

uC/OS-II Part 3:

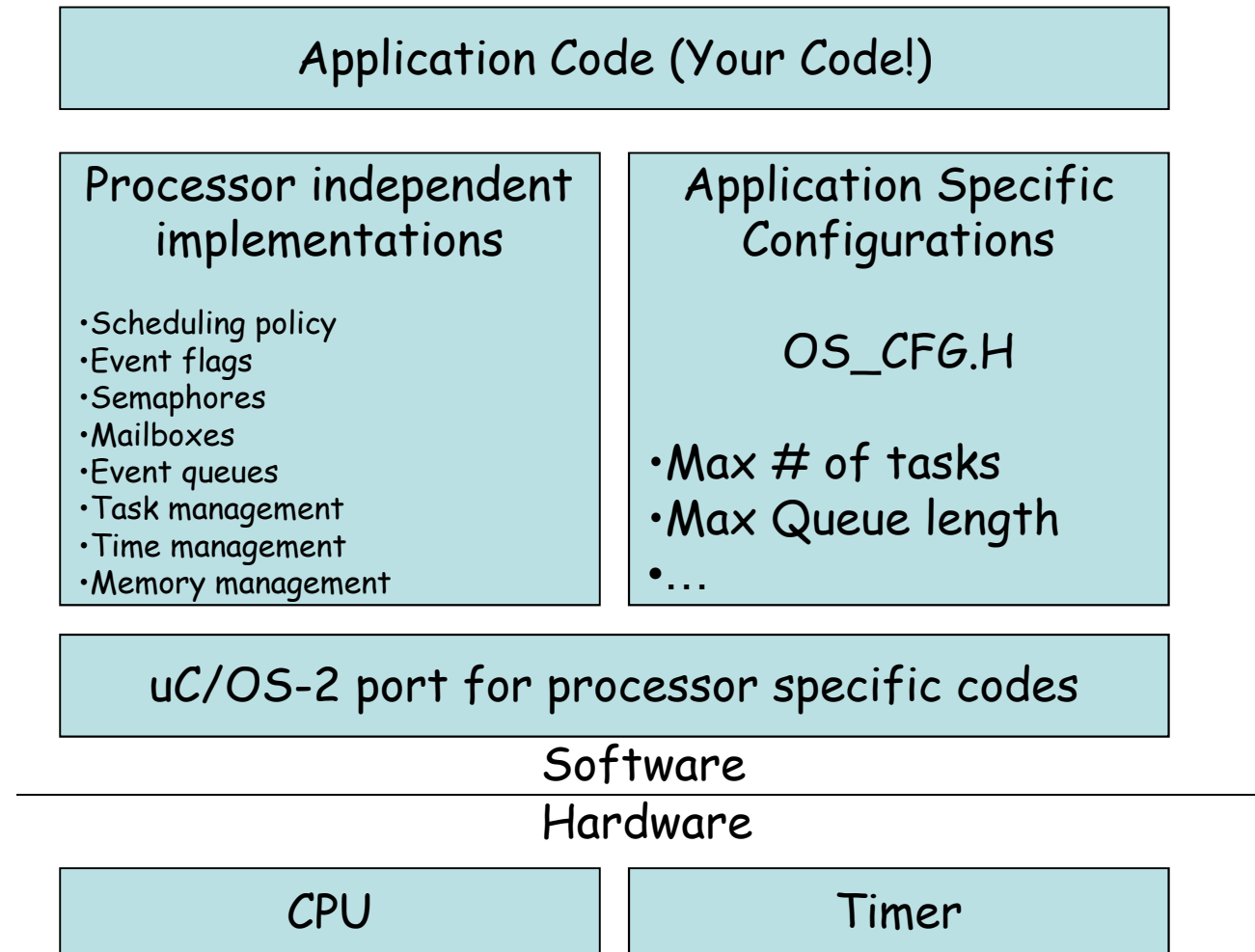
uC/OS-II: Kernel Structure

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Objectives

- To understand what a task is
- To learn how uC/OS-2 manages tasks
- To know how an ISR works

The uC/OS-2 File Structure



Critical Section Concept

Critical Sections

- A critical section is a portion of code that is not safe from race condition
- Use semaphores or mutex locks to protect critical sections
 - A good approach to task-task race in user code

Critical Sections

- Sometimes semaphores (or mutexes) are too heavy-duty or inappropriate
- Task-task race in kernel code
 - Critical sections in kernels are usually short, and semaphores are too expensive
- Task-ISR race
 - ISR cannot call blocking call (e.g., OSSemPend)
 - May cause deadlocks
 - May impose unnecessary/infinite delay on the interrupted task
 - May delay the upcoming interrupts that are handled by the same ISR

Critical Sections

- Disabling interrupts also stops the following
 - Task preemptions
 - Vectoring to ISR
- Suitable to
 - Kernel code; because critical sections in kernel are usually short
 - Task-ISR race; because ISR cannot call blocking calls (e.g., waiting on a semaphore)
- Does not work in multiprocessor systems
 - Use spinlock instead

Critical Sections

- The interrupt latency is part of the specification of an RTOS
 - Interrupt disabling should be as short as possible to improve the responsiveness
- Interrupt disabling must be used carefully:
 - E.g., if `OSTimeDly()` is called with interrupt disabled, the machine may hang!
 - A basic rule: do not call system services when interrupt is disabled

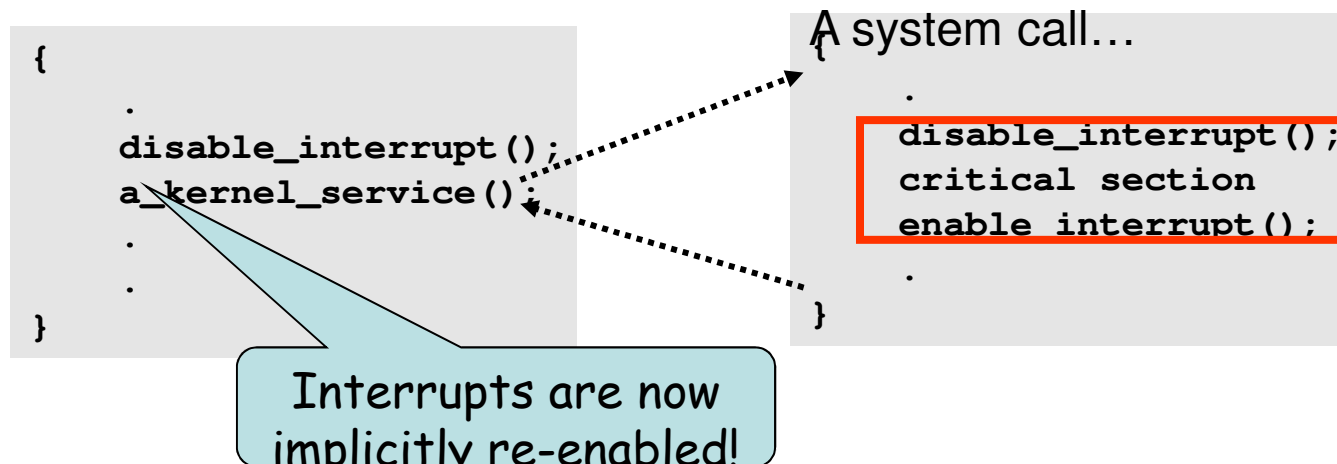
```
{  
    .  
    OS_ENTER_CRITICAL();  
    .    /* Critical Section */  
    OS_EXIT_CRITICAL();  
    .  
}
```


Critical Sections

- The states of the processor must be carefully maintained in nested calls of `OS_ENTER_CRITICAL()` / `OS_EXIT_CRITICAL()`
- There are different implementations for the maintenance of process states:
 - Interrupt enabling/disabling instructions
 - Interrupt status save/restore onto/from stacks

Critical Sections

- OS_CRITICAL_METHOD=1
- Interrupt enabling/disabling instructions.
- The simplest way, however, this approach does **not** have the sense of “**save**” and “**restore**”
 - Avoid to invoke any system calls between a pair of OS_ENTER_CRITICAL() and OS_EXIT_CRITICAL()



Critical Sections

- OS_CRITICAL_METHOD=2
- Processor Status Word (PSW) can be saved/restored onto/from stacks
 - PSW's of nested interrupt enable/disable operations can be exactly recorded in stacks

```
#define OS_ENTER_CRITICAL() \  
    asm("PUSH    PSW");  
    asm("DI");
```

```
#define OS_EXIT_CRITICAL() \  
    asm("POP     PSW");
```

← x86 port uses this method

Task Structure

Tasks

- A task is an active entity that conducts computation
- In real-time systems, a periodic task is typically an infinite loop

```
void YourTask (void *pdata)           (1)
{
    for (;;) {                         (2)
        /* USER CODE */
        Call one of uC/OS-II's services:
        OSMboxPend();
        OSQPend();
        OSSemPend();
        OSTaskDel(OS_PRIO_SELF);
        OSTaskSuspend(OS_PRIO_SELF);
        OSTimeDly();
        OSTimeDlyHMSM();
        /* USER CODE */
    }
}
```

Delay itself for
next event/period,
so that other
tasks can run.

