

  The `TaskStatus_t` structure is shown in Listing 12.5, and the TaskStatus_t structure members are described in the next list.

- `uxArraySize`

  The size of the array pointed to by the `pxTaskStatusArray` parameter. The size is specified as the number of indexes in the array (the number of `TaskStatus_t` structures contained in the array), not by the number of bytes in the array.

- `pulTotalRunTime`

  If `configGENERATE_RUN_TIME_STATS` is set to 1 in `FreeRTOSConfig.h`, then `*pulTotalRunTime` is set by `uxTaskGetSystemState()` to the total run time (as defined by the run-time statistics clock provided by the application) since the target booted.

  `pulTotalRunTime` is optional, and can be set to NULL if the total run time is not required.

- Return value

  The number of `TaskStatus_t` structures that were populated by `uxTaskGetSystemState()` is returned.

  The returned value should equal the number returned by the `uxTaskGetNumberOfTasks()` API function, but will be zero if the value passed in the `uxArraySize` parameter was too small.

```
typedef struct xTASK_STATUS
{
    TaskHandle_t xHandle;
    const char *pcTaskName;
    UBaseType_t xTaskNumber;
    eTaskState eCurrentState;
    UBaseType_t uxCurrentPriority;
    UBaseType_t uxBasePriority;
    configRUN_TIME_COUNTER_TYPE ulRunTimeCounter;
    StackType_t * pxStackBase;
    #if ( ( portSTACK_GROWTH > 0 ) || ( configRECORD_STACK_HIGH_ADDRESS == 1 ) )
        StackType_t * pxTopOfStack;
        StackType_t * pxEndOfStack;
    #endif
    uint16_t usStackHighWaterMark;
    #if ( ( configUSE_CORE_AFFINITY == 1 ) && ( configNUMBER_OF_CORES > 1 ) )
        UBaseType_t uxCoreAffinityMask;
    #endif
} TaskStatus_t;
```

Listing 12.5 *The TaskStatus_t structure*

TaskStatus_t structure members

- `xHandle`

  The handle of the task to which the information in the structure relates.

- `pcTaskName`

  The human readable text name of the task.

- `xTaskNumber`

  Each task has a unique `xTaskNumber` value.

  If an application creates and deletes tasks at run time then it is possible that a task will have the same handle as a task that was previously deleted. `xTaskNumber` is provided to allow application code, and kernel aware debuggers, to distinguish between a task that is still valid, and a deleted task that had the same handle as the valid task.

- `eCurrentState`

  An enumerated type that holds the state of the task. `eCurrentState` can be one of the following values:

  - `eRunning`
  - `eReady`
  - `eBlocked`
  - `eSuspended`
  - `eDeleted`

  A task will only be reported as being in the `eDeleted` state for the short period between the time the task was deleted by a call to `vTaskDelete()`, and the time the Idle task frees the memory that was allocated to the deleted task's internal data structures and stack. After that time, the task will no longer exist in any way, and it is invalid to attempt to use its handle.

- `uxCurrentPriority`

  The priority at which the task was running at the time `uxTaskGetSystemState()` was called. `uxCurrentPriority` will only be higher than the priority assigned to the task by the application writer if the task has temporarily been assigned a higher priority in accordance with the priority inheritance mechanism described in section 8.3 Mutexes (and Binary Semaphores).

- `uxBasePriority`

  The priority assigned to the task by the application writer. `uxBasePriority` is only valid if `configUSE_MUTEXES` is set to 1 in FreeRTOSConfig.h.

- `ulRunTimeCounter`

  The total run time used by the task since the task was created. The total run time is provided as an absolute time that uses the clock provided by the application writer for the collection of run-time

statistics. `ulRunTimeCounter` is only valid if `configGENERATE_RUN_TIME_STATS` is set to 1 in FreeRTOSConfig.h.

- `pxStackBase`

  Points to the base address of the stack region allotted to this task.

- `pxTopOfStack`

  Points to the current top address of the stack region allotted to this task. The field `pxTopOfStack` is only valid if either the stack grows upwards (i.e. `portSTACK_GROWTH` is greater than zero) or `configRECORD_STACK_HIGH_ADDRESS` is set to 1 in FreeRTOSConfig.h.

- `pxEndOfStack`

  Points to the end address of the of the stack region allotted to this task. The field `pxEndOfStack` is only valid if either the stack grows upwards (i.e. `portSTACK_GROWTH` is greater than zero) or `configRECORD_STACK_HIGH_ADDRESS` is set to 1 in FreeRTOSConfig.h.

- `usStackHighWaterMark`

  The task's stack high water mark. This is the minimum amount of stack space that has remained for the task since the task was created. It is an indication of how close the task has come to overflowing its stack; the closer this value is to zero, the closer the task has come to overflowing its stack. `usStackHighWaterMark` is specified in bytes.

- `uxCoreAffinityMask`

  A bitwise value that indicates the cores on which the task can run. Cores are numbered from 0 to `configNUMBER_OF_CORES` - 1. For example, a task that can run on core 0 and core 1 will have its `uxCoreAffinityMask` set to 0x03. The field `uxCoreAffinityMask` is only available if both `configUSE_CORE_AFFINITY` is set to 1 and `configNUMBER_OF_CORES` is set to greater than 1 in FreeRTOSConfig.h.

12.5.5 The vTaskListTasks() Helper Function

`vTaskListTasks()` provides similar task status information to that provided by `uxTaskGetSystemState()`, but it presents the information as a human readable ASCII table, rather than an array of binary values.

