Real Time Operating System "FreeRTOS"
Interrupt Management
Counting Semaphores/Queues

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[Using the FreeRTOS Real Time Kernel - a Practical Guide - Cortex M3 Edition (FreeRTOS Tutorial Books) by Richard Barry]

Agenda

- **Binary semaphore pitfall**
- **Counting semaphore handling of fast interrupts (Example 13)**
- **Sending/Receiving to Queues from ISR (Example 14)**

Binary Semaphore Synchronization (Maximum One Pending Interrupt)

Figure 29. A binary semaphore can latch at most one event

Counting Semaphore

Counting Semaphore Synchronization

Figure 30. Using a counting semaphore to 'count' events

Counting Semaphore; Use Cases

- **Counting events**
  - An event handler will 'give' a semaphore each time an event occurs—causing the semaphore’s count value to be incremented on each ‘give’.
  - A handler task will 'take' a semaphore each time it processes an event—causing the semaphore’s count value to be decremented on each take.
  - The count value is the difference between the number of events that have occurred and the number that have been processed.
  - Counting semaphores that are used to count events are created with an initial count value of zero.

- **Resource management.**
  - The count value indicates the number of resources available.
  - To obtain control of a resource a task must first obtain a semaphore—decrementing the semaphore’s count value.
  - When the count value reaches zero, there are no free resources.
  - When a task finishes with the resource, it 'gives' the semaphore back—incrementing the semaphore’s count value.
  - Counting semaphores that are used to manage resources are created so that their initial count value equals the number of resources that are available.

Counting Semaphore; FreeRtos API

```
xSemaphoreHandle xSemaphoreCreateCounting( unsigned portBASE_TYPE uxMaxCount,
                                           unsigned portBASE_TYPE uxInitialCount );
```

- **uxMaxCount: The maximum value the semaphore will count to.**
  - **uxMaxCount value is effectively the length of the "queue".**
  - **When the semaphore is to be used to count or latch events, uxMaxCount is the maximum number of events that can be latched.**
  - **When the semaphore is to be used to manage access to a collection of resources, uxMaxCount should be set to the total number of resources that are available.**

- **uxInitialCount: The initial count value of the semaphore after it has been created.**
  - **When the semaphore is to be used to count or latch events, uxInitialCount should be set to zero—as, presumably, when the semaphore is created, no events have yet occurred.**
  - **When the semaphore is to be used to manage access to a collection of resources, uxInitialCount should be set to equal uxMaxCount—as, presumably, when the semaphore is created, all the resources are available.**

Counting Semaphore; Example 13

```
/* Before a semaphore is used it must be explicitly created.  In this example
a counting semaphore is created.  The semaphore is created to have a maximum
count value of 10, and an initial count value of 0. */
xCountingSemaphore = xSemaphoreCreateCounting( 10, 0 );
```