Tasks

- uC/OS-2 can have up to 64 priorities
 - Each task has an unique priority
 - Priorities 63 and 62 are reserved (idle, stat)
- Insufficient number of priority will damage the schedulability of a real-time scheduler
 - Fortunately, # of tasks in embedded systems is usually not large so unique task priorities are possible

Tasks

- A task is created by OSTaskCreate() or OSTaskCreateExt()
- The priority of a task can be changed by OSTaskChangePrio()
- A task can delete itself when done

```
void YourTask (void *pdata)
{
    /* USER CODE */
    OSTaskDel(OS_PRIO_SELF);
}
```

The priority of the
current task

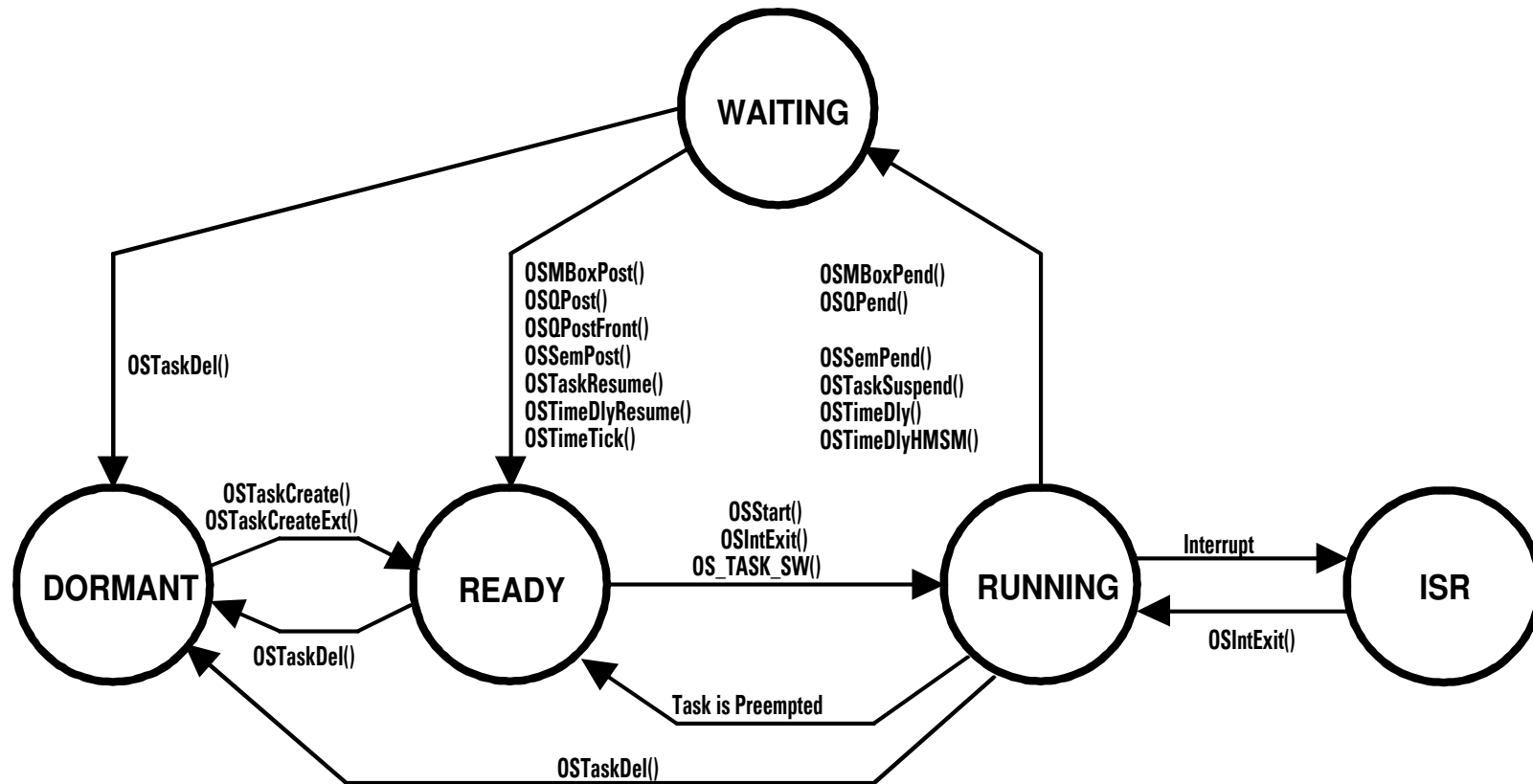
Task States

- Dormant: Procedures residing in RAM/ROM is not a task yet unless you call OSTaskCreate() to create one to execute them
- Ready: A task is neither delayed nor waiting for any event to occur
 - A task is ready once it is created
- Running: A ready task is running on the CPU
 - There must be only one running task.
 - The task running might be preempted and then become ready

Task States

- Waiting: A task is waiting for certain events to occur
 - Timer expiration, signaling of semaphores, messages in mailboxes, and etc
- ISR: A task is preempted by an interrupt
 - The stack of the interrupted task is utilized by the ISR

Task States



Task States

- A task can delay itself by calling `OSTimeDly()` or `OSTimeDlyHMSM()`.
 - The task is placed in the waiting state.
 - The task will be made ready by `OSTimeTick()`.
 - It is the clock ISR, you don't have to call it explicitly from your code.
- A task can wait for an event by `OSFlagPend()`, `OSSemPend()`, `OSMboxPend()`, or `OSQPend()`.
 - The task remains waiting until the occurrence of the desired event. (or timeout)
- The running task is always preempted by ISR's, unless interrupts are disabled.
 - ISR's could make one or more tasks ready by signaling events.
 - On the return of an ISR, the scheduler will check if rescheduling is needed.
- Once new tasks become ready, the next highest priority ready task is scheduled to run (due to occurrences of events, timer expirations).
- If no task is running and all tasks are not in the ready state, the idle task executes.

Task States

- A task can delay itself by calling `OSTimeDly()` or `OSTimeDlyHMSM()`.
 - The task is placed in the waiting state
 - The task will later be ready when the timer expires
 - The clock ISR `OSTimeTick()` decrements the timer
- A task can wait for an event by `OSFlagPend()`, `OSSemPend()`, `OSMboxPend()`, or `OSQPend()`
 - The task remains waiting until the desired event is signaled (or timeout)

Task Control Blocks (TCB)

- A TCB is a RAM-resident per-task data structure
- Each task is associated with a TCB
 - All valid TCB's are doubly linked
 - Free TCB's are linked in a free list
- The contents of a TCB is saved/restored during context switches
 - Task priority, delay counter, event to wait, stack pointer
 - CPU registers are saved to the stack, not TCB

```

typedef struct os_tcb {
    OS_STK          *OSTCBStkPtr;
#if OS_TASK_CREATE_EXT_EN
    void            *OSTCBExtPtr;
    OS_STK          *OSTCBStkBottom;
    INT32U          OSTCBStkSize;
    INT16U          OSTCBOpt;
    INT16U          OSTCBId;
#endif
    struct os_tcb *OSTCBNext;
    struct os_tcb *OSTCBPrev;
#if (OS_Q_EN && (OS_MAX_QS >= 2)) || OS_MBOX_EN || OS_SEM_EN
    OS_EVENT        *OSTCBEvtPtr;
#endif
#if (OS_Q_EN && (OS_MAX_QS >= 2)) || OS_MBOX_EN
    void            *OSTCBMsg;
#endif

    INT16U          OSTCBDly;
    INT8U           OSTCBStat;
    INT8U           OSTCBPrio;
    INT8U           OSTCBX;
    INT8U           OSTCBY;
    INT8U           OSTCBBitX;
    INT8U           OSTCBBitY;
#if OS_TASK_DEL_EN
    BOOLEAN         OSTCBDelReq;
#endif
} OS_TCB;

```

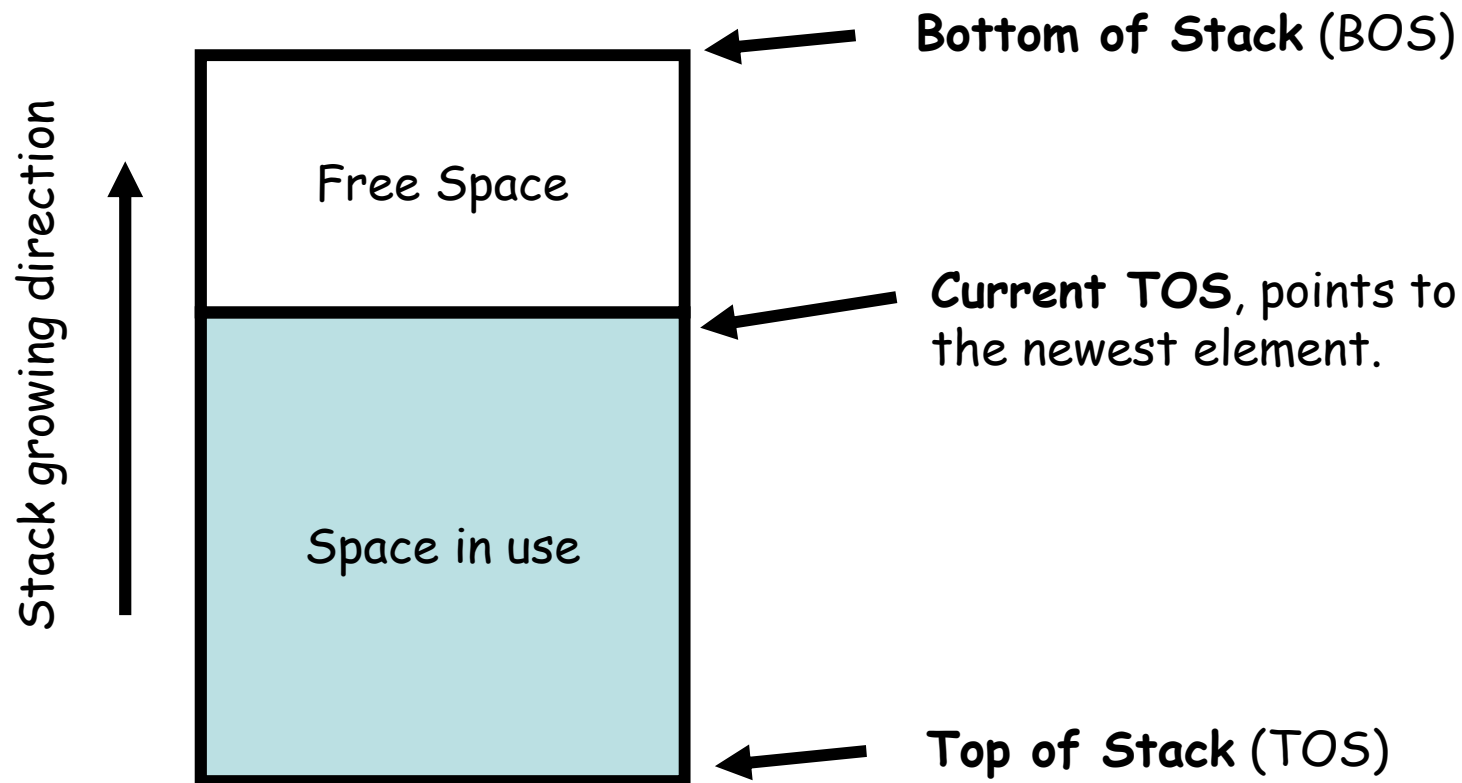
Task Control Blocks (TCB)