`vTaskListTasks()` is a very processor intensive function, and leaves the scheduler suspended for an extended period. Therefore, it is recommended to use the function for debug purposes only, and not in a production real-time system.

`vTaskListTasks()` is available if `configUSE_TRACE_FACILITY` is set to 1 and `configUSE_STATS_FORMATTING_FUNCTIONS` is set to greater than 0 in FreeRTOSConfig.h.

```
void vTaskListTasks( char * pcWriteBuffer, size_t uxBufferLength );
```

Listing 12.6 *The vTaskListTasks() API function prototype*

vTaskListTasks() parameters

- `pcWriteBuffer`

  A pointer to a character buffer into which the formatted and human readable table is written. This buffer is assumed to be large enough to contain the generated report. Approximately 40 bytes per task should be sufficient.

- `uxBufferLength`

  Length of the `pcWriteBuffer`.

An example of the output generated by `vTaskListTasks()` is shown in Figure 12.7. In the output:

- Each row provides information on a single task.
- The first column is the task's name.
- The second column is the task's state, where 'X' means Running, 'R' means Ready, 'B' means Blocked, 'S' means Suspended, and 'D' means the task has been deleted. A task will only be reported as being in the deleted state for the short period between the time the task was deleted by a call to `vTaskDelete()`, and the time the Idle task frees the memory that was allocated to the deleted task's internal data structures and stack. After that time, the task will no longer exist in any way, and it is invalid to attempt to use its handle.
- The third column is the task's priority.
- The fourth column is the task's stack high water mark. See the description of `usStackHighWaterMark`.
- The fifth column is the unique number allocated to the task. See the description of `xTaskNumber`.

```
tcpip          R       3       393     0
Tmr Svc        R       3       111     48
QConsB1        R       1       143     3
QProdB5        R       0       144     7
QConsB6        R       0       143     8
PolSEM1        R       0       145     11
PolSEM2        R       0       145     12
GenQ           R       0       155     17
MuLow          R       0       147     18
Rec3           R       0       141     30
SUSP_RX        R       0       148     36
Math1          R       0       167     38
Math2          R       0       167     39
```

Figure 12.7 *Example output generated by vTaskListTasks()*

> Note: The older version of `vTaskListTasks` is `vTaskList`. `vTaskList` assumes that the `pcWriteBuffer` is of length `configSTATS_BUFFER_MAX_LENGTH`. This function is there only for backward compatibility. New applications are recommended to use `vTaskListTasks` and supply the length of the `pcWriteBuffer` explicitly.

```
void vTaskList( signed char *pcWriteBuffer );
```

Listing 12.7 *The vTaskList() API function prototype*

vTaskList() parameters

- `pcWriteBuffer`

  A pointer to a character buffer into which the formatted and human readable table is written. The buffer must be large enough to hold the entire table, as no boundary checking is performed.

12.5.6 The vTaskGetRunTimeStatistics() Helper Function

`vTaskGetRunTimeStatistics()` formats collected run-time statistics into a human readable ASCII table.

`vTaskGetRunTimeStatistics()` is a very processor intensive function and leaves the scheduler suspended for an extended period. Therefore, it is recommended to use the function for debug purposes only, and not in a production real-time system.

`vTaskGetRunTimeStatistics()` is available when `configGENERATE_RUN_TIME_STATS` is set to 1, `configUSE_STATS_FORMATTING_FUNCTIONS` is set greater than 0, and `configUSE_TRACE_FACILITY` is set to 1 in FreeRTOSConfig.h.

```
void vTaskGetRunTimeStatistics( char * pcWriteBuffer, size_t uxBufferLength );
```

Listing 12.8 *The vTaskGetRunTimeStatistics() API function prototype*

vTaskGetRunTimeStatistics() parameters

- `pcWriteBuffer`

  A pointer to a character buffer into which the formatted and human readable table is written. This buffer is assumed to be large enough to contain the generated report. Approximately 40 bytes per task should be sufficient.

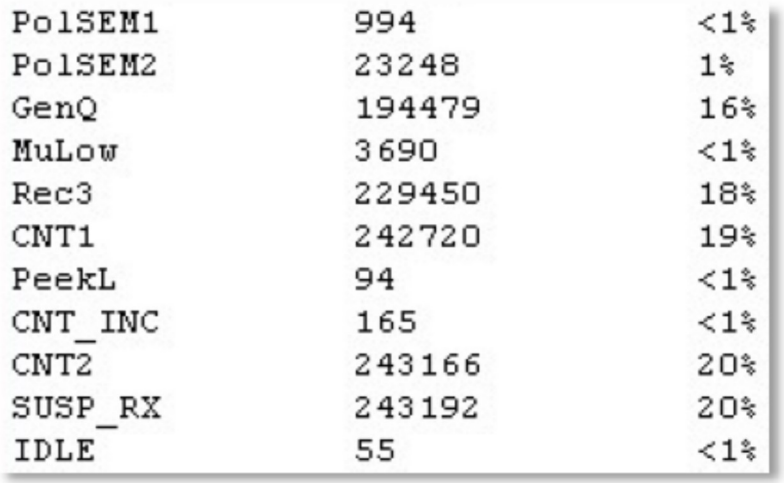
- `uxBufferLength`

  Length of the `pcWriteBuffer`.

An example of the output generated by `vTaskGetRunTimeStatistics()` is shown in Figure 12.8. In the output:

- Each row provides information on a single task.
- The first column is the task name.
- The second column is the amount of time the task has spent in the Running state as an absolute value. See the description of `ulRunTimeCounter`.

