2 Kernel Structure

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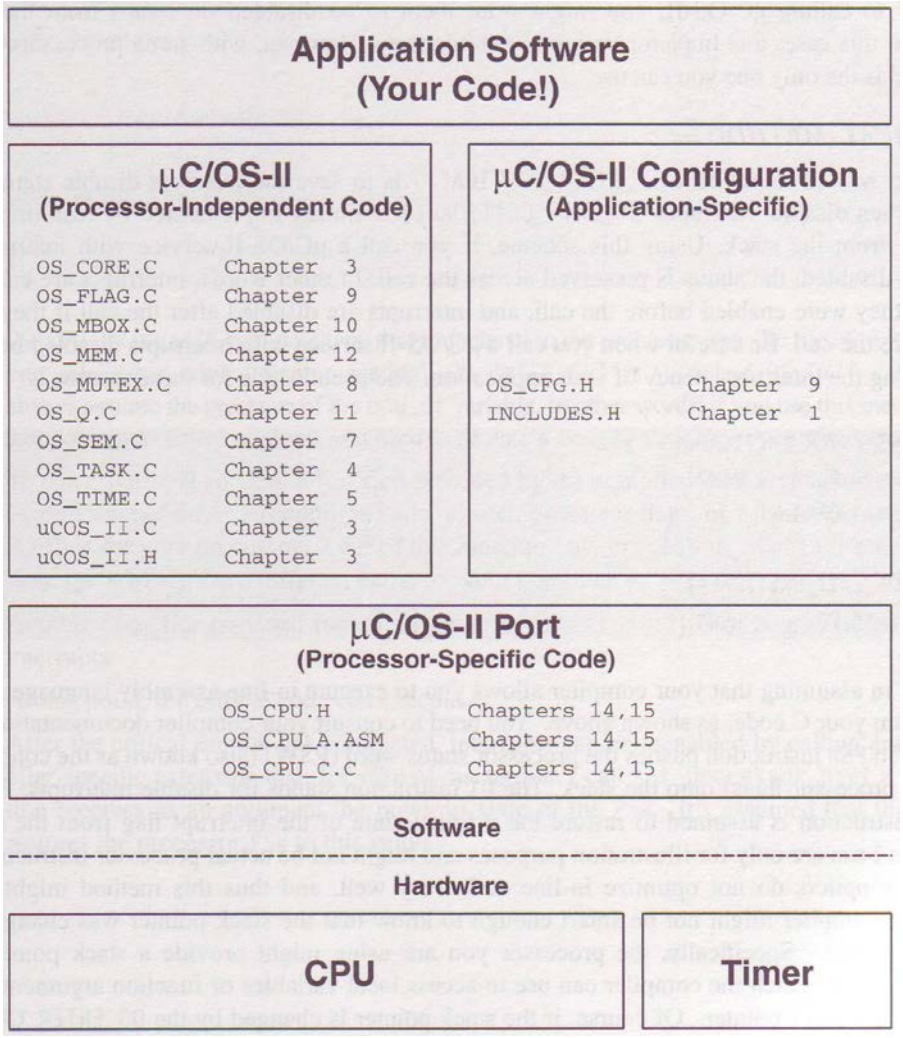
uC/OS-II

- What is µC/OS-II?
  - µC/OS-II is a portable, ROMable, scalable, preemptive, real-time deterministic multitasking kernel for microprocessors, microcontrollers and DSPs.
- Applications
  - Avionics - used in the Mars Curiosity Rover!
  - Medical Equipment/Devices
  - Data Communications Equipment
  - White Goods (Appliances)
  - Mobile Phones, PDAs, Mobile Internet Devices
  - Industrial Controls
  - Consumer Electronics
  - Automotive
  - A wide range of other safety critical embedded applications

uC/OS-II File Structure



Critical Sections

- uC/OS-II provides 2 macros in `os_cpu.h`
  - `OS_ENTER_CRITICAL()`
  - `OS_EXIT_CRITICAL()`
- Notes
  - Be sure not to call some kernel functions (eg: `OSTimeDly`) when interrupts are disabled
  - If you call a kernel function with interrupts disabled, interrupts are enabled on return