- **.OSTCBStkPtr** points to the current TOS for the task
 - It is the first entry of TCB so that it can be accessed directly via assembly language (offset=0)
- **.OSTCBExtPtr** is a pointer to a user-definable task control block extension.
 - Set OS_TASK_CREATE_EXT_EN to 1.
 - The pointer is set when OSTaskCreateExt() is called

Task Control Blocks (TCB)

- **.OSTCBStkBottom** is a pointer to the bottom of the task's stack
- **.OSTCBStkSize** holds the size of the stack in number of elements instead of bytes
 - The element size is the macro `OS_STK` (16 bits in x86)
 - Total stack size is `OSTCBStkSize*OS_STK` bytes
 - `.OSTCBStkBottom` and `.OSTCBStkSize` are used to check stack

Task Control Blocks (TCB)



Task Control Blocks (TCB)

- **.OSTCBOpt** holds “options” that can be passed to OSTaskCreateExt()
 - OS_TASK_OPT_STK_CHK: stack checking is enable for the task being created.
 - OS_TASK_OPT_STK_CLR: indicates that the stack needs to be cleared when the task is created.
 - OS_TASK_OPT_SAVE_FP: tells OSTaskCreateExt() that the task will be doing floating-point computations. Floating point processor’s registers must be saved to the stack on context-switches.
- **.OSTCBId**: holds an identifier for the task.
- **.OSTCBNext** and **.OSTCBPrev** are used to double link OS_TCBs
- **.OSTCBEVEventPtr** is pointer to an event control block.
- **.OSTCBMsg** is a pointer to a message that is sent to a task.
- **.OSTCBFlagNode** is a pointer to a flagnode.
- **.OSTCBFlagsRdy** maintains which event flags make the task ready.
- **.OSTCBDly** is used when:
 - a task needs to be delayed for a certain number of clock ticks, or
 - a task needs to pend for an event to occur with a timeout.
- **.OSTCBStat** contains the state of the task. (0 is ready to run)
- **.OSTCBPrio** contains the task priority.

Task Control Blocks (TCB)

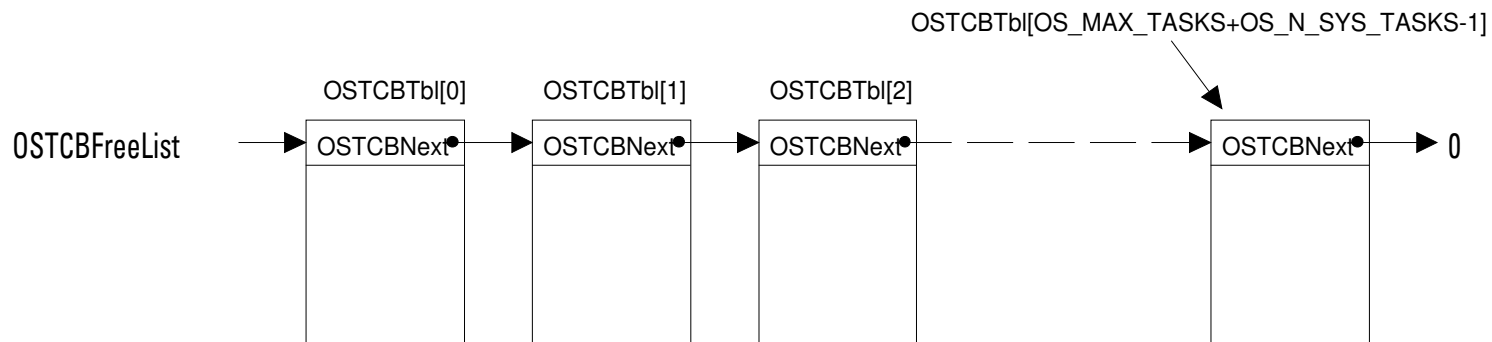
- **.OSTCBX .OSTCBY .OSTCBBitX and .OSTCBBitY**
 - They are used to accelerate the process of making a task ready to run or make a task wait for an event.

```
OSTCBY  = priority >> 3;  
OSTCBBitY      = OSMaPtbl[priority >> 3];  
OSTCBX  = priority & 0x07;  
OSTCBBitX      = OSMaPtbl[priority & 0x07];
```

- **.OSTCBDeReq** is boolean used to indicate whether or not a task request that the current task to be deleted.
- **OS_MAX_TASKS** is specified in **OS_CFG.H**
 - # OS_TCBs allocated by μ C/OS-II
- **OSTCBtbl[]** : an array holding all OS_TCBs
- When μ C/OS-II is initialized, all OS_TCBs in the table are linked in a singly linked list of free OS_TCBs

Task Control Blocks (TCB)

- A task receives/frees its OS_TCB from/to the free list
- An OS_TCB is initialized by the function OS_TCBInit(), which is called by OSTaskCreate().



```

INT8U OS_TCBInit (INT8U prio, OS_STK *ptos, OS_STK *pbos, INT16U id, INT32U stk_size, void *pext, INT16U
opt)
{
    #if OS_CRITICAL_METHOD == 3
        OS_CPU_SR cpu_sr;
    #endif
    OS_TCB *ptcb;

    OS_ENTER_CRITICAL();
    ptcb = OSTCBFreeList;
    if (ptcb != (OS_TCB *)0) {
        OSTCBFreeList = ptcb->OSTCBNext;
        OS_EXIT_CRITICAL();
        ptcb->OSTCBStkPtr = ptos;
        ptcb->OSTCBPrio = (INT8U)prio;
        ptcb->OSTCBStat = OS_STAT_RDY;
        ptcb->OSTCBDly = 0;

        #if OS_TASK_CREATE_EXT_EN > 0
            ptcb->OSTCBExtPtr = pext;
            ptcb->OSTCBStkSize = stk_size;
            ptcb->OSTCBStkBottom = pbos;
            ptcb->OSTCBOpt = opt;
            ptcb->OSTCBId = id;
        #else
            pext = pext;
            stk_size = stk_size;
            pbos = pbos;
            opt = opt;
            id = id;
        #endif

        #if OS_TASK_DEL_EN > 0
            ptcb->OSTCBDelReq = OS_NO_ERR;
        #endif

        ptcb->OSTCBY = prio >> 3;
        ptcb->OSTCBBitY = OSMaPtbl[ptcb->OSTCBY];
        ptcb->OSTCBX = prio & 0x07;
        ptcb->OSTCBBitX = OSMaPtbl[ptcb->OSTCBX];
    }
}

```

/* Allocate storage for CPU status register */

/* Get a free TCB from the free TCB list */

/* Update pointer to free TCB list */

/* Load Stack pointer in TCB */

/* Load task priority into TCB */

/* Task is ready to run */

/* Task is not delayed */

/* Store pointer to TCB extension */

/* Store stack size */

/* Store pointer to bottom of stack */

/* Store task options */

/* Store task ID */

/* Prevent compiler warning if not used */

/* Pre-compute X, Y, BitX and BitY */

Get a free TCB from
the free list

```

#if OS_EVENT_EN > 0
    ptcb->OSTCBEventPtr = (OS_EVENT *)0;          /* Task is not pending on an event */
#endif

#if (OS_VERSION >= 251) && (OS_FLAG_EN > 0) && (OS_MAX_FLAGS > 0) && (OS_TASK_DEL_EN > 0)
    ptcb->OSTCBFlagNode = (OS_FLAG_NODE *)0;      /* Task is not pending on an event flag */
#endif

#if (OS_MBOX_EN > 0) || ((OS_Q_EN > 0) && (OS_MAX_QS > 0))
    ptcb->OSTCBMsg = (void *)0;                   /* No message received */
#endif

#if OS_VERSION >= 204
    OSTCBInitHook(ptcb);
#endif

    OSTaskCreateHook(ptcb);                       /* Call user defined hook */

    OS_ENTER_CRITICAL();
    OSTCBPrioTbl[prio] = ptcb;
    ptcb->OSTCBNext = OSTCBList;
    ptcb->OSTCBPrev = (OS_TCB *)0;
    if (OSTCBList != (OS_TCB *)0) {
        OSTCBList->OSTCBPrev = ptcb;
    }
    OSTCBList = ptcb;
    OSRdyGrp |= ptcb->OSTCBBitY;
    OSRdyTbl[ptcb->OSTCBy] |= ptcb->OSTCBBitX;
    OS_EXIT_CRITICAL();
    return (OS_NO_ERR);
}
OS_EXIT_CRITICAL();
return (OS_NO_MORE_TCB);
}

```

User-defined hook is called here.