- The third column is the amount of time the task has spent in the Running state as a percentage of the total time since the target was booted. The total of the displayed percentage times will normally be less than the expected 100% because statistics are collected and calculated using integer calculations that round down to the nearest integer value.



PolSEM1	994	<1%
PolSEM2	23248	1%
GenQ	194479	16%
MuLow	3690	<1%
Rec3	229450	18%
CNT1	242720	19%
PeekL	94	<1%
CNT_INC	165	<1%
CNT2	243166	20%
SUSP_RX	243192	20%
IDLE	55	<1%

Figure 12.8 *Example output generated by vTaskGetRunTimeStatistics()*

> Note: The older version of `vTaskGetRunTimeStatistics` is `vTaskGetRunTimeStats`. `vTaskGetRunTimeStats` assumes that the pcWriteBuffer is of length `configSTATS_BUFFER_MAX_LENGTH`. This function is there only for backward compatiblity. New applications are recommended to use `vTaskGetRunTimeStatistics` and supply the length of the pcWriteBuffer explicitly.

```
void vTaskGetRunTimeStats( signed char *pcWriteBuffer );
```

Listing 12.9 *The vTaskGetRunTimeStats() API function prototype*

vTaskGetRunTimeStats() parameters

- `pcWriteBuffer`

  A pointer to a character buffer into which the formatted and human readable table is written. The buffer must be large enough to hold the entire table, as no boundary checking is performed.

12.5.7 Generating and Displaying Run-Time Statistics, a Worked Example

This example uses a hypothetical 16-bit timer to generate a 32-bit run-time statistics clock. The counter is configured to generate an interrupt each time the 16-bit value reaches its maximum value—effectively creating an overflow interrupt. The interrupt service routine counts the number of overflow occurrences.

The 32-bit value is created by using the count of overflow occurrences as the two most significant bytes of the 32-bit value, and the current 16-bit counter value as the two least significant bytes of the 32-bit value. Pseudo code for the interrupt service routine is shown in Listing 12.10.

```
void TimerOverflowInterruptHandler( void )
{
    /* Just count the number of interrupts. */
    ulOverflowCount++;

    /* Clear the interrupt. */
    ClearTimerInterrupt();
}
```

Listing 12.10 *16-bit timer overflow interrupt handler used to count timer overflows*

Listing 12.11 shows the lines added to FreeRTOSConfig.h to enable the collection of run-time statistics.

```
/* Set configGENERATE_RUN_TIME_STATS to 1 to enable collection of run-time
   statistics. When this is done, both portCONFIGURE_TIMER_FOR_RUN_TIME_STATS()
   and portGET_RUN_TIME_COUNTER_VALUE() or
   portALT_GET_RUN_TIME_COUNTER_VALUE(x) must also be defined. */
#define configGENERATE_RUN_TIME_STATS 1

/* portCONFIGURE_TIMER_FOR_RUN_TIME_STATS() is defined to call the function
   that sets up the hypothetical 16-bit timer (the function's implementation
   is not shown). */
void vSetupTimerForRunTimeStats( void );
#define portCONFIGURE_TIMER_FOR_RUN_TIME_STATS()  vSetupTimerForRunTimeStats()

/* portALT_GET_RUN_TIME_COUNTER_VALUE() is defined to set its parameter to the
   current run-time counter/time value. The returned time value is 32-bits
   long, and is formed by shifting the count of 16-bit timer overflows into
   the top two bytes of a 32-bit number, then bitwise ORing the result with
   the current 16-bit counter value. */
#define portALT_GET_RUN_TIME_COUNTER_VALUE( ulCountValue )                  \
{                                                                           \
    extern volatile unsigned long ulOverflowCount;                          \
                                                                            \
    /* Disconnect the clock from the counter so it does not change          \
       while its value is being used. */                                    \
    PauseTimer();                                                           \
                                                                            \
    /* The number of overflows is shifted into the most significant         \
       two bytes of the returned 32-bit value. */                           \
    ulCountValue = ( ulOverflowCount << 16UL );                             \
                                                                            \
    /* The current counter value is used as the two least significant       \
       bytes of the returned 32-bit value. */                               \
    ulCountValue |= ( unsigned long ) ReadTimerCount();                     \
                                                                            \
    /* Reconnect the clock to the counter. */                               \
    ResumeTimer();                                                          \
}
```

Listing 12.11 *Macros added to FreeRTOSConfig.h to enable the collection of run-time statistics*

The task shown in Listing 12.12 prints out the collected run-time statistics every 5 seconds.

```
#define RUN_TIME_STATS_STRING_BUFFER_LENGTH       512

/* For clarity, calls to fflush() have been omitted from this code listing. */
static void prvStatsTask( void *pvParameters )
{
    TickType_t xLastExecutionTime;

    /* The buffer used to hold the formatted run-time statistics text needs to
       be quite large. It is therefore declared static to ensure it is not
       allocated on the task stack. This makes this function non re-entrant. */
    static signed char cStringBuffer[ RUN_TIME_STATS_STRING_BUFFER_LENGTH ];

    /* The task will run every 5 seconds. */
    const TickType_t xBlockPeriod = pdMS_TO_TICKS( 5000 );

    /* Initialize xLastExecutionTime to the current time. This is the only
       time this variable needs to be written to explicitly. Afterwards it is
       updated internally within the vTaskDelayUntil() API function. */
    xLastExecutionTime = xTaskGetTickCount();

    /* As per most tasks, this task is implemented in an infinite loop. */
    for( ;; )
    {
        /* Wait until it is time to run this task again. */
        xTaskDelayUntil( &xLastExecutionTime, xBlockPeriod );

        /* Generate a text table from the run-time stats. This must fit into
           the cStringBuffer array. */
        vTaskGetRunTimeStatistics( cStringBuffer,
RUN_TIME_STATS_STRING_BUFFER_LENGTH );

        /* Print out column headings for the run-time stats table. */
        printf( "\nTask\t\tAbs\t\t\t%%\n" );
        printf( "-------------------------------------------------------------\n"
);

        /* Print out the run-time stats themselves. The table of data contains
           multiple lines, so the vPrintMultipleLines() function is called
           instead of calling printf() directly. vPrintMultipleLines() simply
           calls printf() on each line individually, to ensure the line
           buffering works as expected. */
        vPrintMultipleLines( cStringBuffer );
    }
}
```

