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THIRD COLLEGE ON MICROPROCESSOR-BASED REAL-TIME CONTROL - PRINCIPLES AND APPLICATIONS IN PHYSICS
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CROSS-DEVLOPMENT OF EMBEDDED SYSTEMS

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These are preliminary lecture notes, intended only for distribution to participants.

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Cross-Development of Embedded Systems (2)

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A Real-Time Kernel for Embedded Systems

- Recent surveys show that there are more then 40 real-time kernel manufacturers.
- Real-time kernels are available for 8, 16 and 32-bit processors, including proprietary and open market ones.
- The price ranges from $100 to $10,000.
- There are also a small number of real-time kernels appearing in journals, magazines and books, which are normally available in source code.
- We shall look at one designed by Jean J. Labrosse called μC/OS.

µC/OS

- Jean J. Labrosse published an early version of µC/OS in *Embedded Systems Programming* magazine in June 1992. It was written in C with the initial goal for creating a small but powerful kernel for 68HC11 microcontroller.
- It has since been extended to a portable system suitable for use with any microcontroller/microprocessor provided that it has a stack pointer and the processor status can be stacked and unstacked.
- Labrosse has written a book describing µC/OS.
  - Jean J. Labrosse, *µC/OS The Real-Time Kernel*, R & D Publications, Lawrence, Kansas. ISBN 0-13-031352-1
- The complete source listing of µC/OS is available in the book. It is also available in a companion disk which costs \$24.95 + \$15.00 for postage and handling.
- The code is protected by copyright. However, you do not need a license to use the code in your application if it is distributed in object format. You should indicate in you document that you are using µC/OS.

Main Features of μC/OS

- Portable
  - It is written in C, with a small processor specific code in assembly to *create task, start multitasking* and *perform context switching*.
  - For 80186/80188 the assemble language code is less than 4 pages.
- ROMable
- Priority driven
  - Always runs the highest priority task that is ready to run.
- Preemptive
  - When a task makes a higher priority task ready to run, the current task is preempted or suspended and the higher priority task is immediately given control of the processor.
  - Execution of the highest priority task is deterministic.
- Multitasking
  - Up to 63 tasks
- Interrupt feature
  - Interrupts can suspend the execution of a task.
  - If a higher priority task is awakened as a result of the interrupt, the highest priority task will run as soon as the interrupt completes.
  - Interrupts can be nested up to 255 levels deep.