Priority table

TCB list

Ready list

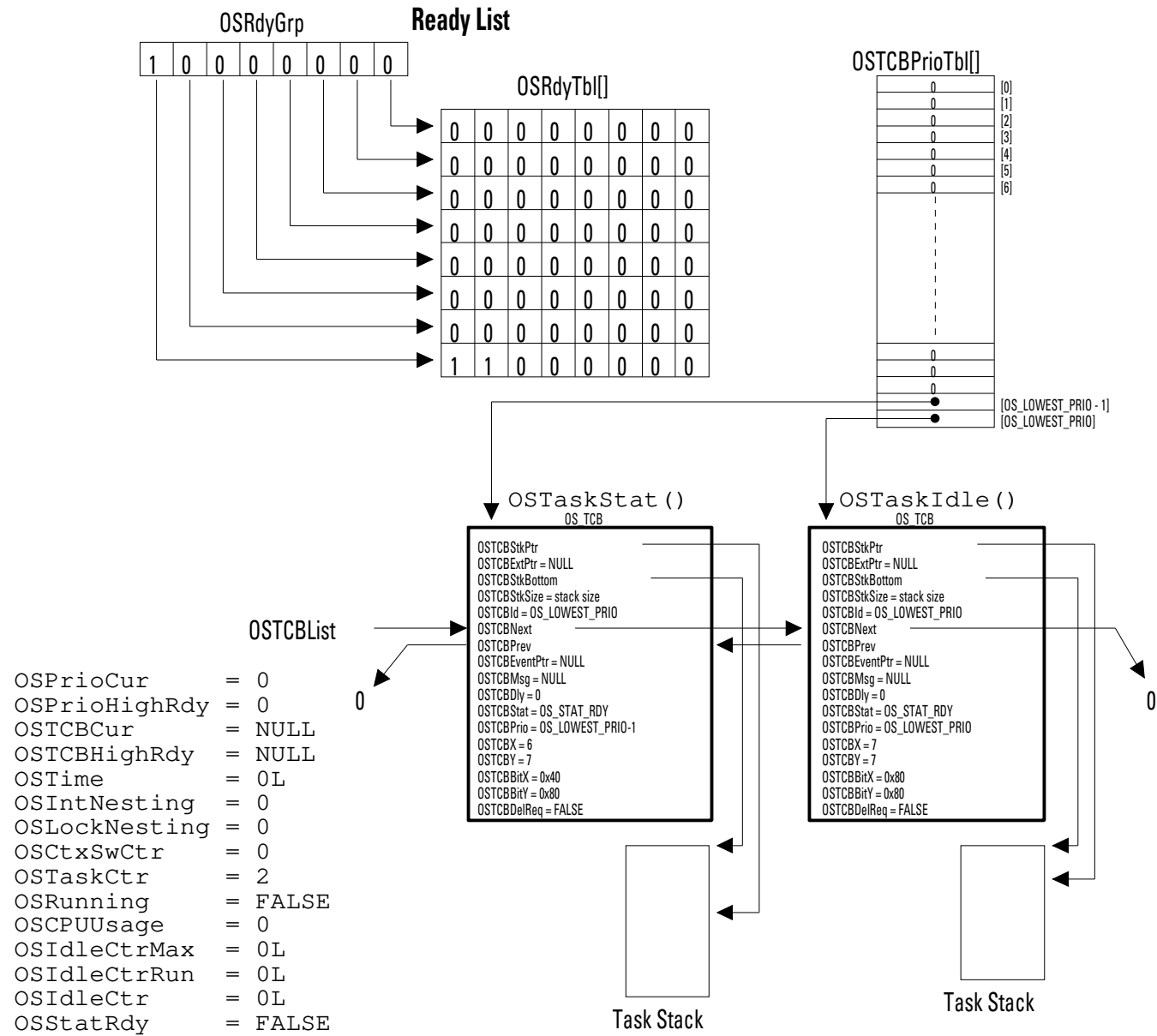
/* Link into TCB chain

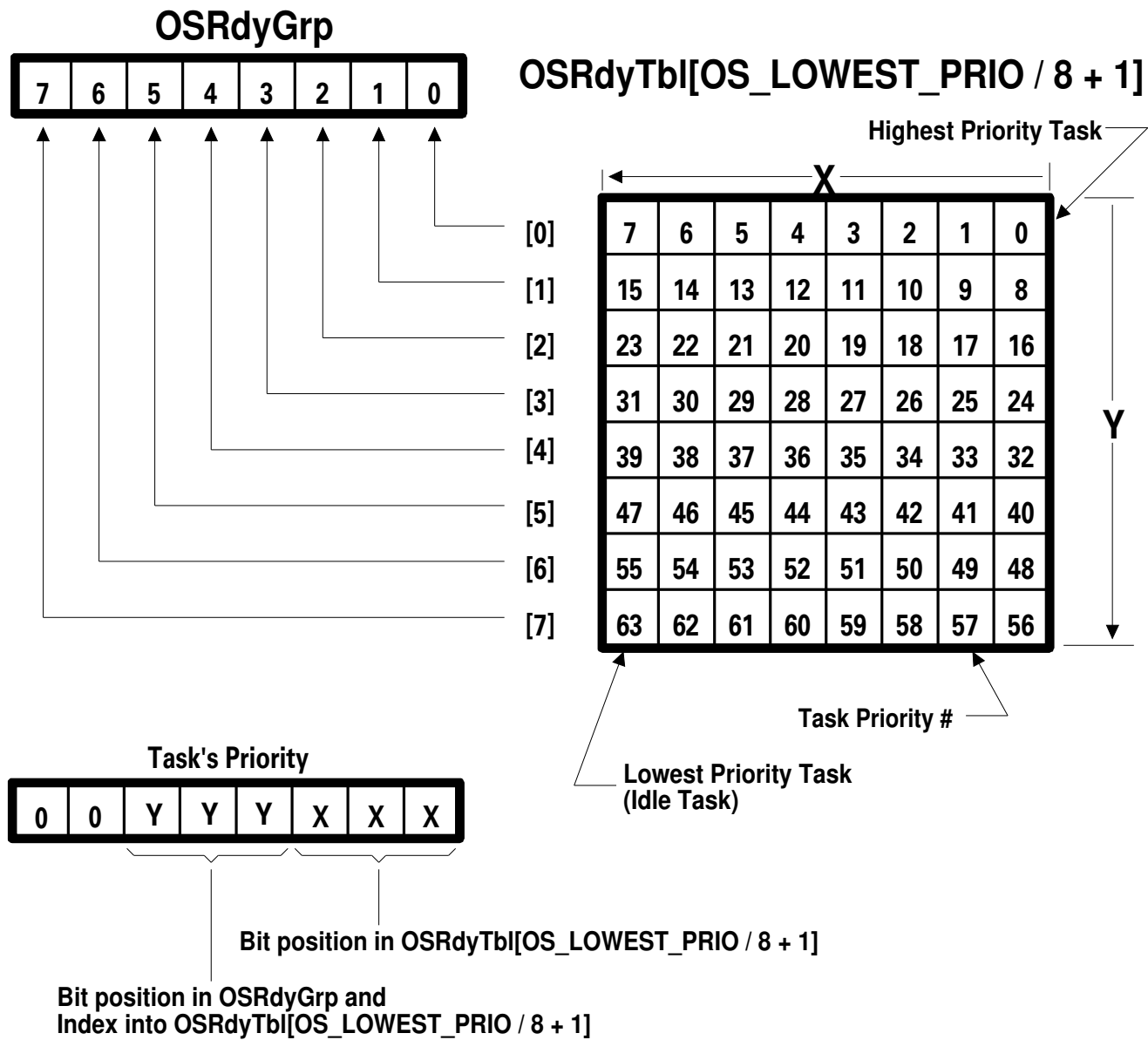
/* Make task ready to run

Context Switch and Scheduling

Ready List

- Ready list is a special bitmap that indicates which tasks are ready
- If a linear list is adopted, it takes $O(n)$ to locate the highest-priority ready task
 - It takes $O(\log n)$ if a heap is adopted
 - It takes only $O(1)$ in uC/OS-II using table lookups





OSMapTbl

Index	Bit mask (Binary)
0	00000001
1	00000010
2	00000100
3	00001000
4	00010000
5	00100000
6	01000000
7	10000000

Bit 0 in **OSRdyGrp** is 1 when **any** bit in **OSRdyTbl[0]** is 1.
Bit 1 in **OSRdyGrp** is 1 when **any** bit in **OSRdyTbl[1]** is 1.
Bit 2 in **OSRdyGrp** is 1 when **any** bit in **OSRdyTbl[2]** is 1.
Bit 3 in **OSRdyGrp** is 1 when **any** bit in **OSRdyTbl[3]** is 1.
Bit 4 in **OSRdyGrp** is 1 when **any** bit in **OSRdyTbl[4]** is 1.
Bit 5 in **OSRdyGrp** is 1 when **any** bit in **OSRdyTbl[5]** is 1.
Bit 6 in **OSRdyGrp** is 1 when **any** bit in **OSRdyTbl[6]** is 1.
Bit 7 in **OSRdyGrp** is 1 when **any** bit in **OSRdyTbl[7]** is 1.

