HCM IU
Subject: ERTS
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Multi-Tasking and Real-Time Operating Systems

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Outline

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Multitasking

- Nearly all microcontroller-based systems perform more than one activity. For example, a temperature monitoring system is made up of three tasks that normally repeat after a short delay, namely:
  - Task 1 Reads the temperature
  - Task 2 Formats the temperature
  - Task 3 Displays the temperature
- More complex systems may have many complex tasks. In a multi-tasking system, numerous tasks require CPU time, and since there is only one CPU, some form of organization and coordination is needed so each task has the CPU time it needs. In practice, each task takes a very brief amount of time, so it seems as if all the tasks are executing in parallel and simultaneously.

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Multitasking

- What is Multitasking?
  - Separate tasks share one processor (or processors)
  - Each task executes within its own context
    - Owns processor
    - Sees its own variables
    - May be interrupted
  - Tasks may interact to execute as a whole program

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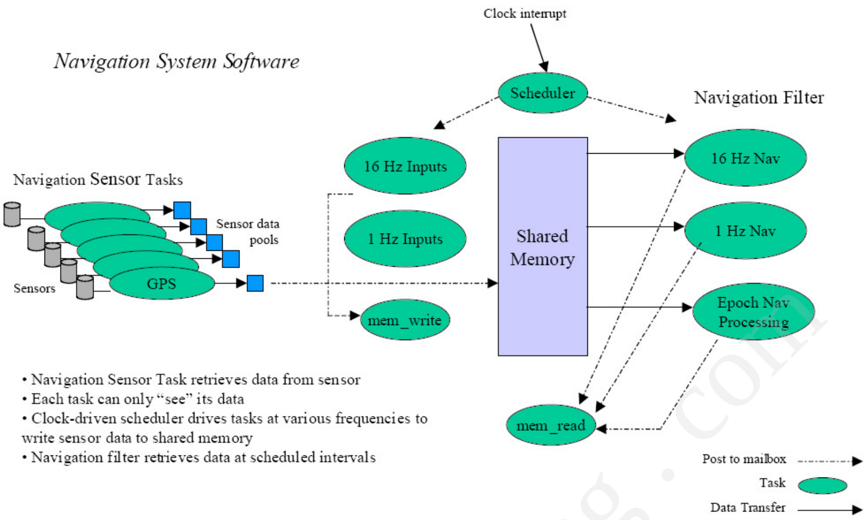
Multitasking Example



- Navigation Sensor Task retrieves data from sensor
- Each task can only "see" its data
- Clock-driven scheduler drives tasks at various frequencies to write sensor data to shared memory
- Navigation filter retrieves data at scheduled intervals

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Multitasking

- Context switching
  - When the CPU switches from running one task to running another, it is said to have switched contexts.
  - Save the MINIMUM needed to restore the interrupted process
    - Back to the book example, what might be needed? *(name, page, paragraph , word#)*
  - In a Computer System, the MINIMUM is often
    - contents of registers
    - contents of the program counter
    - contents of coprocessor registers (if applicable)
    - memory page registers
    - memory-mapped I/O
    - special variables
  - During context switching, interrupts are often disabled
  - Real Time Systems require minimal times for context switches

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Multitasking

- How do many tasks share the same CPU?
  - Cyclic Executive Systems
  - Round Robin Systems
  - Pre-emptive Priority Systems

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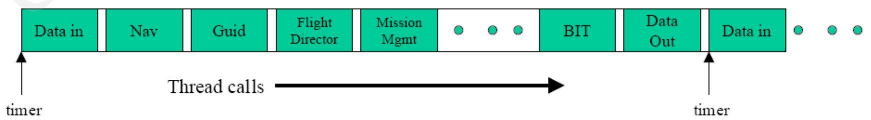
Multitasking

- Cyclic Executive
  - Calls to statically ordered threads



  - Pros:
    - Easy to implement (used extensively in complex safety critical systems)
  - Cons:
    - Not efficient in overall usage of CPU processing
    - Does not provide optimal response time

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Multitasking

- Round Robin Systems
  - Several processes execute sequentially to completion
  - Often in conjunction with a cyclic executive
  - Each task is assigned a fixed time slice
  - Fixed rate clock initiates an interrupt at a rate corresponding to the time slice
    - Task executes until it completes or its execution time expires
    - Context saved if task does not complete

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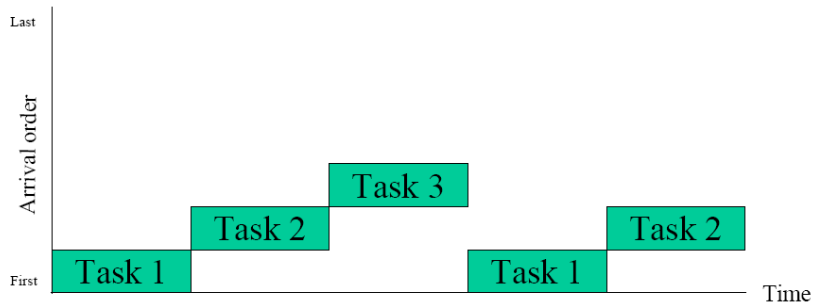
Multitasking

- Round Robin Systems - Time Slicing of 3 Tasks



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Multitasking

- Pre-emptive Priority Systems
  - Higher priority task can preempt a lower priority task if it interrupts the lower-priority task
  - Priorities assigned to each interrupt are based upon the urgency of the task associated with the interrupt
  - Priorities can be fixed or dynamic