Critical Sections - Method 1

- `OS_CRITICAL_METHOD == 1` (`os_cpu.h`)
- Code example

```
#define OS_ENTER_CRITICAL() asm("DI");
#define OS_EXIT_CRITICAL() asm("EI");
```

- With this method, interrupt status is not preserved between before and after the macros

Critical Sections - Method 2

- `OS_CRITICAL_METHOD == 2` (`os_cpu.h`)
- Code example

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

- With this method, interrupt status is preserved between before and after the macros

Critical Sections - Method 3

- `OS_CRITICAL_METHOD == 3` (`os_cpu.h`)
- Use of a local variable `OS_CPU_SR cpu_sr;`
- Code example

```
#define OS_ENTER_CRITICAL() \
  cpu_sr = get_processor_psw(); \
  disable_interrupt();
#define OS_EXIT_CRITICAL() \
  set_processor_psw(cpu_sr);
```

- With this method, interrupt status is preserved between before and after the macros

Critical Sections - Method 3 on ARM

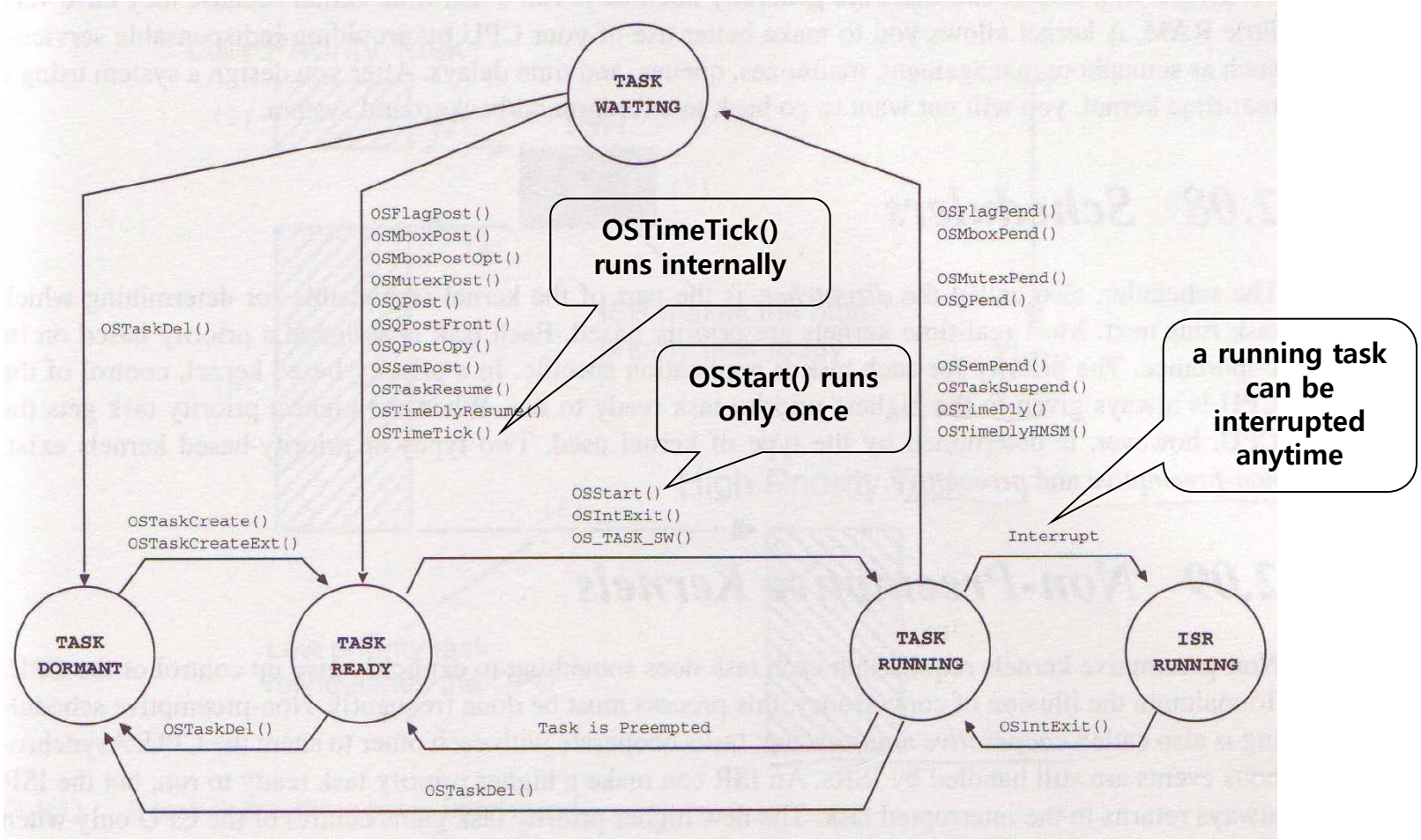
```
#define OS_CRITICAL_METHOD 3

#define OS_ENTER_CRITICAL() \
  cpu_sr = OS_CPU_SR_Save();

#define OS_EXIT_CRITICAL() \
  OS_CPU_SR_Restore(cpu_sr);
```