- Make a task ready:

```
OSRdyGrp      |= OSMapTbl[prio >> 3];  
OSRdyTbl[prio >> 3] |= OSMapTbl[prio & 0x07];
```

- Remove a task from the ready list:

```
if ((OSRdyTbl[prio >> 3] &= ~OSMapTbl[prio & 0x07]) == 0)  
    OSRdyGrp &= ~OSMapTbl[prio >> 3];
```

What does this code do?

```

INT8U const OSUnMapTbl[] = {
    0, 0, 1, 0, 2, 0, 1, 0, 3, 0, 1, 0, 2, 0, 1, 0, /* 0x00 to 0x0F */
    4, 0, 1, 0, 2, 0, 1, 0, 3, 0, 1, 0, 2, 0, 1, 0, /* 0x10 to 0x1F */
    5, 0, 1, 0, 2, 0, 1, 0, 3, 0, 1, 0, 2, 0, 1, 0, /* 0x20 to 0x2F */
    4, 0, 1, 0, 2, 0, 1, 0, 3, 0, 1, 0, 2, 0, 1, 0, /* 0x30 to 0x3F */
    6, 0, 1, 0, 2, 0, 1, 0, 3, 0, 1, 0, 2, 0, 1, 0, /* 0x40 to 0x4F */
    4, 0, 1, 0, 2, 0, 1, 0, 3, 0, 1, 0, 2, 0, 1, 0, /* 0x50 to 0x5F */
    5, 0, 1, 0, 2, 0, 1, 0, 3, 0, 1, 0, 2, 0, 1, 0, /* 0x60 to 0x6F */
    4, 0, 1, 0, 2, 0, 1, 0, 3, 0, 1, 0, 2, 0, 1, 0, /* 0x70 to 0x7F */
    7, 0, 1, 0, 2, 0, 1, 0, 3, 0, 1, 0, 2, 0, 1, 0, /* 0x80 to 0x8F */
    4, 0, 1, 0, 2, 0, 1, 0, 3, 0, 1, 0, 2, 0, 1, 0, /* 0x90 to 0x9F */
    5, 0, 1, 0, 2, 0, 1, 0, 3, 0, 1, 0, 2, 0, 1, 0, /* 0xA0 to 0xAF */
    4, 0, 1, 0, 2, 0, 1, 0, 3, 0, 1, 0, 2, 0, 1, 0, /* 0xB0 to 0xBF */
    6, 0, 1, 0, 2, 0, 1, 0, 3, 0, 1, 0, 2, 0, 1, 0, /* 0xC0 to 0xCF */
    4, 0, 1, 0, 2, 0, 1, 0, 3, 0, 1, 0, 2, 0, 1, 0, /* 0xD0 to 0xDF */
    5, 0, 1, 0, 2, 0, 1, 0, 3, 0, 1, 0, 2, 0, 1, 0, /* 0xE0 to 0xEF */
    4, 0, 1, 0, 2, 0, 1, 0, 3, 0, 1, 0, 2, 0, 1, 0, /* 0xF0 to 0xFF */
};

```

•Finding the highest-priority task ready to run:

```

y  = OSUnMapTbl[OSRdyGrp];
x  = OSUnMapTbl[OSRdyTbl[y]];
prio = (y << 3) + x;

```

This matrix is used to locate the first LSB which is '1', by given a value.

For example, if 00110010 is given, then '1' is returned.

Task Scheduling

- The scheduler always schedules the highest-priority ready task to run
- Task-level scheduling and ISR-level scheduling are performed by `OS_Sched()` and `OSIntExit()`, respectively
- uC/OS-2 scheduling time is a predictable amount of time, i.e., a constant time
 - For example, the design of the ready list intends to achieve this objective

```

void OS_Sched (void)
{
    INT8U y;
    OS_ENTER_CRITICAL();
    if ((OSLockNesting | OSIntNesting) == 0) {           (1)
        y = OSUnMapTbl[OSRdyGrp];                        (2)
        OSPrioHighRdy = (INT8U)((y << 3) + OSUnMapTbl[OSRdyTbl[y]]); (2)
        if (OSPrrioHighRdy != OSPrioCur) {              (3)
            OSTCBHighRdy = OSTCBPrioTbl[OSPrrioHighRdy]; (4)
            OSCtxSwCtr++;                                  (5)
            OS_TASK_SW();                                  (6)
        }
    }
    OS_EXIT_CRITICAL();
}

```

- (1) Rescheduling will not be performed if the scheduler is locked or some interrupt is currently serviced (why?).
- (2) Find the highest-priority ready task.
- (3) If it is not the current task, then
- (4) ~ (6) Perform a context-switch.

OS_TASK_SW() is a macro: “asm int 0x80” that generates a software interrupt

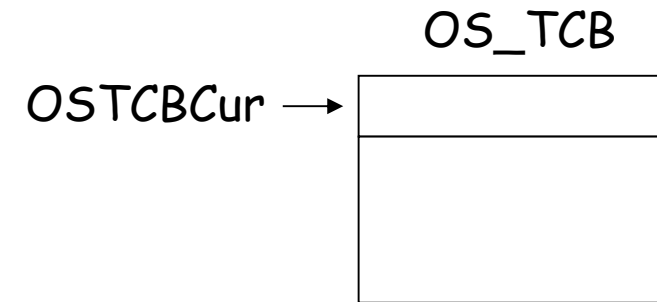
Task Scheduling

- A context switch must save all CPU registers and PSW of the preempted task onto its stack, and then restore the CPU registers and PSW of the highest-priority ready task from its stack
- Written in assembly
 - For efficiency
 - For direct access to registers and stack

Task-Level Context Switch

- Strictly speaking, context switches always happen on the way out of ISRs
 - When leaving the clock tick ISR
 - When leaving the cxtsw ISR
- How to perform cxtsw when a task voluntarily gives up the CPU (task-level cxtsw)?
 - There is no “interrupt” at this time
 - The task generates one by its own!
 - 80h in x86
 - Hardware dependent