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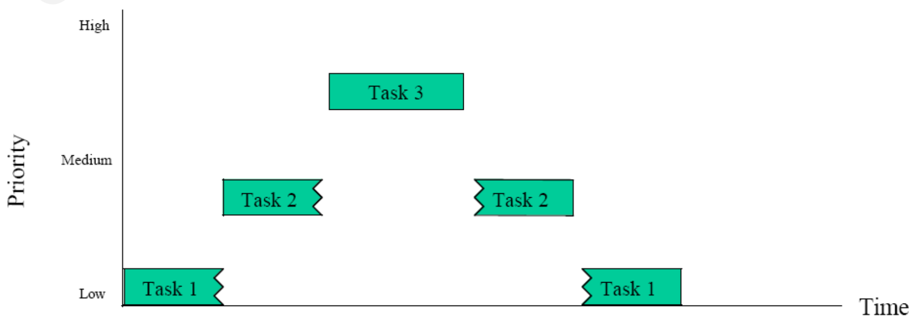
Multitasking

- Round Robin Systems - Preemptive Scheduling of 3 Tasks



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Multitasking

- Preemptive Priority Systems - An Example
  - Aircraft Navigation System:
    - High priority task: Task that gathers accelerometer data every 5 msec
    - Medium priority task: Task that collects gyro data and compensates this data and the accelerometer data every 40 msec
    - Low priority task: Display update, Built-in-Test (BIT)

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Multitasking

- Multitasking is not perfect
  - High priority tasks hog resources and starve low priority tasks
  - Low priority tasks share a resource with high priority tasks and block high priority task
- How does a RTOS deal with some of these issues?
  - Rate Monotonic Systems (higher execution frequency = higher priority)
  - Priority Inheritance

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RTOS

- Almost all microcontroller-based systems work in real time. A real-time system is a time responsive system that can respond to its environment in the shortest possible time.
- Real time does not necessarily mean the microcontroller should operate at high speed. What is important in a real-time system is a fast response time, although high speed can help.
  - For example, a real-time microcontroller-based system with various external switches is expected to respond immediately when a switch is activated or some other event occurs.
- A real-time operating system (RTOS) is a piece of code (usually called the kernel) that controls task allocation when the microcontroller is operating in a multi-tasking environment. RTOS decides, for instance, which task to run next, how to coordinate the task priorities, and how to pass data and messages among tasks.

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Multitasking

Priority Inversion / Priority Inheritance

- Task A and Task C share a resource
- Task A is High Priority
- Task C is Low Priority
- Task A is blocked when Task C runs (effectively assigning A to C's priority, hence Priority Inversion)
- Task A will be blocked for longer, if a Task B of medium priority comes along to keep Task C from finishing
- A good RTOS would sense this condition and temporarily promote task C to the High Priority of Task A (Priority Inheritance)

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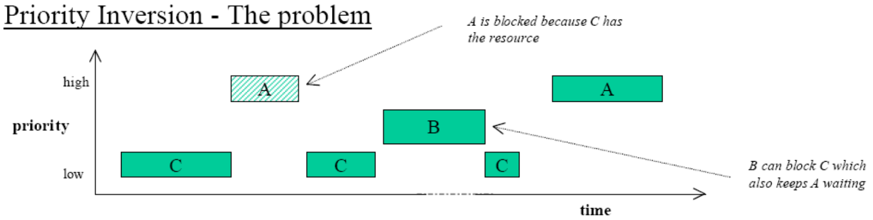
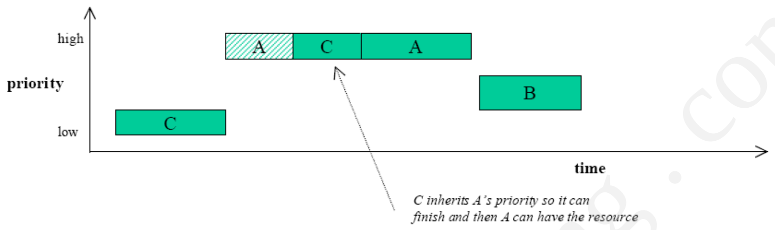
Multitasking

Priority Inversion - The problem



Priority Inheritance - A solution



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- This chapter explores the basic principles of multi-tasking embedded systems and gives examples of an RTOS used in simple projects. Multi-tasking code and RTOS are complex and wide topics, and this chapter describes the concepts pertaining to these tools only briefly.
- There are several commercially available RTOS systems for PIC microcontrollers.
  - Two popular high-level RTOS systems for PIC microcontrollers are Salvo (www.pumpkin.com), which can be used from a Hi-Tech PIC C compiler, and
  - the CCS (Customer Computer Services) built-in RTOS system.
- In this chapter, the example RTOS projects are based on the CCS (www.ccsinfo.com) compiler, one of the popular PIC C compilers developed for the PIC16 and PIC18 series of microcontrollers.

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10.1 State Machines

- State machines are simple constructs used to perform several activities, usually in a sequence. Many real-life systems fall into this category. For example, the operation of a washing machine or a dishwasher is easily described with a state machine construct.
- Perhaps the simplest method of implementing a state machine construct in C is to use a switch-case statement. For example, our temperature monitoring system has three tasks, named Task 1, Task 2, and Task 3 as shown in Figure 10.1.
- The state machine implementation of the three tasks using switch-case statements is shown in Figure 10.2.
  - The starting state is 1, and each task increments the state number by one to select the next state to be executed.
  - The last state selects state 1, and there is a delay at the end of the switch-case statement.
  - The state machine construct is executed continuously inside an endless for loop.