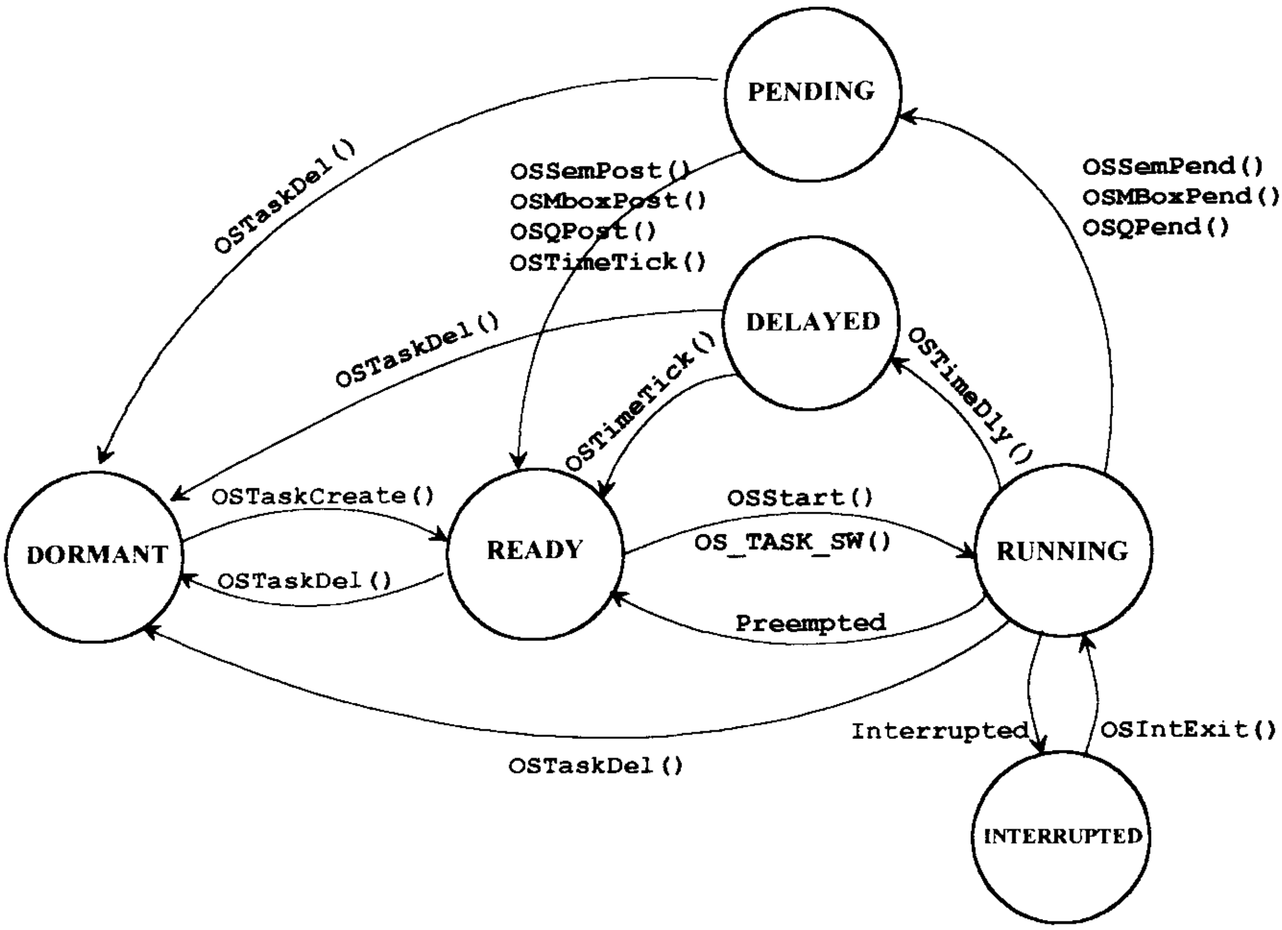
μC/OS Tasks

- A *task* is an infinite loop function or one that deletes itself when it is finished.
- The infinite loop can be preempted by an interrupt that can cause a higher priority task to run.
- A task can also call the following μC/OS services:
  - `OSTaskDel()`
  - `OSTimeDly()`
  - `OSSemPend()`
  - `OSMboxPend()`
  - `OSQPend()`
- Each task has a unique priority, ranging form 0 to 62. The lower the value the higher the task priority.

μC/OS Task States

- **DORMANT**
  - The state when a task has not been made available to μC/OS.
- **READY**
  - When a task is created by calling `OSTaskCreate()`, it is in the **READY** state.
  - Tasks may be created before multitasking starts or dynamically by a running task. If the created task has a higher priority than its creator, the created task is immediately given the control of the processor.
  - A task can return itself or another task to the **DORMANT** state by calling `OSTaskDel()`.
- **RUNNING**
  - The highest priority task created is in the **RUNNING** state when multitasking is started by calling `OSStart()`.
- **DELAYED**
  - The running task may call OSTimeDly() and enters the **DELAYED** state. The next highest priority task then runs.
  - The delayed task is made ready to run by `OSTimeTick()` when the desired delayed time expires.
- **PENDING**
  - The running may have to wait for an event by calling `OSSemPend()`, `OSMboxPend()` or `OSQPend()`. It then enters the **PENDING** state. The next highest priority task then runs. The task is made ready when the event occurs.
  - The occurrence of an event may be signalled by another task or by an interrupt service routine (ISR).
- **INTERRUPTED**
  - A task may be interrupted and enters the **INTERRUPTED** state. The ISR then runs. The ISR may make one or more tasks ready to run.
  - When all tasks are either waiting for events or delayed, an idle task `OSTaskIdle()` is executed.