Low Priority Task

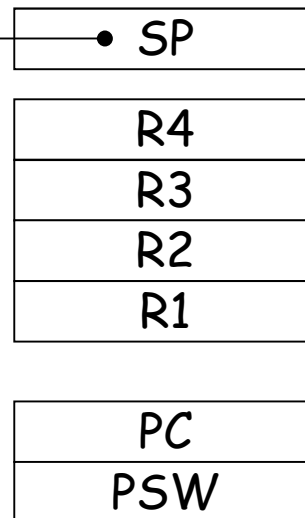


Low Memory

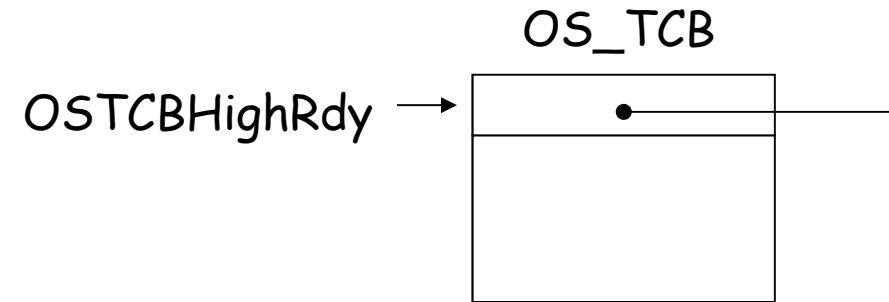


High Memory

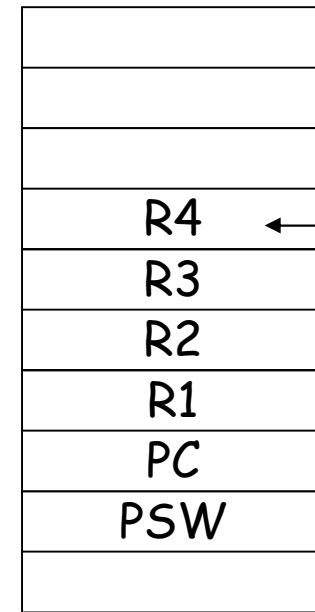
CPU



High Priority Task

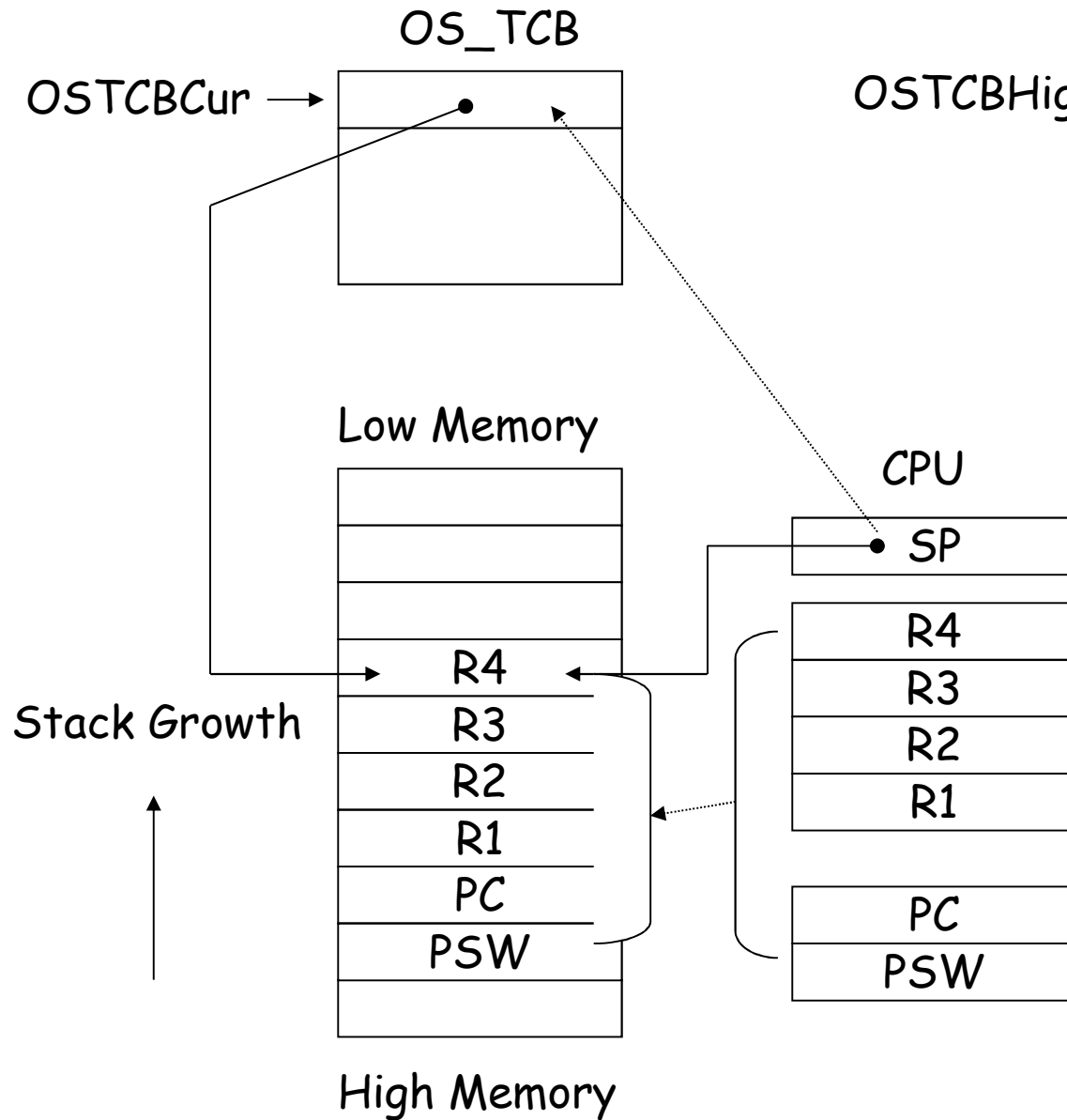


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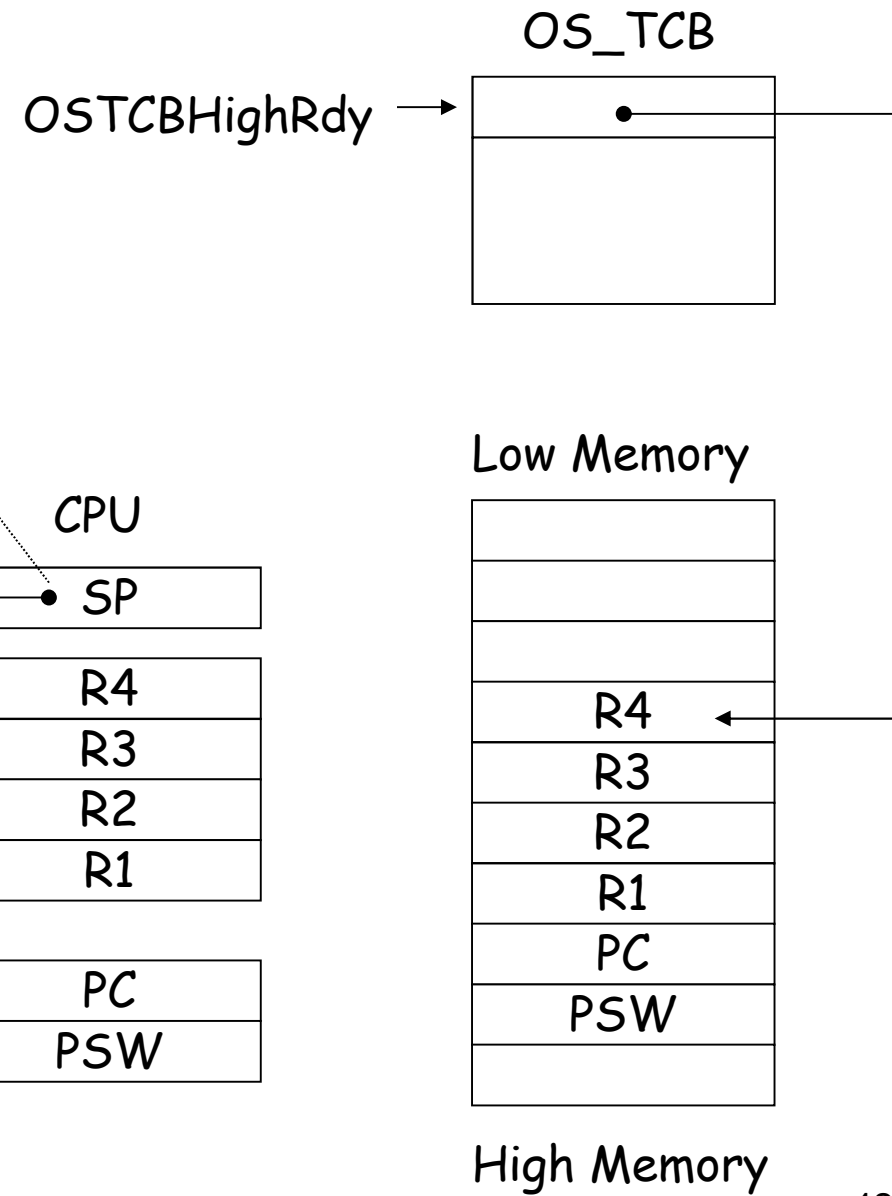