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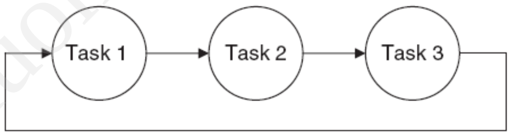

Figure 10.1: State machine implementation

```
state = 1;
for(;;)
{
        switch (state)
        {
            CASE 1:
                        // implement TASK 1
                        state++;
                        break;
            CASE 2:
                        // i/mplement TASK 2
                        state++;
                        break;
            CASE 3:
                        // implement TASK 3
                        state = 1;
                        break;
        }
        delay_ms(n);
}
```

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Figure 10.2: State machine implementation in C

- In many applications, the states need not be executed in sequence. Rather, the next state is selected by the present state either directly or based on some condition. This is shown in Figure 10.3.
- State machines, although easy to implement, are primitive and have limited application. They can only be used in systems which are not truly responsive, where the task activities are well-defined and the tasks are not prioritized.
- Moreover, some tasks may be more important than others. We may want some tasks to run whenever they become eligible. For example, in a manufacturing plant, a task that sets off an alarm when the temperature is too hot must be run. This kind of implementation of tasks requires a sophisticated system like RTOS.

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```
state = 1;
for(;;)
{
        switch (state)
        {
            CASE 1:
                        // implement TASK 1
                        state = 2;
                        break;
            CASE 2:
                        // i/mplement TASK 2
                        state = 3;
                        break;
            CASE 3:
                        // implement TASK 3
                        state = 1;
                        break;
        }
        delay_ms(n);
}
```

Figure 10.3: Selecting the next state from the current state

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10.2 The Real-Time Operating System (RTOS)

- Real-time operating systems are built around a multi-tasking kernel which controls the allocation of time slices to tasks. A time slice is the period of time a given task has for execution before it is stopped and replaced by another task. This process, also known as context switching, repeats continuously.
- When context switching occurs, the executing task is stopped, the processor registers are saved in memory, the processor registers of the next available task are loaded into the CPU, and the new task begins execution.
- An RTOS also provides task-to-task message passing, synchronization of tasks, and allocation of shared resources to tasks.

- The basic parts of an RTOS are:
  - Scheduler
  - RTOS services
  - Synchronization and messaging tools

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10.2.1 The Scheduler

- A scheduler is at the heart of every RTOS, as it provides the algorithms to select the tasks for execution. Three of the more common scheduling algorithms are:
  - ***Cooperative scheduling***
  - ***Round-robin scheduling***
  - ***Preemptive scheduling***

- ***Cooperative scheduling*** is perhaps the simplest scheduling algorithm available.
  - Each task runs until it is complete and gives up the CPU voluntarily.
  - Cooperative scheduling cannot satisfy real-time system needs, since it cannot support the prioritization of tasks according to importance.
  - Also, a single task may use the CPU too long, leaving too little time for other tasks. And the scheduler has no control of the various tasks' execution time.
  - A state machine construct is a simple form of a cooperative scheduling technique.

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Round-robin scheduling

- In round-robin scheduling, each task is assigned an equal share of CPU time (see Figure 10.4).
- A counter tracks the time slice for each task. When one task's time slice completes, the counter is cleared and the task is placed at the end of the cycle.
- Newly added tasks are placed at the end of the cycle with their counters cleared to 0. This, like cooperative scheduling, is not very useful in a real-time system, since very often some tasks take only a few milliseconds while others require hundreds of milliseconds or more.

Figure 10.4: Round-robin scheduling

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Preemptive scheduling

- Preemptive scheduling is considered a real-time scheduling algorithm. It is prioritybased, and each task is given a priority (see Figure 10.5).
- The task with the highest priority gets the CPU time.
- Real-time systems generally support priority levels ranging from 0 to 255, where 0 is the highest priority and 255 is the lowest.

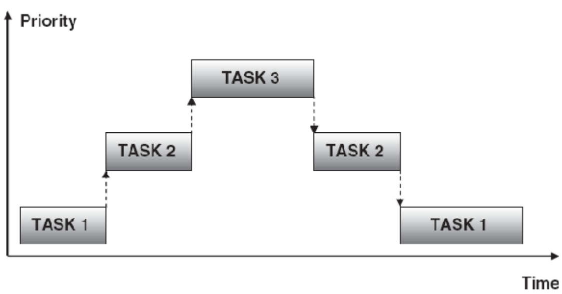

Figure 10.5: Preemptive scheduling

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Mixed scheduling

- In some real-time systems where more than one task can be at the same priority level, preemptive scheduling is mixed with round-robin scheduling.
- In such cases, tasks at higher priority levels run before lower priority ones, and tasks at the same priority level run by round-robin scheduling.
- If a task is preempted by a higher priority task, its run time counter is saved and then restored when it regains control of the CPU.
- In some systems a strict real-time priority class is defined where tasks above this class may run to completion (or run until a resource is not available) even if there are other tasks at the same priority level.

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Task states

- In a real-time system a task can be in any one of the following states:
  - **Ready to run**
  - **Running**
  - **Blocked**

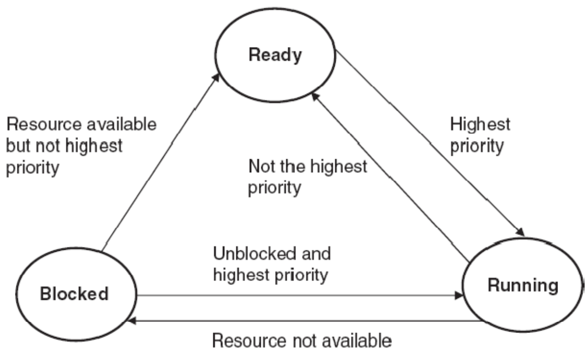

Figure 10.6: Task states

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- When a task is first created, it is usually ready to run and is entered in the task list. From this state, subject to the scheduling algorithm, the task can become a running task.