Tasks

Listing 3.2 A task is an infinite loop.

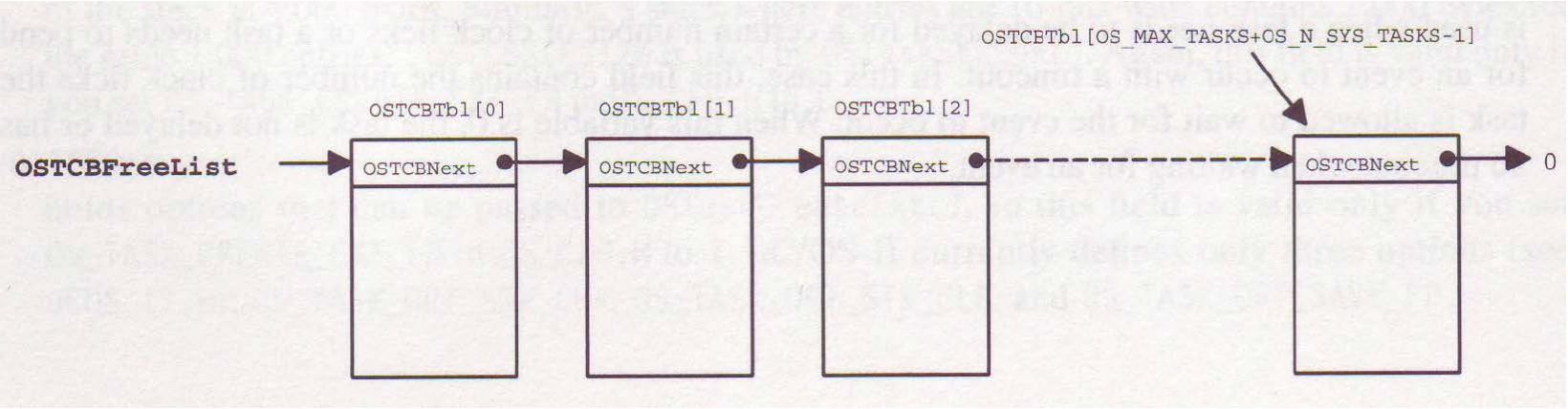
```
void YourTask (void *pdata)                                    (1)
{
   for (;;) {                                                  (2)
      /* USER CODE */
      Call one of uC/OS-II's services:
      OSFlagPend();
      OSMboxPend();
      OSMutexPend();
      OSQPend();
      OSSemPend();
  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

Task States


TASK WAITING
OSFlagPost()
OSMboxPost()
OSMboxPostOpt()
OSMutexPost()
OSQPost()
OSQPostFront()
OSQPostOpy()
OSSemPost()
OSTaskResume()
OSTimeDlyResume()
OSTimeTick()
OSTimeTick() runs internally
OSFlagPend()
OSMboxPend()
OSMutexPend()
OSQPend()
OSSemPend()
OSTaskSuspend()
OSTimeDly()
OSTimeDlyHMSM()
a running task can be interrupted anytime
OSTaskDel()
OSStart() runs only once
OSStart()
OSIntExit()
OS_TASK_SW()
OSTaskCreate()
OSTaskCreateExt()
Interrupt
TASK DORMANT
TASK READY
TASK RUNNING
ISR RUNNING
OSTaskDel()
Task is Preempted
OSIntExit()
OSTaskDel()

Task Control Blocks (OS_TCB)

- When a task is created, it is assigned a task control block (OS_TCB)
- OS_TCBs reside in RAM
- Structure fields are organized to allow for structure packing



typedef struct os_tcb - 1/2