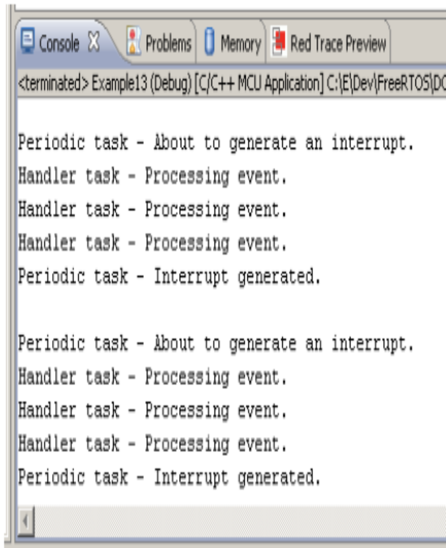
```
void vSoftwareInterruptHandler( void )
{
portBASE_TYPE xHigherPriorityTaskWoken = pdFALSE;

    /* 'Give' the semaphore multiple times.  The first will unblock the handler
    task, the following 'gives' are to demonstrate that the semaphore latches
    the events to allow the handler task to process them in turn without any
    events getting lost.  This simulates multiple interrupts being taken by the
    processor, even though in this case the events are simulated within a single
    interrupt occurrence.*/
    xSemaphoreGiveFromISR( xCountingSemaphore, &xHigherPriorityTaskWoken );
    xSemaphoreGiveFromISR( xCountingSemaphore, &xHigherPriorityTaskWoken );
    xSemaphoreGiveFromISR( xCountingSemaphore, &xHigherPriorityTaskWoken );

    /* Clear the software interrupt bit using the interrupt controllers Clear
    Pending register. */
    mainCLEAR_INTERRUPT();

    /* Giving the semaphore may have unblocked a task - if it did and the
    unblocked task has a priority equal to or above the currently executing
    task then xHigherPriorityTaskWoken will have been set to pdTRUE and
    portEND_SWITCHING_ISR() will force a context switch to the newly unblocked
    higher priority task.

    NOTE: The syntax for forcing a context switch within an ISR varies between
    FreeRTOS ports.  The portEND_SWITCHING_ISR() macro is provided as part of
    the Cortex-M3 port layer for this purpose.  taskYIELD() must never be called
    from an ISR! */
    portEND_SWITCHING_ISR( xHigherPriorityTaskWoken );
}
```



Listing 51. The implementation of the interrupt service routine used by Example 13

Using Queues within an Interrupt Service Routine

```
portBASE_TYPE xQueueSendToBackFromISR( xQueueHandle xQueue,
                                       void *pvItemToQueue
                                       portBASE_TYPE *pxHigherPriorityTaskWoken
                                     );
```

Listing 53. The xQueueSendToBackFromISR() API function prototype

- pxHigherPriorityTaskWoken It is possible that a single queue will have one or more tasks blocked on it waiting for data to become available.
- Calling xQueueSendToFrontFromISR() or xQueueSendToBackFromISR() can make data available, and so cause such a task to leave the Blocked state.
- If calling the API function causes a task to leave the Blocked state, and the unblocked task has a priority equal to or higher than the currently executing task (the task that was interrupted), then, internally, the API function will set *pxHigherPriorityTaskWoken to pdTRUE.

Using Queues within an Interrupt Service Routine; Example 14

```
int main( void )
{
    /* Before a queue can be used it must first be created.  Create both queues
    used by this example.  One queue can hold variables of type unsigned long,
    the other queue can hold variables of type char*.  Both queues can hold a
    maximum of 10 items.  A real application should check the return values to
    ensure the queues have been successfully created. */
    xIntegerQueue = xQueueCreate( 10, sizeof( unsigned long ) );
    xStringQueue = xQueueCreate( 10, sizeof( char * ) );

    /* Enable the software interrupt and set its priority. */
    prvSetupSoftwareInterrupt();

    /* Create the task that uses a queue to pass integers to the interrupt service
    routine.  The task is created at priority 1. */
    xTaskCreate( vIntegerGenerator, "IntGen", 240, NULL, 1, NULL );

    /* Create the task that prints out the strings sent to it from the interrupt
    service routine.  This task is created at the higher priority of 2. */
    xTaskCreate( vStringPrinter, "String", 240, NULL, 2, NULL );

    /* Start the scheduler so the created tasks start executing. */
    vTaskStartScheduler();

    /* If all is well then main() will never reach here as the scheduler will
    now be running the tasks.  If main() does reach here then it is likely that
    there was insufficient heap memory available for the idle task to be created.
    Chapter 5 provides more information on memory management. */
    for( ;; );
}
```