- According to the conditions of preemptive scheduling, the task will run if it is the highest priority task in the system and is not waiting for a resource.
- A running task becomes a blocked task if it needs a resource that is not available. For example, a task may need data from an A/D converter and is blocked until it is available. Once the resource can be accessed, the blocked task becomes a running task if it is the highest priority task in the system, otherwise it moves to the ready state.
- Only a running task can be blocked. A ready task cannot be blocked.
- When a task moves from one state to another, the processor saves the running task's context in memory, loads the new task's context from memory, and then executes the new instructions as required.

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Task operations

- The kernel usually provides an interface to manipulate task operations. Typical task operations are:
  - Creating a task
  - Deleting a task
  - Changing the priority of a task
  - Changing the state of a task

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10.3 RTOS Services

- RTOS services are utilities provided by the kernel that help developers create real-time tasks efficiently. For example, a task can use time services to obtain the current date and time.

- Some of these services are:
  - Interrupt handling services
  - Time services
  - Device management services
  - Memory management services
  - Input-output services

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10.4 Synchronization and Messaging Tools

- Synchronization and messaging tools are kernel constructs that help developers create real-time applications.
- Some of these services are:
  - Semaphores
  - Event flags
  - Mailboxes
  - Pipes
  - Message queues
- Semaphores are used to synchronize access to shared resources, such as common data areas.
- Event flags are used to synchronize the intertask activities.
- Mailboxes, pipes, and message queues are used to send messages among tasks.

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10.5 CCS PIC C Compiler RTOS

- The CCS PIC C compiler is one of the popular C compilers for the PIC16 and PIC18 series of microcontrollers.
- The syntax of the CCS C language is slightly different from that of the mikroC language, but readers who are familiar with mikroC should find CCS C easy to use.
- CCS C supports a rudimentary multi-tasking cooperative RTOS for the PIC18 series of microcontrollers that uses their PCW and PCWH compilers. This RTOS allows a PIC microcontroller to run tasks without using interrupts. When a task is scheduled to run, control of the processor is given to that task. When the task is complete or does not need the processor any more, control returns to a dispatch function, which gives control of the processor to the next scheduled task.
- ***Because the RTOS does not use interrupts and is not preemptive, the user must make sure that a task does not run forever***. Further details about the RTOS are available in the compiler's user manual.

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RTOS in CCS C

- The CCS language provides the following RTOS functions in addition to the normal C functions:
- ***rtos_run()*** initiates the operation of RTOS. All task control operations are implemented after calling this function.
- ***rtos_terminate()*** terminates the operation of RTOS. Control returns to the original program without RTOS. In fact, this function is like a return from rtos_run().
- ***rtos_enable()*** receives the name of a task as an argument. The function enables the task so function rtos_run() can call the task when its time is due.
- ***rtos_disable()*** receives the name of a task as an argument. The function disables the task so it can no longer be called by rtos_run() unless it is re-enabled by calling rtos_enable().
- ***rtos_ yield()*** when called from within a task, returns control to the dispatcher. All tasks should call this function to release the processor so other tasks can utilize the processor time.

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- ***rtos_msg_send()*** receives a task name and a byte as arguments. The function sends the byte to the specified task, where it is placed in the task's message queue.
- ***rtos_msg_read()*** reads the byte located in the task's message queue.
- ***rtos_msg_ poll()*** returns true if there is data in the task's message queue. This function should be called before reading a byte from the task's message queue.
- ***rtos_signal()*** receives a semaphore name and increments that semaphore.
- ***rtos_wait()*** receives a semaphore name and waits for the resource associated with the semaphore to become available. The semaphore count is then decremented so the task can claim the resource.
- ***rtos_await()*** receives an expression as an argument, and the task waits until the expression evaluates to true.
- ***rtos_overrun()*** receives a task name as an argument, and the function returns true if that task has overrun its allocated time.
- ***rtos_stats()*** returns the specified statistics about a specified task. The statistics can be the minimum and maximum task run times and the total task run time. The task name and the type of statistics are specified as arguments to the function.

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RTOS Setup

#use rtos(timer=X, [minor_cycle=cycle_time])

- Timer can be any timer available
- Minor_Cycle is rate of fastest task
- Example:

#use rtos(timer=1, minor_cycle=50ms)

RTOS Tasks

#task(rate=xxxx,
[max=yyyy], [queue=z])

- Following function is RTOS task
- Will be called at specified rate
- Max is slowest execution time, used for budgeting.
- Queue defines RX message size

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RTOS Start and Stop

rtos_run()

- Starts the RTOS
- Will not return until rtos_terminate()

rtos_terminate()

- Stops the RTOS

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```
#use rtos(timer=1)

#task(rate=100ms,     max=5ms)
void  TaskInput(void)
  { /*   get   user  input   */    }

#task(rate=25ms)
void  TaskSystem(void)
  { /*   do   some stuff    */    }

void  main(void)    {
  while(TRUE)   {
       rtos_run();
       sleep();
  }
}
```