μC/OS Task State Transition Diagram



Task Control Block

- Each task has a task control block, `OS_TCB`, which is used by μC/OS to maintain the state of the task when it is preempted. When the task regains control the `OS_TCB` allows it to resume execution properly.
- Each `OS_TCB` has the following field:
  - `OSTCBStkPtr` - points to the top of stack.
  - `OSTCBStat` - state of the task. 0 - ready to run
  - `OSTCBPrio` - task priority. 0 - 63
  - `OSTCBDly` - number of clock ticks the task is to wait for an event.
  - `OSTCBX`, `OSTCBY`, `OSTCBBitX`, `OSTCBBitY` - used for speeding up task handling by precomputing some parameters.

```
OSTCBX      =   priority & 0x07;
OSTCBBitX   =   OSMapTle[priority & 0x07];
OSTCBY      =   priority >> 3;
OSTCBBitY   =   OSMapTbl[Priority >>3];
```

  - `OSTCBNext`, `OSTCBPrev` - to doubly link `OS_TCB`s. `OSTimeTick()` use this link to update `OSTCBDly` field for each task.
  - `OSTCBEventPtr` - points to an event control block.
- All **OSTCB**s are placed in **OSTCBTbl[]**. The maximum number of task is declared in the user's code. An extra **OSTCB** is allocated for the idle task.

Creating a Task

- Tasks are created by calling `OSTaskCreate()` which is target processor specific.
- Tasks can either be created prior to the start of multitasking or by another task at run time.
- A task cannot be created by an interrupt service routine.
- `OSTaskCreate()` has four arguments:
  - *task* - points to the task code.
  - *data* - points to a user definable data area that is used to pass arguments to the task.
  - *pstk* - points to the task stack area for storing local variables and register contents during an interrupt.
  - *p* - task priority.
- `OSTaskCreate()` calls `OSTCBInit()` which obtains an `OS_TCB` from the list of free `OS_TCB`s. If all `OS_TCB`s have been used, an error code is returned. If an `OS_TCB` is available, it is initialised.
- A pointer the `OS_TCB` is place in the `OSTCBPrioTble[]` using the task priority as the index.
- The `OS_TCB` is then inserted in a doubly linked list with `OSTCBList` pointing to the most recently created `OS_TCB`.
- The task is then inserted in the ready list.
- Is a task is created by another task, the scheduler is called to determine if the created task has a higher priority than its creator. If so, the new task is executed immediately. Otherwise, control is returned to its caller.

Deleting a Task

- A task may return itself or another task to the DORMANT state by calling `OSTaskDel()`.
- The idle task cannot be deleted.
- The steps:
  - Removed from the ready list.
  - `OS_TCB` is unlinked and returned to the list of free `OS_TCB`.
  - If `OSTCBEventPtr` field in nonzero, the task must be removed from the event waiting list.

Task Scheduling

- Task scheduling is done by **OSSched()** which determines which task has the highest priority and thus will be the next to run.
- Each task has a unique priority number between 0 and 63. Priority 63, the lowest, is assigned to the idle task when µC/OS is initialised.
- Each task that is ready to run is placed in a ready list.
- The task scheduling time is constant irrespective of the number of tasks created.
- **OSSched()** looks for the highest priority test and verifies that it is not the current task to prevent unnecessary context switch.
- A context switch is then carried out by **OS_TASK_SW()**.
- **OSSched()** runs in a critical section to prevent ISR from changing the ready status of a task.

Interrupt Processing

- μC/OS requires an *interrupt service routine* (ISR) written in assembly language.
- Interrupts are enabled early in the ISR to allow other higher priority interrupts to enter.
- `OSIntEnter()` is called on entering and `OSIntExit()` on leaving the ISR to keep track of the interrupt nesting level. There may be 255 levels.
- μC/OS's worst case interrupt latency is 550 MPU clock cycles (80186/80188).
- μC/OS's worst case interrupt response time is 685 MPU clock cycles (80186/80188).