Listing 12.12 *The task that prints out the collected run-time statistics*

12.6 Trace Hook Macros

Trace macros are macros that have been placed at key points within the FreeRTOS source code. By default, the macros are empty, and so do not generate any code, and have no run time overhead. By overriding the default empty implementations, an application writer can:

- Insert code into FreeRTOS without modifying the FreeRTOS source files.
- Output detailed execution sequencing information by any means available on the target hardware. Trace macros appear in enough places in the FreeRTOS source code to allow them to be used to create a full and detailed scheduler activity trace and profiling log.

12.6.1 Available Trace Hook Macros

It would take too much space to detail every macro here. The list below details the subset of macros deemed to be most useful to an application writer.

Many of the descriptions in the list below refer to a variable called `pxCurrentTCB`. `pxCurrentTCB` is a FreeRTOS private variable that holds the handle of the task in the Running state, and is available to any macro that is called from the FreeRTOS/Source/tasks.c source file.

A selection of the most commonly used trace hook macros

- `traceTASK_INCREMENT_TICK(xTickCount)`

  Called during the tick interrupt, before the tick count is incremented. The `xTickCount` parameter passes the new tick count value into the macro.

- `traceTASK_SWITCHED_OUT()`

  Called before a new task is selected to run. At this point, `pxCurrentTCB` contains the handle of the task about to leave the Running state.

- `traceTASK_SWITCHED_IN()`

  Called after a task is selected to run. At this point, `pxCurrentTCB` contains the handle of the task about to enter the Running state.

- `traceBLOCKING_ON_QUEUE_RECEIVE(pxQueue)`

  Called immediately before the currently executing task enters the Blocked state following an attempt to read from an empty queue, or an attempt to 'take' an empty semaphore or mutex. The `pxQueue` parameter passes the handle of the target queue or semaphore into the macro.

- `traceBLOCKING_ON_QUEUE_SEND(pxQueue)`

  Called immediately before the currently executing task enters the Blocked state following an attempt to write to a queue that is full. The `pxQueue` parameter passes the handle of the target queue into the macro.

- `traceQUEUE_SEND(pxQueue)`

  Called from within `xQueueSend()`, `xQueueSendToFront()`, `xQueueSendToBack()`, or any of the semaphore 'give' functions, when the queue send or semaphore 'give' is successful. The `pxQueue` parameter passes the handle of the target queue or semaphore into the macro.

- `traceQUEUE_SEND_FAILED(pxQueue)`

  Called from within `xQueueSend()`, `xQueueSendToFront()`, `xQueueSendToBack()`, or any of the semaphore 'give' functions, when the queue send or semaphore 'give' operation fails. A queue send or semaphore 'give' will fail if the queue is full and remains full for the duration of any block time specified. The `pxQueue` parameter passes the handle of the target queue or semaphore into the macro.

- `traceQUEUE_RECEIVE(pxQueue)`

  Called from within `xQueueReceive()` or any of the semaphore 'take' functions when the queue receive or semaphore 'take' is successful. The `pxQueue` parameter passes the handle of the target queue or semaphore into the macro.

- `traceQUEUE_RECEIVE_FAILED(pxQueue)`

  Called from within `xQueueReceive()` or any of the semaphore 'take' functions when the queue or semaphore receive operation fails. A queue receive or semaphore 'take' operation will fail if the queue or semaphore is empty and remains empty for the duration of any block time specified. The `pxQueue` parameter passes the handle of the target queue or semaphore into the macro.

- `traceQUEUE_SEND_FROM_ISR(pxQueue)`

  Called from within `xQueueSendFromISR()` when the send operation is successful. The `pxQueue` parameter passes the handle of the target queue into the macro.

- `traceQUEUE_SEND_FROM_ISR_FAILED(pxQueue)`

  Called from within `xQueueSendFromISR()` when the send operation fails. A send operation will fail if the queue is already full. The `pxQueue` parameter passes the handle of the target queue into the macro.

- `traceQUEUE_RECEIVE_FROM_ISR(pxQueue)`

  Called from within `xQueueReceiveFromISR()` when the receive operation is successful. The `pxQueue` parameter passes the handle of the target queue into the macro.

- `traceQUEUE_RECEIVE_FROM_ISR_FAILED(pxQueue)`

  Called from within `xQueueReceiveFromISR()` when the receive operation fails due to the queue already being empty. The `pxQueue` parameter passes the handle of the target queue into the macro.

- `traceTASK_DELAY_UNTIL( xTimeToWake )`

  Called from within `xTaskDelayUntil()` immediately before the calling task enters the Blocked state.

- `traceTASK_DELAY()`

  Called from within `vTaskDelay()` immediately before the calling task enters the Blocked state.