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RTOS Task Control

rtos_enable(task)

rtos_disable(task)

- Dynamic task control
- Enable/Disable the specified task
- Task is the function name
- All tasks are enabled at start

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RTOS Messaging

rtos_msg_send(task, char)
- Sends char to task

avail=rtos_msg_poll()
- TRUE if a char is waiting for this task

byte=rtos_msg_read()
- Read next char destined for this task

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RTOS Yielding

rtos_yield()
- Stops processing current task
- Returns to this point on next cycle

rtos_await(expression)
- rtos_yield() if expression not TRUE

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```
#task(rate=100ms,      max=5ms)
void   TaskInput(void)      {
   if    (KeyReady())
         rtos_msg_send(TaskSystem,      KeyGet());
}

#task(rate=25ms,      queue=1)
void   TaskSystem(void)      {
   SystemPrepare();
   rtos_await(rtos_msg_poll());
   SystemDo(rtos_msg_read());
   rtos_yield();
   SystemVerify();
}
```


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RTOS Semaphores

Semaphore
- Determine shared resource availability
- A user defined global variable
- Set to non-zero if used
- Set to zero if free

rtos_wait(semaphore)
- rtos_yield() until semaphore free
- Once free, sets semaphore as used

rtos_signal(semaphore)
- Release semaphore

RTOS Timing Statistics

overrun=rtos_overrun(task)
- TRUE if task took longer than max

rtos_stats(task, rtos_stats)
- Get timing statistics for specified task

```
typedef  struct  {
  int32   total;    //  total   ticks    used  by  task
  int16   min;      //  minimum tick  time   used
  int16   max;      //  maximum tick   time  used
  int16   hns;      //  us  =  (ticks*hns)/10
}  rtos_stats;
```

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RTOS Application Ideas

User I/O

Communication Protocols

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10.5.1 Preparing for RTOS

- In addition to the preceding functions, the #use rtos() preprocessor command must be specified at the beginning of the program before calling any of the RTOS functions.
- The format of this preprocessor command is:

  #use rtos(timer=n, minor_cycle=m)

  where timer is between 0 and 4 and specifies the processor timer that will be used by the RTOS, and minor_cycle is the longest time any task will run. The number entered here must be followed by s, ms, us, or ns.
- In addition, a *statistics* option can be specified after the minor_cycle option, in which case the compiler will keep track of the minimum and maximum processor times the task uses at each call and the task's total time used.

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10.5.2 Declaring a Task

- A task is declared just like any other C function, but tasks in a multi-tasking application do not have any arguments and do not return any values. Before a task is declared, a #task preprocessor command is needed to specify the task options.
- The format of this preprocessor command is:

  #task(rate=n, max=m, queue=p)

  – ***rate*** specifies how often the task should be called. The number specified must be followed by s, ms, us, or ns.
  – ***max*** specifies how much processor time a task will use in one execution of the task. The time specifed here must be equal to or less than the time specified by minor_cycle.
  – ***queue*** is optional and if present specifies the number of bytes to be reserved for the task to receive messages from other tasks. The default value is 0.

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- In the following example, a task called my_ticks is every 20ms and is expected to use no more than 100ms of processor time.

- This task is specified with no queue option:

```
#task(rate=20ms, max=100ms)
void my_ticks()
{
...........
...........
}
```


PROJECT 10.1—LEDs

- In the following simple RTOS-based project, four LEDs are connected to the lower half of PORTB of a PIC18F452-type microcontroller. The software consists of four tasks, where each task flashes an LED at a different rate:
  - Task 1, called task_B0, flashes the LED connected to port RB0 at a rate of 250ms.
  - Task 2, called task_B1, flashes the LED connected to port RB1 at a rate of 500ms.
  - Task 3, called task_B2, flashes the LED connected to port RB2 once a second.
  - Task 4, called task_B3, flashes the LED connected to port RB3 once every two seconds.
- Figure 10.7 shows the circuit diagram of the project. A 4MHz crystal is used as the clock. PORTB pins RB0–RB3 are connected to the LEDs through current limiting resistors.

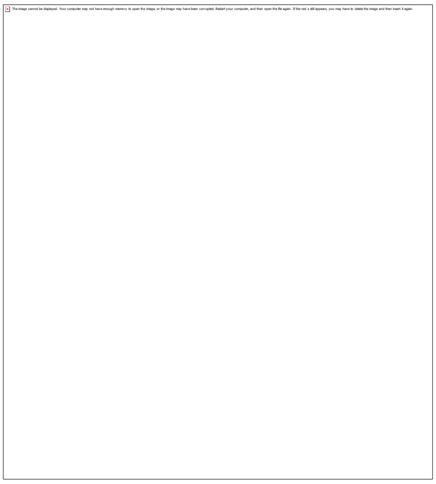

Figure 10.7: Circuit diagram of the project

- The software is based on the CCS C compiler, and the program listing (RTOS1.C) is given in *Figure 10.8*. The main program is at the end of the program, and inside the main program PORTB pins are declared as outputs and RTOS is started by calling function rtos_run().
- The file that contains CCS RTOS declarations should be included at the beginning of the program. The preprocessor command **#use delay** tells the compiler that we are using a 4MHz clock. Then the RTOS timer is declared as Timer 0, and minor_cycle time is declared as 10ms using the preprocessor command **#use rtos**.
- The program consists of four similar tasks:
  - task_B0 flashes the LED connected to RB0 at a rate of 250ms. Thus, the LED is ON for 250ms, then OFF for 250ms, and so on. CCS statement ***output_toggle*** is used to change the state of the LED every time the task is called. In the CCS compiler PIN_B0 refers to port pin RB0 of the microcontroller.
  - task_B1 flashes the LED connected to RB1 at a rate of 500ms as described.
  - task_B2 flashes the LED connected to RB2 every second as described.
  - Finally, task_B3 flashes the LED connected to RB3 every two seconds as described.
- The program given in Figure 10.8 is a multi-tasking program where the LEDs flash independently of each other and concurrently.

RTOS1.c (1/3)

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RTOS1.c (2/3)

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RTOS1.c (3/3)