High Memory

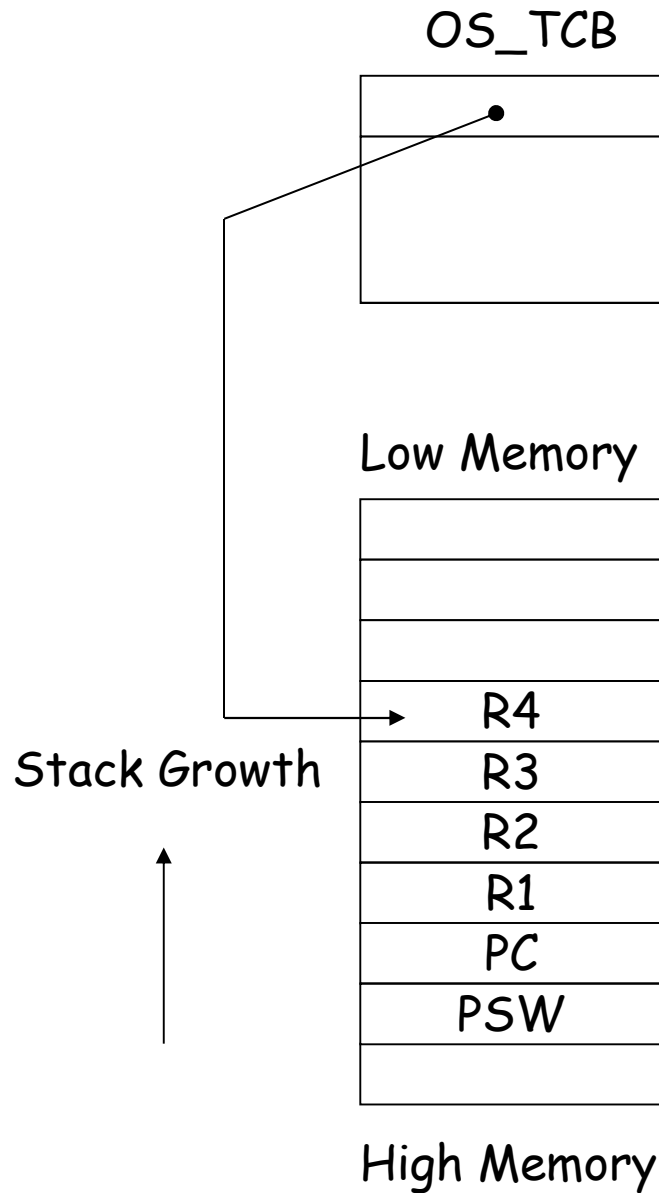
Low Priority Task



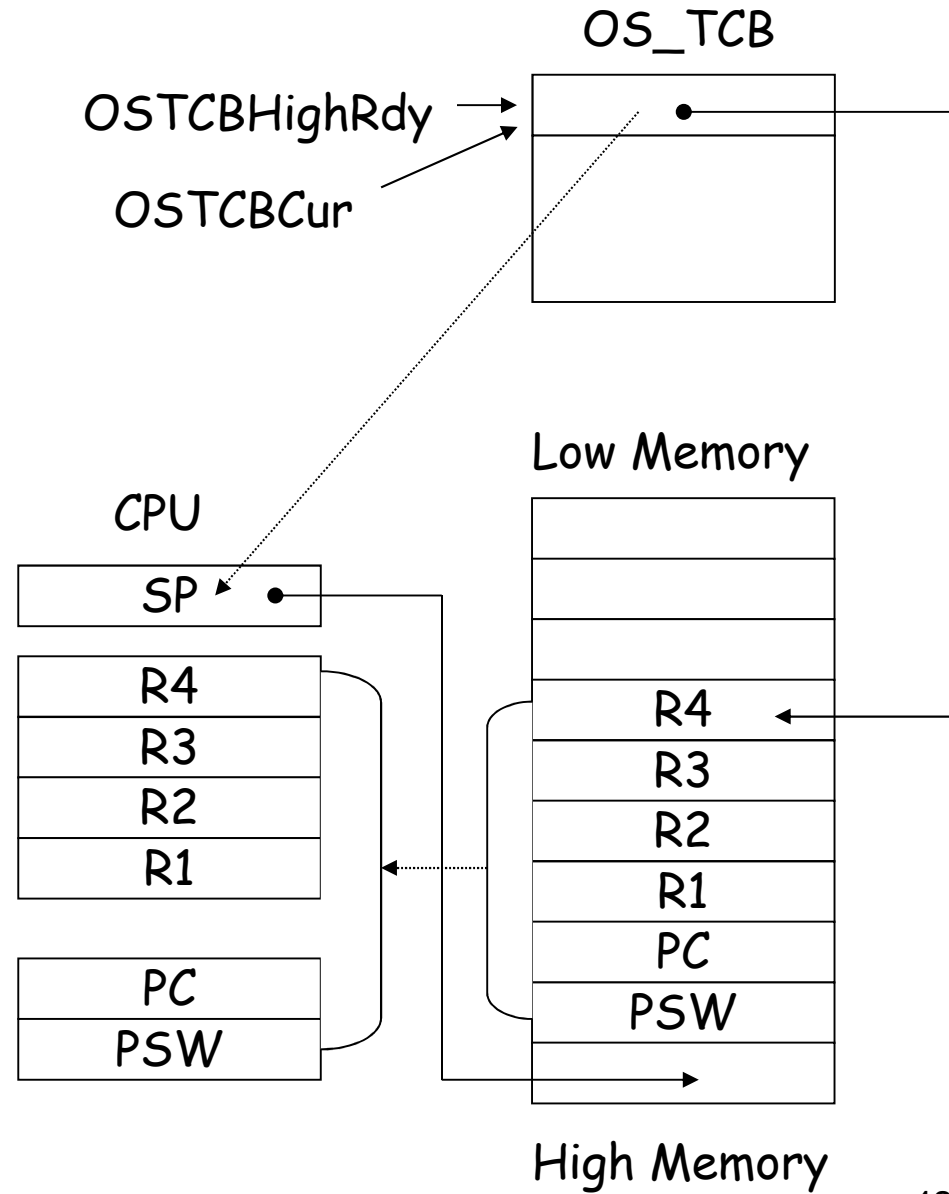
High Priority Task



Low Priority Task



High Priority Task



Interrupt Handling

Interrupts under uC/OS-2

- ISRs in uC/OS-2 are written in assembly

(1) and (4) → for possible cxt switch

YourISR:

```
Save all CPU registers; (1)
Call OSIntEnter() or, increment OSIntNesting directly; (2)
If(OSIntNesting == 1) (3)
    OSTCBCur->OSTCBStkPtr = SP; (4)
Clear the interrupting device; (5)
Re-enable interrupts (optional); (6)
Execute user code to service ISR; (7)
Call OSIntExit(); (8)
Restore all CPU registers; (9)
Execute a return from interrupt instruction; (10)
```

Interrupts under uC/OS-2

- (1) Upon entry of an ISR, all CPU registers must be saved in **the interrupted task's stack**
 - As the execution of the ISR may alter the registers
- (2) Increase the interrupt-nesting counter
- (4) If it is the first interrupt-nesting level, we immediately save the stack pointer to OSTCBCur.
 - We do this because a context-switch might occur

Interrupts under uC/OS-2

- (8) Call OSIntExit(), which checks if we are in the inner-level of nested interrupts. If we are at the outmost level ISR, the scheduler is called
 - Decrementing the Interrupt-nesting counter
 - A potential context-switch might occur
- (9) On the return to this point, several high-priority tasks may have been run by the CPU
 - If OSIntExit() performs a context switch
- (10) The CPU registers are restored from the stack and CPU execution returns to the interrupted instruction (of a task)

Interrupts under uC/OS-2

```
void OSIntExit (void)
{
    OS_ENTER_CRITICAL();
    if ((--OSIntNesting | OSLockNesting) == 0) {
        OSIntExitY = OSUnMapTbl[OSRdyGrp];
        OSPrioHighRdy = (INT8U)((OSIntExitY << 3) +
                                OSUnMapTbl[OSRdyTbl[OSIntExitY]]);
        if (OSPrioHighRdy != OSPrioCur) {
            OSTCBHighRdy = OSTCBPrioTbl[OSPrioHighRdy];
            OSCtxSwCtr++;
            OSIntCtxSw();
        }
    }
    OS_EXIT_CRITICAL();
}
```

If scheduler is not locked and no interrupt nesting

If there is another high-priority task ready

A context switch is performed.

Note that OSIntCtxSw() is called instead of calling OS_TASK_SW() because we are already in an ISR

```
void OSIntEnter (void)
{
    OS_ENTER_CRITICAL();
    OSIntNesting++;
    OS_EXIT_CRITICAL();
}
```

Interrupt-Level Task Scheduling

- OSIntExit() checks if a higher-priority task becomes ready
 - If so, perform context switch
- Task-level vs. Interrupt-level cxtsw
 - Task-level cxtsw actually “emulates” a interrupt-level cxtsw via a software interrupt

Clock Tick

- A timer is needed to keep track of time delays and timeouts
- You must install uC/OS-2 tick ISR after OSStart()
 - Do this in the startup task
- Tick ISR calls OSTimeTick()
- Clock tick ISR is also written in assembly

Clock Tick

```
void OSTickISR(void)
{
    Save processor registers;
    Call OSIntEnter() or increment OSIntNesting;
    If(OSIntNesting == 1)
        OSTCBCur->OSTCBStkPtr = SP;
    Call OSTimeTick();
    Clear interrupting device;
    Re-enable interrupts (optional);
    Call OSIntExit();
    Restore processor registers;
    Execute a return from interrupt instruction;
}
```

```
void OSTimeTick (void)
```

```
{
```

```
    OS_TCB  *ptcb;
```

```
    OSTimeTickHook();
```

```
    if (OSRunning == TRUE) {
```

```
        ptcb = OSTCBList;
```

```
        while (ptcb->OSTCBPrio != OS_IDLE_PRIO) {
```

```
            OS_ENTER_CRITICAL();
```

```
            if (ptcb->OSTCBDly != 0) {
```

```
                if (--ptcb->OSTCBDly == 0) {
```

```
                    if ((ptcb->OSTCBStat & OS_STAT_SUSPEND) == OS_STAT_RDY) {
```

```
                        OSRdyGrp      |= ptcb->OSTCBBitY;
```

```
                        OSRdyTbl[ptcb->OSTCBY] |= ptcb->OSTCBBitX;
```

```
                    } else {
```

```
                        ptcb->OSTCBDly = 1;
```

```
                    }
```

```
                }
```

```
            }
```

```
            ptcb = ptcb->OSTCBNext;
```

```
            OS_EXIT_CRITICAL();
```

```
        }
```

```
    }
```

```
}
```

For all TCB's

Decrement delay-counter if needed

If the delay-counter reaches zero, make the task ready.

Clock Tick

- OSTimeTick() is hardware **independent**
 - Called by OSTickISR, which is hardware **dependent**
- Linearly visiting all TCBs and decrementing delay
 - $O(n)$ to progress 1 unit of time
 - $O(1)$ to insert a new sleeping task
- Alternative: delta list
 - $O(1)$ to progress 1 unit of time
 - $O(n)$ to insert a new sleeping task

Clock Tick

- You can also move a bunch of code in the tick ISR to a user task:

```
void OSTickISR(void)
{
    Save processor registers;
    Call OSIntEnter() or increment OSIntNesting;
    If(OSIntNesting == 1)
        OSTCBCur->OSTCBStkPtr = SP;

    Post a 'dummy' message (e.g. (void *)1)
        to the tick mailbox;

    Call OSIntExit();
    Restore processor registers;
    Execute a return from interrupt instruction;
}
```

```
void TickTask (void *pdata)
{
    pdata = pdata;
    for (;;) {
        OSMBboxPend(...);
        OSTimeTick();
        OS_Sched();
    }
}
```

Post a
message

Do the rest of
the work

Locking and Unlocking the Scheduler

- `OSSchedLock()` prevent high-priority ready tasks from preempting the current task without disabling interrupts
- `OSSchedLock()` and `OSSchedUnlock()` are used in pairs
- `OSLockNesting` keeps track of the number of `OSSchedLock()` has been called (how? why?)

Locking and Unlocking the Scheduler

- After calling OSSchedLock(), **you must not** call kernel services which might cause context switch, such as OSFlagPend(), OSMboxPend(), OSMutexPend(), OSQPend(), OSSemPend(), OSTaskSuspend(), OSTimeDly, OSTimeDlyHMSM() until OSLockNesting == 0. Or the system will be locked up
- To lock the scheduler is to prevent from task-task race conditions while interrupts are still handled

OSSchedLock()

```
void OSSchedLock (void)
{
    #if OS_CRITICAL_METHOD == 3          /* Allocate storage for CPU status register */
        OS_CPU_SR  cpu_sr;
    #endif

    if (OSRunning == TRUE) {             /* Make sure multitasking is running */
        OS_ENTER_CRITICAL();
        if (OSLockNesting < 255) { /* Prevent OSLockNesting from wrapping back to 0 */
            OSLockNesting++;          /* Increment lock nesting level */
        }
        OS_EXIT_CRITICAL();
    }
}
```

OSSchedUnlock()

```
void OSSchedUnlock (void)
{
    #if OS_CRITICAL_METHOD == 3                /* Allocate storage for CPU status register */
        OS_CPU_SR  cpu_sr;
    #endif

    if (OSRunning == TRUE) {                  /* Make sure multitasking is running */
        OS_ENTER_CRITICAL();
        if (OSLockNesting > 0) {              /* Do not decrement if already 0 */
            OSLockNesting--;                  /* Decrement lock nesting level */
            if ((OSLockNesting == 0) &&
                (OSIntNesting == 0)) { /* See if sched. enabled and not an ISR */
                OS_EXIT_CRITICAL();
                OS_Sched();                 /* See if a HPT is ready */
            } else {
                OS_EXIT_CRITICAL();
            }
        } else {
            OS_EXIT_CRITICAL();
        }
    }
}
```

Recap: Race Avoidance

- `OS_ENTER_CRITICAL/OS_EXIT_CRITICAL`
 - Nothing happens; neither interrupt nor preemption
- `OSSchedLock()/OSSchedUlock()`
 - Preemption is prohibited but interrupts are handled
 - However, all tasks are affected (no rescheduling)
- `OSSemPend()/OSSemPost()`
 - Both preemption and interrupt are allowed
 - Only pending/posting tasks are affected

Recap: Interrupt Handling

- Do's
 - Make ISR as short as possible
 - Defer long job to a worker thread
- Don'ts
 - Call a system service with interrupt disabled
 - Call a system service with scheduler locked
 - Call a blocking call from an ISR