12.6.2 Defining Trace Hook Macros

Each trace macro has a default empty definition. The default definition can be overridden by providing a new macro definition in FreeRTOSConfig.h. If trace macro definitions become long or complex, then they can be implemented in a new header file that is then itself included from FreeRTOSConfig.h.

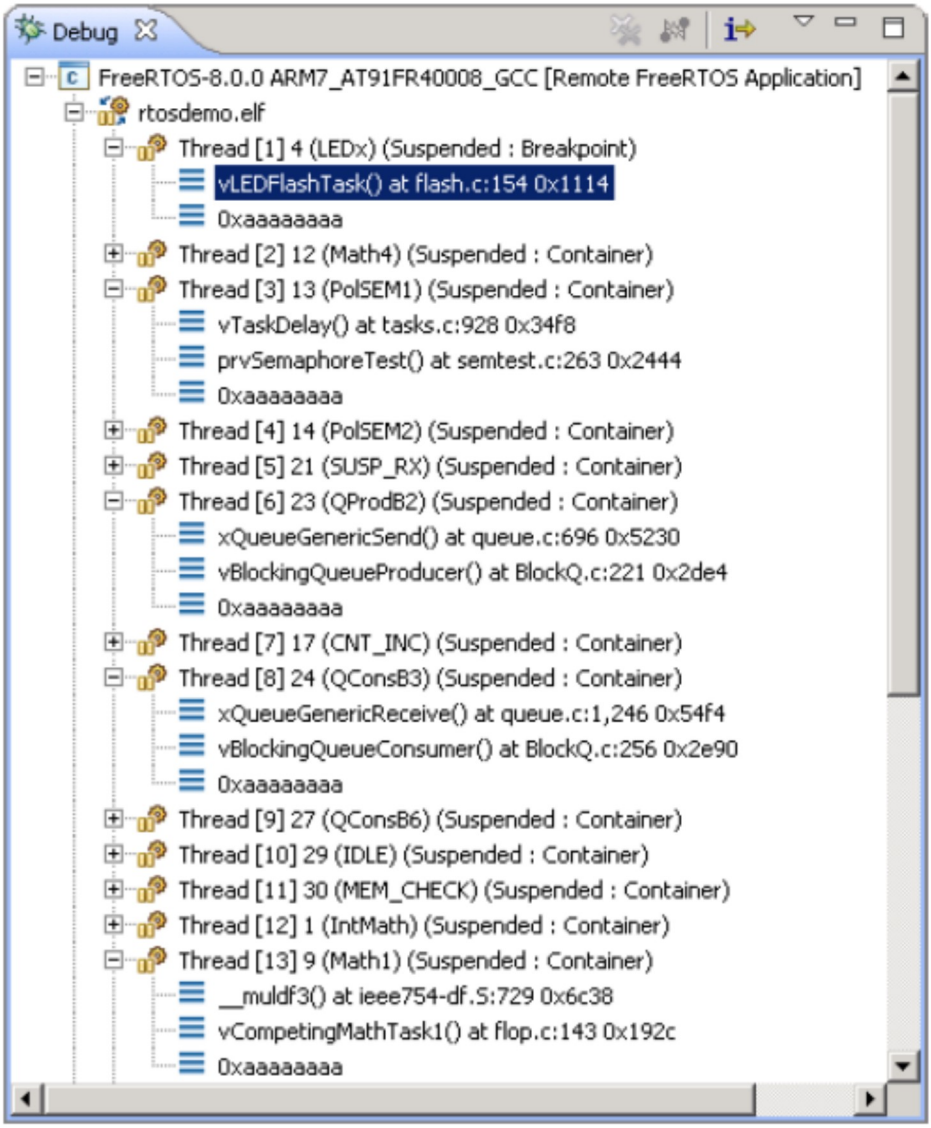
In accordance with software engineering best practice, FreeRTOS maintains a strict data hiding policy. Trace macros allow user code to be added to the FreeRTOS source files, so the data types visible to the trace macros will be different to those visible to application code:

- Inside the FreeRTOS/Source/tasks.c source file, a task handle is a pointer to the data structure that describes a task (the task's *Task Control Block*, or *TCB*). Outside of the FreeRTOS/Source/tasks.c source file a task handle is a pointer to void.
- Inside the FreeRTOS/Source/queue.c source file, a queue handle is a pointer to the data structure that describes a queue. Outside of the FreeRTOS/Source/queue.c source file a queue handle is a pointer to void.

> *Extreme caution is required if a normally private FreeRTOS data structure is accessed directly by a trace macro, as private data structures might change between FreeRTOS versions.*

12.6.3 FreeRTOS Aware Debugger Plug-ins

Plug-ins that provide some FreeRTOS awareness are available for the following IDEs. This list may not be an exhaustive:



- Eclipse (StateViewer)
- Eclipse (ThreadSpy)
- IAR
- ARM DS-5
- Atollic TrueStudio
- Microchip MPLAB
- iSYSTEM WinIDEA
- STM32CubeIDE

13 Troubleshooting

13.1 Chapter Introduction and Scope

This chapter highlights the most common issues encountered by users who are new to FreeRTOS. First, it focuses on three issues that have proven to be the most frequent source of support requests over the years: incorrect interrupt priority assignment, stack overflow, and inappropriate use of printf(). It then briefly, and in an FAQ style, touches on other common errors, their possible causes, and their solutions.