```
//
  #task(rate=1s, max=10ms)
  void task_B2()
  {
    output_toggle(PIN_B2);                         // Toggle RB2
  }

//
// Declare TASK 4 - called every 2 seconds
//
  #task(rate=2s, max=10ms)
  void task_B3()
  {
    output_toggle(PIN_B3);                         // Toggle RB3
  }



//
// Start of MAIN program
//
void main()
{
  set_tris_b(0);                          // Configure PORTB as outputs
  rtos_run();                             // Start RTOS
}
```


PROJECT 10.2—Random Number Generator

- In this slightly more complex RTOS project, a random number between 0 and 255 is generated. Eight LEDs are connected to PORTB of a PIC18F452 microcontroller. In addition, a push-button switch is connected to bit 0 of PORTD (RD0), and an LED is connected to bit 7 of PORTD (RD7).
- Three tasks are used in this project: Live, Generator, and Display.
  - ***Task Live*** runs every 200ms and flashes the LED on port pin RD7 to indicate that the system is working.
  - ***Task Generator*** increments a variable from 0 to 255 continuously and checks the status of the push-button switch. When the push-button switch is pressed, the value of the current count is sent to task Display using a *messaging queue*.
  - ***Task Display*** reads the number from the message queue and sends the received byte to the LEDs connected to PORTB. Thus, the LEDs display a random pattern every time the push button is pressed.
- Figure 10.9 shows the project's block diagram. The circuit diagram is given in Figure 10.10. The microcontroller is operated from a 4MHz crystal.

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Figure 10.9: Block diagram of the project

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Figure 10.10: Circuit diagram of the project

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- The program listing of the project (RTOS2.C) is given in Figure 10.11. The main part of the program is in the later portion, and it configures PORTB pins as outputs. Also, bit 0 of PORTD is configured as input and other pins of PORTD are configured as outputs. Timer 0 is used as the RTOS timer, and the minor_cycle is set to 1s.
- The program consists of three tasks:
  - ***Task Live*** runs every 200ms and flashes the LED connected to port pin RD7. This LED indicates that the system is working.
  - ***Task Generator*** runs every millisecond and increments a byte variable called count continuously. When the push-button switch is pressed, pin 0 of PORTD (RD0) goes to logic 0. When this happens, the current value of count is sent to task Display using RTOS function call ***rtos_msg_send(display, count)***, where Display is the name of the task where the message is sent and count is the byte sent.
  - ***Task Display*** runs every 10ms. This task checks whether there is a message in the queue. If so, the message is extracted using RTOS function call ***rtos_msg_read()***, and the read byte is sent to the LEDs connected to PORTB. Thus, the LEDs display the binary value of count as the switch is pressed. The message queue should be checked by using function ***rtos_msg_poll()***, as trying to read the queue without any bytes in the queue may freeze the program.

TROS2.C (1/4)

```
////////////////////////////////////////////////////////////////////////////////////////////////////////////////////
//
//        SIMPLE RTOS EXAMPLE - RANDOM NUMBER GENERATOR
//        --------------------------------------------------------------------------------
//
// This is a simple RTOS example. 8 LEDs are connected to PORTB
// of a PIC18F452 microcontroller. Also, a push-button switch is
// connected to port RC0 of PORTC, and an LED is connected to port
// RC7 of the microcontroller. The push-button switch is normally at logic 1.
//
// The program consists of 3 tasks called "Generator", "Display", and "Live".
//
// Task "Generator" runs in a loop and increments a counter from 0 to 255.
// This task also checks the state of the push-button switch. When the
// push-button switch is pressed, the task sends the value of the count to the
// "Display" task using messaging passing mechanism. The "Display" task
// receives the value of count and displays it on the PORTB LEDs.
//
// Task "Live" flashes the LED connected to port RC7 at a rate of 250ms.
// This task is used to indicate that the system is working and is ready for
// the user to press the push-button.
//
// The microcontroller is operated from a 4MHz crystal
//
// Programmer:    Dogan Ibrahim
// Date:          September, 2007
// File:          RTOS2.C
//
////////////////////////////////////////////////////////////////////////////
```

TROS2.C (2/4)

```
#include "C:\NEWNES\PROGRAMS\rtos.h"
#use delay (clock=4000000)
int count;

//
// Define which timer to use and minor_cycle for RTOS
//
  #use rtos(timer=0, minor_cycle=1ms)