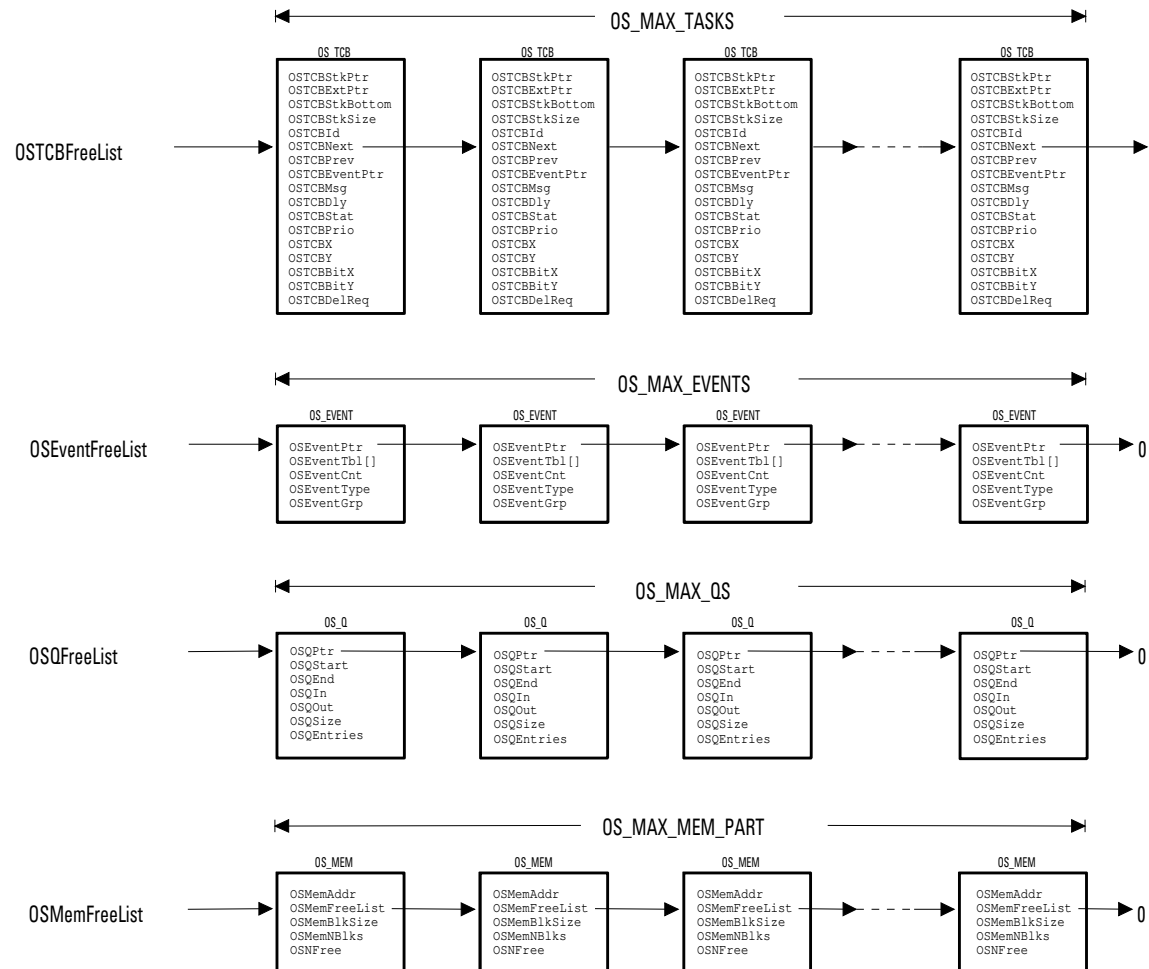
The Idle Task

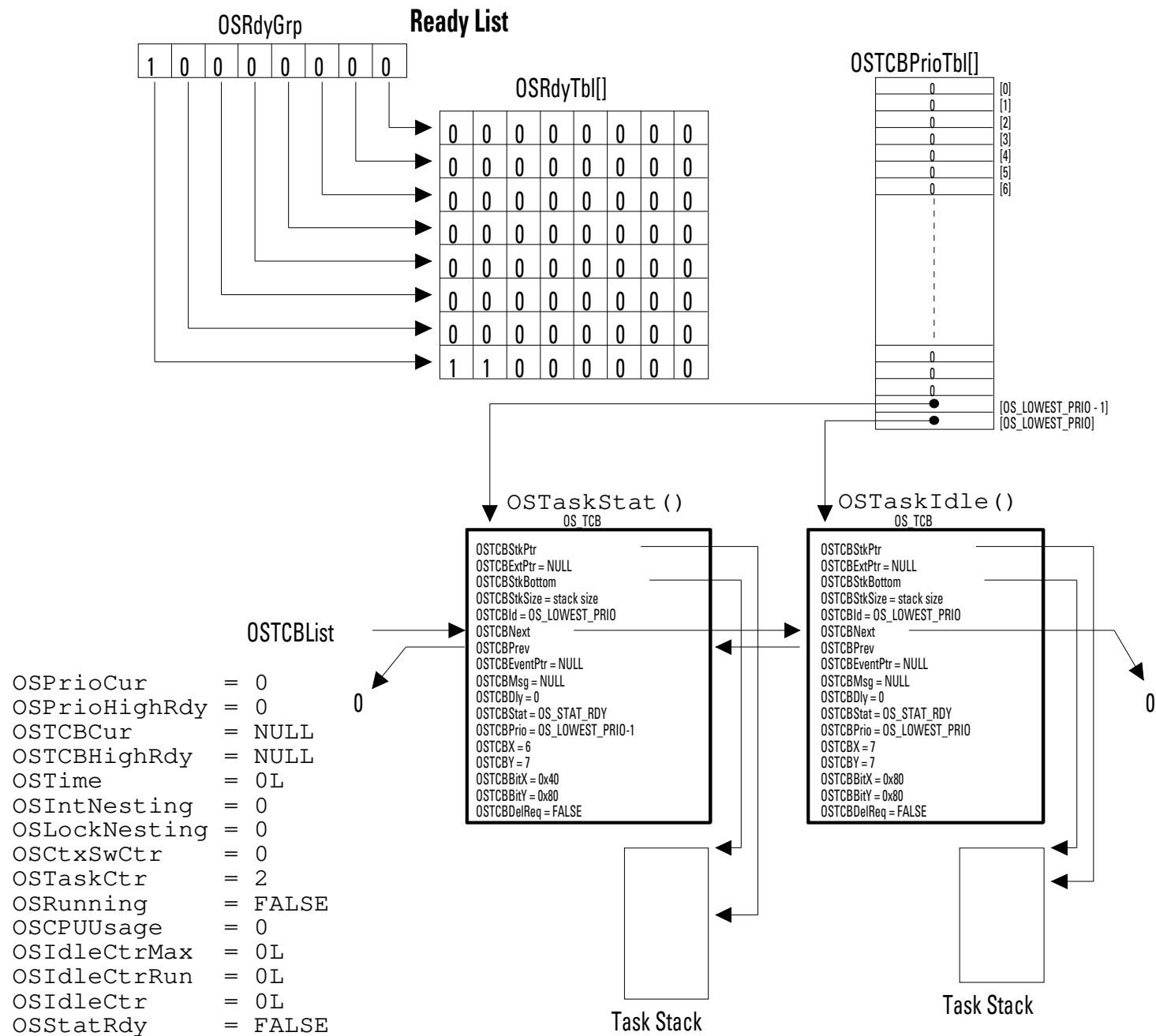
- The idle task is the lowest-priority task and can not be deleted or suspended
- To conserve power dissipation, you can issue a HALT instruction in the idle task
- Do not call delay or suspend services in OSTaskIdleHook()!!

```
void OS_TaskIdle (void *pdata)
{
    #if OS_CRITICAL_METHOD == 3
        OS_CPU_SR cpu_sr;
    #endif

    pdata = pdata;
    for (;;) {
        OS_ENTER_CRITICAL();
        OSIdleCtr++;
        OS_EXIT_CRITICAL();
        OSTaskIdleHook();
    }
}
```

uC/OS-2 Initialization





Starting uC/OS-2

- OSInit() initializes the data structures for uC/OS-2 and creates OS_TaskIdle()
- OSStart() pops the CPU registers of the highest-priority ready task and then executes a **return from interrupt instruction (IRET)**
 - It never returns to the caller of OSStart() (i.e., main())
 - IRET: Actually no task is currently interrupted, things on the stack are “emulated”

Starting uC/OS-2

```
void main (void)
{
    OSInit();          /* Initialize uC/OS-II          */
    .
    Create at least 1 task using either OSTaskCreate() or OSTaskCreateExt();
    .
    OSStart();         /* Start multitasking! OSStart() will not return */
}
```

```
void OSStart (void)
{
    INT8U y;
    INT8U x;
    if (OSRunning == FALSE) {
        y      = OSUnMapTbl[OSRdyGrp];
        x      = OSUnMapTbl[OSRdyTbl[y]];
        OSPrioHighRdy = (INT8U)((y << 3) + x);
        OSPrioCur    = OSPrioHighRdy;
        OSTCBHighRdy  = OSTCBPrioTbl[OSPrioHighRdy];
        OSTCBCur      = OSTCBHighRdy;
        OSStartHighRdy();
    }
}
```

Start the highest-priority ready task

Quick Review

- There are several places at which the scheduling decision is made. What are they?

Summary

- In this chapter, you should learn:
 - What a task is, how uC/OS-2 manages a task, and related data structures
 - How the scheduler works, and the detailed operations done in context switches
 - The responsibility of the idle task
 - How interrupts are serviced in uC/OS-2
 - The initializing and starting of uC/OS-2