> *Using `configASSERT()` improves productivity by immediately trapping and identifying many of the most common sources of error. It is strongly advised to have `configASSERT()` defined while developing or debugging a FreeRTOS application. `configASSERT()` is described in section 12.2.*

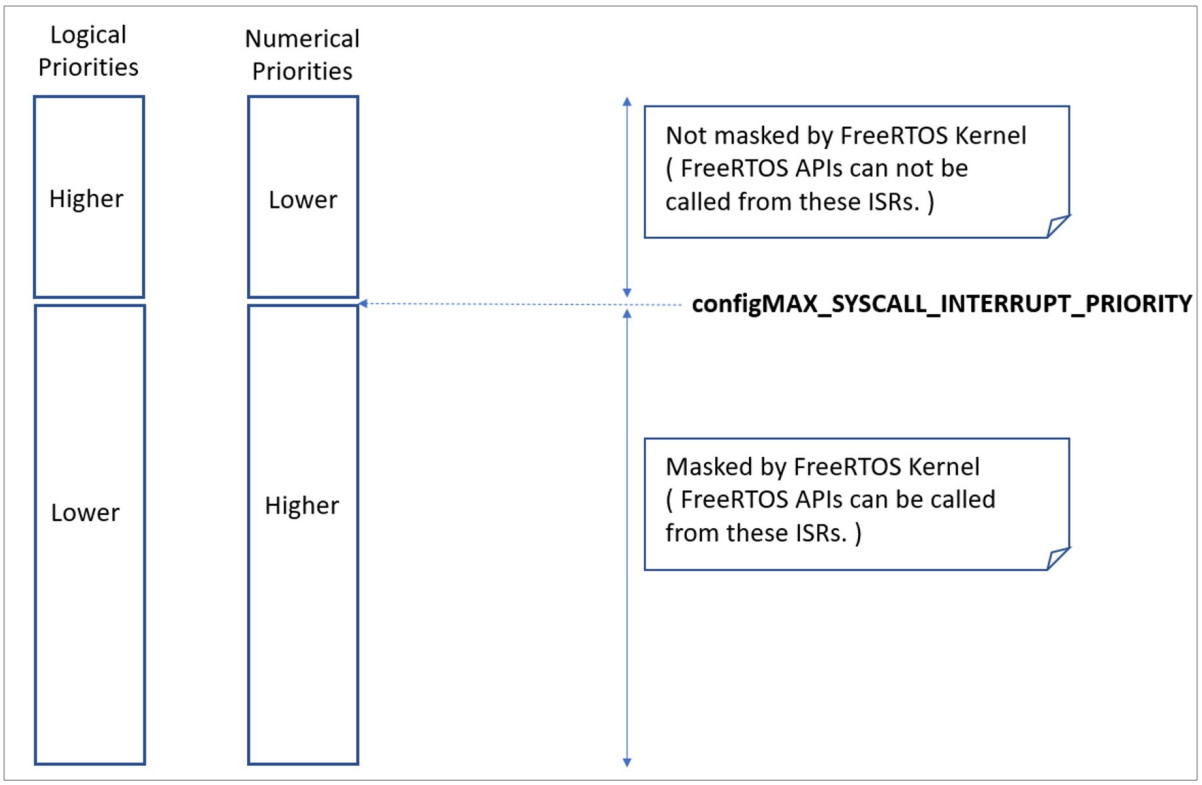
13.2 Interrupt Priorities

> *Note: This is the number one cause of support requests, and in most ports defining `configASSERT()` will trap the error immediately!*

If the FreeRTOS port in use supports interrupt nesting, and the service routine for an interrupt makes use of the FreeRTOS API, then it is *essential* the interrupt's priority is set at or below `configMAX_SYSCALL_INTERRUPT_PRIORITY`, as described in section 7.8, Interrupt Nesting. Failure to do this will result in ineffective critical sections, which in turn will result in intermittent failures.

Take particular care if running FreeRTOS on a processor where:

- Interrupt priorities default to having the highest possible priority, which is the case on some ARM Cortex processors, and possibly others. On such processors, the priority of an interrupt that uses the FreeRTOS API cannot be left uninitialized.
- Numerically high priority numbers represent logically low interrupt priorities, which may seem counterintuitive, and therefore cause confusion. Again this is the case on ARM Cortex processors, and possibly others.
- For example, on such a processor an interrupt that is executing at priority 5 can itself be interrupted by an interrupt that has a priority of 4. Therefore, if `configMAX_SYSCALL_INTERRUPT_PRIORITY` is set to 5, any interrupt that uses the FreeRTOS API can only be assigned a priority numerically higher than or equal to 5. In that case, interrupt priorities of 5 or 6 would be valid, but an interrupt priority of 3 is definitely invalid.



- Different library implementations expect the priority of an interrupt to be specified in a different way. Again, this is particularly relevant to libraries that target ARM Cortex processors, where interrupt priorities are bit shifted before being written to the hardware registers. Some libraries will perform the bit shift themselves, whereas others expect the bit shift to be performed before the priority is passed into the library function.
- Different implementations of the same architecture implement a different number of interrupt priority bits. For example, a Cortex-M processor from one manufacturer may implement 3 priority bits, while a Cortex-M processor from another manufacturer may implement 4 priority bits.
- The bits that define the priority of an interrupt can be split between bits that define a pre-emption priority, and bits that define a sub-priority. Ensure all the bits are assigned to specifying a pre-emption priority, so that sub-priorities are not used.

In some FreeRTOS ports, `configMAX_SYSCALL_INTERRUPT_PRIORITY` has the alternative name `configMAX_API_CALL_INTERRUPT_PRIORITY`.