Listing 57. The main() function for Example 14

Using Queues within an Interrupt Service Routine; Example 14

```
static void vIntegerGenerator( void *pvParameters )
{
portTickType xLastExecutionTime;
unsigned long ulValueToSend = 0;
int i;

    /* Initialize the variable used by the call to vTaskDelayUntil(). */
    xLastExecutionTime = xTaskGetTickCount();

    for( ;; )
    {
        /* This is a periodic task.  Block until it is time to run again.
        The task will execute every 200ms. */
        vTaskDelayUntil( &xLastExecutionTime, 200 / portTICK_RATE_MS );

        /* Send an incrementing number to the queue five times.  The values will
        be read from the queue by the interrupt service routine.  The interrupt
        service routine always empties the queue so this task is guaranteed to be
        able to write all five values, so a block time is not required. */
        for( i = 0; i < 5; i++ )
        {
            xQueueSendToBack( xIntegerQueue, &ulValueToSend, 0 );
            ulValueToSend++;
        }

        /* Force an interrupt so the interrupt service routine can read the
        values from the queue. */
        vPrintString( "Generator task - About to generate an interrupt.\n" );
        mainTRIGGER_INTERRUPT();
        vPrintString( "Generator task - Interrupt generated.\n\n" );
    }
}
```

Listing 54. The implementation of the task that writes to the queue in Example 14

Using Queues within an Interrupt Service Routine; Example 14

```
void vSoftwareInterruptHandler( void )
{
portBASE_TYPE xHigherPriorityTaskWoken = pdFALSE;
static unsigned long ulReceivedNumber;

/* The strings are declared static const to ensure they are not allocated to the
interrupt service routine stack, and exist even when the interrupt service routine
is not executing. */
static const char *pcStrings[] =
{
    "String 0\n",
    "String 1\n",
    "String 2\n",
    "String 3\n"
};

    /* Loop until the queue is empty. */
    while( xQueueReceiveFromISR( xIntegerQueue,
                                 &ulReceivedNumber,
                                 &xHigherPriorityTaskWoken ) != errQUEUE_EMPTY )
    {
        /* Truncate the received value to the last two bits (values 0 to 3 inc.),
        then send the string that corresponds to the truncated value to the other
        queue. */
        ulReceivedNumber &= 0x03;
        xQueueSendToBackFromISR( xStringQueue,
                                 &pcStrings[ ulReceivedNumber ],
                                 &xHigherPriorityTaskWoken );
    }

    /* Clear the software interrupt bit using the interrupt controllers Clear
    Pending register. */
    mainCLEAR_INTERRUPT();

    /* xHigherPriorityTaskWoken was initialised to pdFALSE.  It will have then
    been set to pdTRUE only if reading from or writing to a queue caused a task
    of equal or greater priority than the currently executing task to leave the
    Blocked state.  When this is the case a context switch should be performed.
    In all other cases a context switch is not necessary.

    NOTE: The syntax for forcing a context switch within an ISR varies between
    FreeRTOS ports.  The portEND_SWITCHING_ISR() macro is provided as part of
    the Cortex-M3 port layer for this purpose.  taskYIELD() must never be called
    from an ISR! */
    portEND_SWITCHING_ISR( xHigherPriorityTaskWoken );
}
```

Listing 55. The implementation of the interrupt service routine used by Example 14

Using Queues within an Interrupt Service Routine; Example 14

```c
static void vStringPrinter( void *pvParameters )
{
char *pcString;

     for( ;; )
     {
          /* Block on the queue to wait for data to arrive. */
          xQueueReceive( xStringQueue, &pcString, portMAX_DELAY );

          /* Print out the string received. */
          vPrintString( pcString );
     }
}
```

Listing 56. The task that prints out the strings received from the interrupt service routine in Example 14

Console ⌧ | Problems | Memory | Red Trace Preview

```
<terminated> Example14 (Debug) [C/C++ MCU Application] C:\E\Dev\FreeRTOS\DOC\Projects\191-ApplicationNotesAndBook\Source-Code-For-Example
Generator task - About to generate an interrupt.
String 2
String 3
String 0
String 1
String 2
Generator task - Interrupt generated.

Generator task - About to generate an interrupt.
String 3
String 0
String 1
String 2
String 3
Generator task - Interrupt generated.
```