//
// Declare TASK "Live" - called every 200ms
// This task flashes the LED on port RC7
//
  #task(rate=200ms, max=1ms)
  void Live()
  {
    output_toggle(PIN_D7);
  }


//
```

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TROS2.C (3/4)

```
// Declare TASK "Display" - called every 10ms
//
  #task(rate=10ms, max=1ms, queue=1)
  void Display()
  {
    if(rtos_msg_poll() > 0)                          // Is there a message ?
    {
      output_b(rtos_msg_read());                     // Send to PORTB
    }
  }


//
// Declare TASK "Generator" - called every millisecond
//
  #task(rate=1ms, max=1ms)
  void Generator()
  {
    count++;                                         // Increment count
    if(input(PIN_D0) == 0)                           // Switch pressed ?
    {
      rtos_msg_send(Display,count);                  // send a message
    }
  }
```

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TROS2.C (4/4)

```
//
// Start of MAIN program
//
void main()
{
   set_tris_b(0);                          // Configure PORTB as outputs
   set_tris_d(1);                          // RD0=input, RD7=output
   rtos_run();                             // Start RTOS
}
```


PROJECT 10.3—Voltmeter with RS232 Serial Output

- In this RTOS project, which is more complex than the preceding ones, the voltage is read using an A/D converter and then sent over the serial port to a PC. The project consists of three tasks: Live, Get_voltage, and To_RS232.
  - ***Task Live*** runs every 200ms and flashes an LED connected to port RD7 of the microcontroller to indicate that the system is working.
  - ***Task Get_voltage*** reads channel 0 of the A/D converter where the voltage to be measured is connected. The read value is formatted and then stored in a variable. This task runs every two seconds.
  - ***Task To_RS232*** reads the formatted voltage and sends it over the RS232 line to a PC every second.
- Figure 10.12 shows the block diagram of the project. The circuit diagram is given in Figure 10.13. A PIC18F8520-type microcontroller with a 10MHz crystal is used in this project (though any PIC18F-series microcontroller can be used). The voltage to be measured is connected to analog port AN0 of the microcontroller. The RS232 TX output of the microcontroller (RC6) is connected to a MAX232-type RS232-level converter chip and then to the serial input of a PC (e.g., COM1) using a 9-pin D-type connector. Port pin RD7 is connected to an LED to indicate whether the project is working.

Figure 10.12: Block diagram of the project

Figure 10.13: Circuit diagram of the project

- In the main part of the program PORTD is configured as output and all PORTD pins are cleared. Then PORTA is configured as input (RA0 is the analog input), the microcontroller's analog inputs are configured, the A/D clock is set, and the A/D channel 0 is selected (AN0). The RTOS is then started by calling function rtos_run().
- The program consists of three tasks:
  - ***Task Live*** runs every 200ms and flashes an LED connected to port pin RD7 of the microcontroller to indicate that the project is working.
  - ***Task Get_voltage*** reads the analog voltage from channel 0 (pin RA0 or AN0) of the microcontroller. The value is then converted into millivolts by multiplying by 5000 and dividing by 1024 (in a 10-bit A/D there are 1024 quantization levels, and when working with a reference voltage of þ5V, each quantization level corresponds to 5000/1024mV). The voltage is stored in a global variable called Volts.
  - ***Task To_RS232*** reads the measured voltage from common variable Volts and sends it to the RS232 port using the C printf statement. The result is sent in the following format:

Measured voltage = nnnn mV

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RTOS3.C (1/4)

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RTOS3.C (2/4)

The image cannot be displayed. Your computer may not have enough memory to open the image, or the image may have been corrupted. Restart your computer, and then open the file again. If the red x still appears, you may have to delete the image and then insert it again.

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RTOS3.C (3/4)

The image cannot be displayed. Your computer may not have enough memory to open the image, or the image may have been corrupted. Restart your computer, and then open the file again. If the red x still appears, you may have to delete the image and then insert it again.

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RTOS3.C (4/4)

```
//
// Declare TASK "To_RS232" - called every millisecond
//
  #task(rate=2s, max=100ms)
  void To_RS232()
  {
    printf("Measured Voltage = %LumV\n\r",Volts);          // send to RS232
  }