13.3 Stack Overflow

Stack overflow is the second most common source of support requests. FreeRTOS provides several features to assist trapping and debugging stack related issues[^28].

[^28]: These features are not available in the FreeRTOS Windows port.

13.3.1 The uxTaskGetStackHighWaterMark() API Function

Each task maintains its own stack, the total size of which is specified when the task is created. `uxTaskGetStackHighWaterMark()` is used to query how close a task has come to overflowing the stack space allocated to it. This value is called the stack 'high water mark'.

```
UBaseType_t uxTaskGetStackHighWaterMark( TaskHandle_t xTask );
```

Listing 13.1 *The uxTaskGetStackHighWaterMark() API function prototype*

uxTaskGetStackHighWaterMark() parameters and return value

- `xTask`

  The handle of the task whose stack high water mark is being queried (the subject task)—see the pxCreatedTask parameter of the `xTaskCreate()` API function for information on obtaining handles to tasks.

  A task can query its own stack high water mark by passing NULL in place of a valid task handle.

- Return value

  The amount of stack used by the task grows and shrinks as the task executes and interrupts are processed. `uxTaskGetStackHighWaterMark()` returns the minimum amount of remaining stack space that has been available since the task started executing. This is the amount of stack that remains unused when stack usage is at its greatest (or deepest) value. The closer the high water mark is to zero, the closer the task has come to overflowing its stack.

`uxTaskGetStackHighWaterMark2()` API can be used instead of `uxTaskGetStackHighWaterMark()` which only differs in the return type.

```
configSTACK_DEPTH_TYPE uxTaskGetStackHighWaterMark2( TaskHandle_t xTask );
```

Listing 13.2 *The uxTaskGetStackHighWaterMark2() API function prototype*

Using `configSTACK_DEPTH_TYPE` allows the application writer to control the type used for stack depth.

13.3.2 Run Time Stack Checking—Overview

FreeRTOS includes three optional run time stack checking mechanisms. These are controlled by the `configCHECK_FOR_STACK_OVERFLOW` compile time configuration constant within FreeRTOSConfig.h. Both methods increase the time it takes to perform a context switch.

The stack overflow hook (or stack overflow callback) is a function that is called by the kernel when it detects a stack overflow. To use a stack overflow hook function:

1. Set `configCHECK_FOR_STACK_OVERFLOW` to either 1 , 2 or 3 in FreeRTOSConfig.h, as described in the following sub-sections.
2. Provide the implementation of the hook function, using the exact function name and prototype shown in Listing 13.3.

```
void vApplicationStackOverflowHook( TaskHandle_t *pxTask, signed char *pcTaskName
);
```

Listing 13.3 *The stack overflow hook function prototype*

The stack overflow hook is provided to make trapping and debugging stack errors easier, but there is no real way to recover from a stack overflow when it occurs. The function's parameters pass the handle and name of the task that has overflowed its stack into the hook function.

The stack overflow hook gets called from the context of an interrupt.

Some microcontrollers generate a fault exception when they detect an incorrect memory access, and it is possible for a fault to be triggered before the kernel has a chance to call the stack overflow hook function.

13.3.3 Run Time Stack Checking—Method 1

Method 1 is selected when `configCHECK_FOR_STACK_OVERFLOW` is set to 1.

A task's entire execution context is saved onto its stack each time it gets swapped out. It is likely that this will be the time at which stack usage reaches its peak. When `configCHECK_FOR_STACK_OVERFLOW` is set to 1, the kernel checks that the stack pointer remains within the valid stack space after the context has been saved. The stack overflow hook is called if the stack pointer is found to be outside its valid range.

Method 1 is quick to execute, but can miss stack overflows that occur between context switches.

13.3.4 Run Time Stack Checking—Method 2

Method 2 performs additional checks to those already described for method 1. It is selected when `configCHECK_FOR_STACK_OVERFLOW` is set to 2.

When a task is created, its stack is filled with a known pattern. Method 2 tests the last valid 20 bytes of the task stack space to verify that this pattern has not been overwritten. The stack overflow hook function is called if any of the 20 bytes have changed from their expected values.

Method 2 is not as quick to execute as method 1, but is still relatively fast, as only 20 bytes are tested. Most likely, it will catch all stack overflows; however, it is possible (but highly improbable) that some overflows will be missed.

13.3.4 Run Time Stack Checking—Method 3

Method 3 is selected when `configCHECK_FOR_STACK_OVERFLOW` is set to 3.

This method is available only for selected ports. When available, this method enables ISR stack checking. When an ISR stack overflow is detected, an assert is triggered. Note that the stack overflow hook function is not called in this case because it is specific to a task stack and not the ISR stack.

13.4 Use of printf() and sprintf()

Logging via `printf()` is a common source of error, and, unaware of this, it is common for application developers to then add further calls to `printf()` to aid debugging, and in-so-doing, exacerbate the problem.

Many cross compiler vendors will provide a `printf()` implementation that is suitable for use in small embedded systems. Even when that is the case, the implementation may not be thread safe, probably won't be

suitable for use inside an interrupt service routine, and depending on where the output is directed, take a relatively long time to execute.

Particular care must be taken if a `printf()` implementation that is specifically designed for small embedded systems is not available, and a generic `printf()` implementation is used instead, as:

- Just including a call to `printf()` or `sprintf()` can massively increase the size of the application's executable.
- `printf()` and `sprintf()` may call `malloc()`, which might be invalid if a memory allocation scheme other than heap_3 is in use. See section 3.2, Example Memory Allocation Schemes, for more information.
- `printf()` and `sprintf()` may require a stack that is many times bigger than would otherwise be required.