Figure 32. The output produced when Example 14 is executed

Using Queues within an Interrupt Service Routine; Example 14

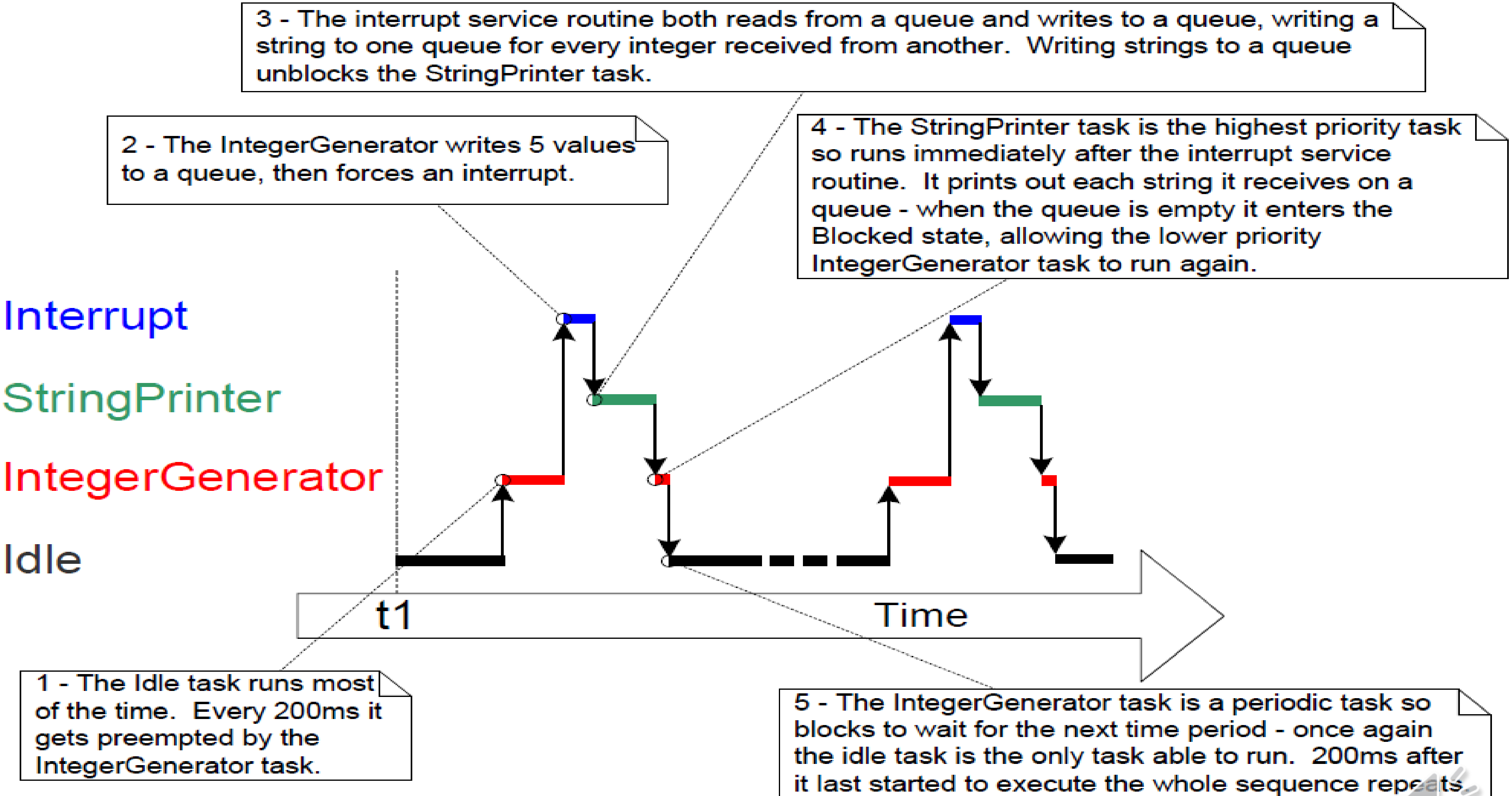


Figure 33. The sequence of execution produced by Example 14