Clock Tick

- Time measurement in suspending execution and in waiting for an event is provided by `OSTimeTick()`, which supplies the *clock ticks* or the heartbeats.
- `OSTimeTick()` also decrements the `OSTCBDly` field for each `OS_TCB` that is not zero.
- The time between tick interrupts is application specific and is typically between 10 ms and 200 ms.
- `OSTimeTick()` increments a 32-bit variable OSTime since power up. This provides a system time.

Communication and Synchronisation

- μC/OS supports message *mailboxes* and *queues* for communication.
  - A task can deposit, through a kernel service, a message (the pointer) into the mailbox. Similarly, one or more tasks can received messages through a service provided by the kernel. Both the sending and receiving task have to agree as to what the pointer is pointing to.
  - A message queue is an array of mailboxes.
- μC/OS supports *semaphore* (0-32767) for synchronisation and coordination.
- These services are *events.*
- A task can signal the occurrence of an event (**POST**) or wait for an event to occur (**PEND**).
- ISR can **POST** an event but cannot **PEND** on an event.
- When an event occurs, the highest priority task waiting for the event is made ready to run.

Event Control Blocks

- The state of an event consists of:
  - the event itself - a counter for semaphores, a message for mailboxes, and a message queue for queues,
  - a waiting list for tasks waiting for the event to occur.
- Each event is assigned an Event Control Block which has the following data structure:
  - `OSEventGrp`
  - `OSEventTbl[8]`
  - `OSEventCnt` for semaphore count
  - `OSEventPtr` for mailbox or queue

Memory Requirements

- Program memory - less than 3150 (for 80186/80188)
- Data memory
  - 200
  - +((1 + OSMAX_TASK) * 16)
  - +(OS_MAX_EVENTS * 13)
  - +(OS_MAX_QS * 13)
  - +SUM(Storage requirements for each message queue)
  - +SUM(Storage requirements for each task stack)
  - +(OS_IDLE_TASK_STK_SIZE)
- Example: 20 tasks, 256 bytes for each task stack, 10 semaphores, 5 mailboxes and 5 queues of 10 entries would require 6337 bytes of RAM.

Kernel Services

#	Service	Description
1	`OSInit()`	Initialise µC/OS
2	`OSIntEnter()`	Signal ISR entry
3	`OSIntExit()`	Signal ISR exit
4	`OSMboxCreate()`	Create a mailbox
5	`OSMboxPend()`	Pend for message from mailbox
6	`OSMbox Post()`	Post a message to mailbox
7	`OSQCreate()`	Create a queue
8	`OSQPend()`	Pend for message from queue
9	`OSQPost()`	Post a message to queue
10	`OSSchedLock()`	Prevent rescheduling
11	`OSSchedUnlock()`	Allow rescheduling
12	`OSSemCreate()`	Create a semaphore
13	`OSSemPend()`	Wait for a semaphore
14	`OSSemPost()`	Signal a semaphore
15	`OSStart()`	Start multitasking
16	`OSTaskChangePrio()`	Change a task's priority
17	`OSTaskCreate()`	Create a task
18	`OSTaskDel()`	Delete a task
19	`OSTimeDly()`	Delay a task for n system ticks
20	`OSTimeGet()`	Get current system time
21	`OSTimeSet()`	Set system time
22	`OSTimeTick()`	Process a system tick

A µC/OS Programming Example

- An example to show a number of µC/OS features.
- 6 tasks are created.
- `TaskStat()` - First task to execute. It creates the other five which have higher priorities. It then displays statistics on the screen.
- `TaskKey()` - Monitors the keyboard. A message is sent to `Task1()` through a mailbox if key `1` is pressed.
- `Task1()` - Waits for message from TaskKey(). If not received within 36 system ticks, a timeout counter is incremented. Otherwise, a message counter is incremented.
- `Task2()` - Like Task1() except it waits for messages from a queue.
- `Task3()` - Displays one of four characters at random positions on the upper right hand side of the screen.
- `TaskClk()` - Displays date and time on the lower right hand corner.