13.4.1 Printf-stdarg.c

Many of the FreeRTOS demonstration projects use a file called printf-stdarg.c, which provides a minimal and stack-efficient implementation of `sprintf()` that 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 also provides a mechanism for directing the `printf()` output to a port character by character which, while slow, allows stack usage to be decreased even further.

Note that not all copies of `printf-stdarg.c` included in the FreeRTOS download implement `snprintf()`. Copies that do not implement `snprintf()` simply ignore the buffer size parameter, as they map directly to `sprintf()`.

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

13.5 Other Common Sources of Error

13.5.1 Symptom: Adding a simple task to a demo causes the demo to crash

Creating a task requires memory to be obtained from the heap. Many of the demo application projects dimension the heap to be exactly big enough to create the demo tasks—so, after the tasks are created, there will be insufficient heap remaining for any further tasks, queues, event groups, or semaphores to be added.

The idle task, and possibly also the RTOS daemon task, are created automatically when `vTaskStartScheduler()` is called. `vTaskStartScheduler()` will return only if there is not enough heap memory remaining for these tasks to be created. Including a null loop `[ for(;;); ]` after the call to `vTaskStartScheduler()` can make this error easier to debug.

To be able to add more tasks, you must either increase the heap size, or remove some of the existing demo tasks. The increase in heap size will always be limited by the amount of RAM available. See section 3.2, Example Memory Allocation Schemes, for more information.

13.5.2 Symptom: Using an API function within an interrupt causes the application to crash

Do not use API functions within interrupt service routines, unless the name of the API function ends with '...FromISR()'. In particular, do not create a critical section within an interrupt unless using the interrupt safe macros. See section 7.2, Using the FreeRTOS API from an ISR, for more information.

In FreeRTOS ports that support interrupt nesting, do not use any API functions in an interrupt that has been assigned an interrupt priority above `configMAX_SYSCALL_INTERRUPT_PRIORITY`. See section 7.8, Interrupt Nesting, for more information.

13.5.3 Symptom: Sometimes the application crashes within an interrupt service routine

The first thing to check is that the interrupt is not causing a stack overflow. Some ports only check for stack overflow within tasks, and not within interrupts.

The way interrupts are defined and used differs between ports and between compilers. Therefore, the second thing to check is that the syntax, macros, and calling conventions used in the interrupt service routine are exactly as described on the documentation page provided for the port being used, and exactly as demonstrated in the demo application provided with the port.

If the application is running on a processor that uses numerically low priority numbers to represent logically high priorities, then ensure the priority assigned to each interrupt takes that into account, as it can seem counter-intuitive. If the application is running on a processor that defaults the priority of each interrupt to the maximum possible priority, then ensure the priority of each interrupt is not left at its default value. See section 7.8, Interrupt Nesting, and section 13.2, Interrupt Priorities, for more information.

13.5.4 Symptom: The scheduler crashes when attempting to start the first task

Ensure the FreeRTOS interrupt handlers have been installed. Refer to the documentation page for the FreeRTOS port in use for information, and the demo application provided for the port for an example.

Some processors must be in a privileged mode before the scheduler can be started. The easiest way to achieve this is to place the processor into a privileged mode within the C startup code, before main() is called.

13.5.5 Symptom: Interrupts are unexpectedly left disabled, or critical sections do not nest correctly

If a FreeRTOS API function is called before the scheduler has been started then interrupts will deliberately be left disabled, and not re-enabled again until the first task starts to execute. This is done to protect the system from crashes caused by interrupts that attempt to use FreeRTOS API functions during system initialization, before the scheduler has been started, and while the scheduler may be in an inconsistent state.

Do not alter the microcontroller interrupt enable bits or priority flags using any method other than calls to `taskENTER_CRITICAL()` and `taskEXIT_CRITICAL()`. These macros keep a count of their call nesting depth to ensure interrupts become enabled again only when the call nesting has unwound completely to zero. Be aware that some library functions may themselves enable and disable interrupts.

13.5.6 Symptom: The application crashes even before the scheduler is started

An interrupt service routine that could potentially cause a context switch must not be permitted to execute before the scheduler has been started. The same applies to any interrupt service routine that attempts to send

to or receive from a FreeRTOS object, such as a queue or semaphore. A context switch cannot occur until after the scheduler has started.

Many API functions cannot be called until after the scheduler has been started. It is best to restrict API usage to the creation of objects such as tasks, queues, and semaphores, rather than the use of these objects, until after `vTaskStartScheduler()` has been called.

13.5.7 Symptom: Calling API functions while the scheduler is suspended, or from inside a critical section, causes the application to crash

The scheduler is suspended by calling `vTaskSuspendAll()` and resumed (unsuspended) by calling `xTaskResumeAll()`. A critical section is entered by calling `taskENTER_CRITICAL()`, and exited by calling `taskEXIT_CRITICAL()`.

Do not call API functions while the scheduler is suspended, or from inside a critical section.

13.6 Additional Debugging Steps

If you encounter an issue not covered in the common causes described above, you can try to use some of the following debugging steps.

- Define `configASSERT()`, enable malloc failed checking and stack overflow checking in the application's FreeRTOSConfig file.
- Check the return values of the FreeRTOS APIs to make sure those were successful.
- Check that the secheduler related configuration, like `configUSE_TIME_SLICING`, and `configUSE_PREEMPTION` are set correctly as per the application requirements.
- This page provides details about debugging hard faults on Cortex-M microcontrollers.