//
// Start of MAIN program
//
void main()
{
  set_tris_d(0);                                          // PORTD all outputs
  output_d(0);                                            // Clear PORTD
  set_tris_a(0xFF);                                       // PORTA all inputs
  setup_adc_ports(ALL_ANALOG);                            // A/D ports
  setup_adc(ADC_CLOCK_DIV_32);                            // A/D clock
  set_adc_channel(0);                                     // Select channel 0 (AN0)
  delay_us(10);
  rtos_run();                                             // Start RTOS
}
```

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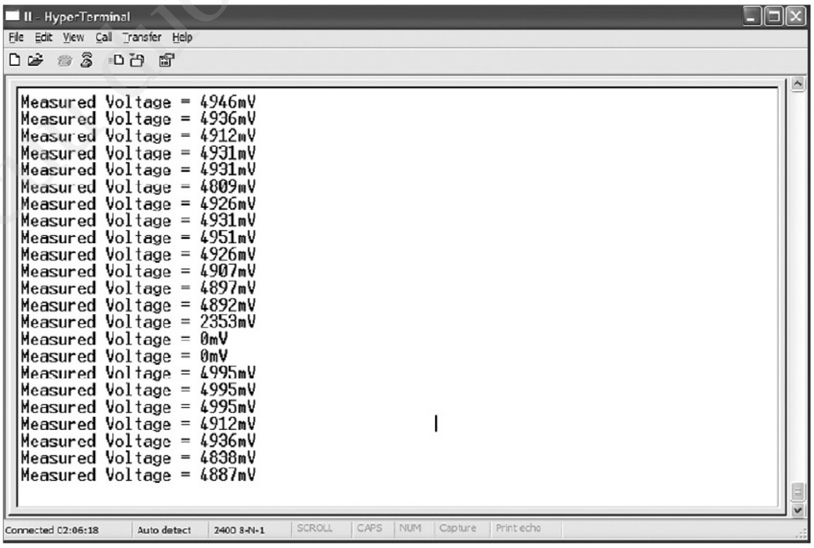

Figure 10.15: Typical output from the program

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Using a Semaphore

- The program given in Figure 10.14 is working and displays the measured voltage on the PC screen. This program can be improved slightly by using a semaphore to synchronize the display of the measured voltage with the A/D samples. The modified program (RTOS4.C) is given in Figure 10.16. The operation of the new program is as follows:
  - The semaphore variable (sem) is set to 1 at the beginning of the program.
  - Task Get_voltage decrements the semaphore (calls rtos_wait) variable so that task To_RS232 is blocked (semaphore variable sem = 0) and cannot send data to the PC. When a new A/D sample is ready, the semaphore variable is incremented (calls rtos_signal) and task To_RS232 can continue.
  - TaskTo_RS232 then sends the measured voltage to the PC and increments the semaphore variable to indicate that it had access to the data. Task Get_voltage can then get a new sample. This process is repeated forever.

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RTOS.C (1/4)

```
/////////////////////////////////////////////////////////////////////////////////////////////
//
//          SIMPLE RTOS EXAMPLE - VOLTMETER WITH RS232 OUTPUT
//          ---------------------------------------------------------------------
//
// This is a simple RTOS example. Analog voltage to be measured (between 0V
// and +5V) is connected to analog input AN0 of a PIC18F8520 type
// microcontroller. The microcontroller is operated from a 10MHz crystal. In
// addition, an LED is connected to port in RD7 of the microcontroller.
//
// RS232 serial output of the mirocontroller (RC6) is connected to a MAX232
// type RS232 voltage level converter chip. The output of this chip can be
// connected to the serial input of a PC (e.g., COM1) so that the measured
// voltage can be seen on the PC screen.
//
// The program consists of 3 tasks called "live", "Get_voltage", and "To_RS232".
//
// Task "Live" runs every 200ms and it flashes the LED connected to port RD7
// of the microcontroller to indicate that the program is running and is ready to
// measure voltages.
//
// task "Get_voltage" reads analog voltage from port AN0 and then converts the
// voltage into millivolts and stores in a variable called Volts.
//
```

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RTOS.C (2/4)

```
// Task "To_RS232" gets the measured voltage  and then sends to the PC over
// the RS232 serial line. The serial line is configured to operate at 2400 Baud
// (higher Baud rates can also be used if desired).
//
// In this modified program, a semaphore is used to synchronize
// the display of the measured value with the A/D samples.
//
// Programmer:        Dogan Ibrahim
// Date:              September, 2007
// File:              RTOS4.C
//
////////////////////////////////////////////////////////////////////////////////////////////////////////

#include <18F8520.h>
#device adc=10
#use delay (clock=10000000)
#use rs232(baud=2400,xmit=PIN_C6,rcv=PIN_C7)

unsigned int16 adc_value;
unsigned int32 Volts;
int8 sem;

//
// Define which timer to use and minor_cycle for RTOS
//
  #use rtos(timer=0, minor_cycle=100ms)
```

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RTOS.C (3/4)

```
//
// Declare TASK "Live" - called every 200ms
// This task flashes the LED on port RD7
//
  #task(rate=200ms, max=1ms)
  void Live()
  {
    output_toggle(PIN_D7);                              // Toggle RD7 LED
  }


//
// Declare TASK "Get_voltage" - called every 10ms
//
  #task(rate=2s, max=100ms)
  void Get_voltage()
  {
    rtos_wait(sem);                                     // decrement semaphore
    adc_value = read_adc();                             // Read A/D value
    Volts = (unsigned int32)adc_value*5000;
    Volts = Volts / 1024;                               // Voltage in mV
    rtos_signal(sem);                                   // increment semaphore
  }
```

RTOS.C (4/4)

```
//
// Declare TASK "To_RS232" - called every millisecond
//
  #task(rate=2s, max=100ms)
  void To_RS232()
  {
    rtos_wait(sem);                                      // Decrement semaphore
    printf("Measured Voltage = %LumV\n\r",Volts);        // Send to RS232
    rtos_signal(sem);                                    // Increment semaphore
  }



//
// Start of MAIN program
//
void main()
{
  set_tris_d(0);                                         // PORTD all outputs
  output_d(0);                                           // Clear PORTD
  set_tris_a(0xFF);                                      // PORTA all inputs
  setup_adc_ports(ALL_ANALOG);                           // A/D ports
  setup_adc(ADC_CLOCK_DIV_32);                           // A/D clock
  set_adc_channel(0);                                    // Select channel 0 (AN0)

  delay_us(10);
  sem = 1;                                               // Semaphore is 1
  rtos_run();                                            // Start RTOS
}
```

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