```
typedef struct os_tcb {
    OS_STK *OSTCBStkPtr;              /* Pointer to current top of stack */

#if OS_TASK_CREATE_EXT_EN > 0
    void *OSTCBExtPtr;                /* Pointer to user definable data for TCB extension */
    OS_STK   *OSTCBStkBottom;         /* Pointer to bottom of stack */
    INT32U   OSTCBStkSize;            /* Size of task stack (in number of stack elements) */
    INT16U   OSTCBOpt;                /* Task options as passed by OSTaskCreateExt()  */
    INT16U   OSTCBId;                 /* Task ID (0..65535) */
#endif

    struct os_tcb *OSTCBNext;         /* Pointer to next  TCB in the TCB list */
    struct os_tcb *OSTCBPrev;         /* Pointer to previous TCB in the TCB list */

#if ((OS_Q_EN > 0) && (OS_MAX_QS > 0)) || (OS_MBOX_EN > 0) || (OS_SEM_EN > 0) || (OS_MUTEX_EN > 0)
    OS_EVENT *OSTCBEventPtr;          /* Pointer to event control block */
#endif
#if ((OS_Q_EN > 0) && (OS_MAX_QS > 0)) || (OS_MBOX_EN > 0)
    void *OSTCBMsg;                   /* Message received from OSMboxPost() or OSQPost() */
#endif
```

typedef struct os_tcb - 2/2

```
#if (OS_VERSION >= 251) && (OS_FLAG_EN > 0) && (OS_MAX_FLAGS > 0)
#if OS_TASK_DEL_EN > 0
    OS_FLAG_NODE *OSTCBFlagNode;/* Pointer to event flag node */
#endif
    OS_FLAGS OSTCBFlagsRdy;          /* Event flags that made task ready to run */
#endif

    INT16U   OSTCBDly;               /* Nbr ticks to delay task or, timeout waiting for event */
    INT8U    OSTCBStat;              /* Task status */
    INT8U    OSTCBPrio;              /* Task priority (0 == highest, 63 == lowest) */

    INT8U    OSTCBX;                 /* Bit position in group  corresponding to task priority (0..7) */
    INT8U    OSTCBY;                 /* Index into ready table corresponding to task priority */
    INT8U    OSTCBBitX;              /* Bit mask to access bit position in ready table */
    INT8U    OSTCBBitY;              /* Bit mask to access bit position in ready group */

#if OS_TASK_DEL_EN > 0
    BOOLEAN          OSTCBDelReq;          /* Indicates whether a task needs to
#endif
} OS_TCB;
```

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

to make a task ready or wait fast (computed when a task is created or a task's priority is changed

OSTCBStat

- OS_STAT_RDY (=0x00): Ready to run
- OS_STAT_SEM (=0x01): Pending on semaphore
- OS_STAT_MBOX (=0x02): Pending on mailbox
- OS_STAT_Q (=0x04): Pending on queue
- OS_STAT_SUSPEND (=0x08): Task is suspended
- OS_STAT_MUTEX (=0x10): Pending on mutual exclusion semaphore
- OS_STAT_FLAG (=0x20): Pending on event flag group
- OS_STAT_PEND_ANY (=0x3E): (OS_STAT_SEM | OS_STAT_MBOX | OS_STAT_Q | OS_STAT_MUTEX | OS_STAT_FLAG)

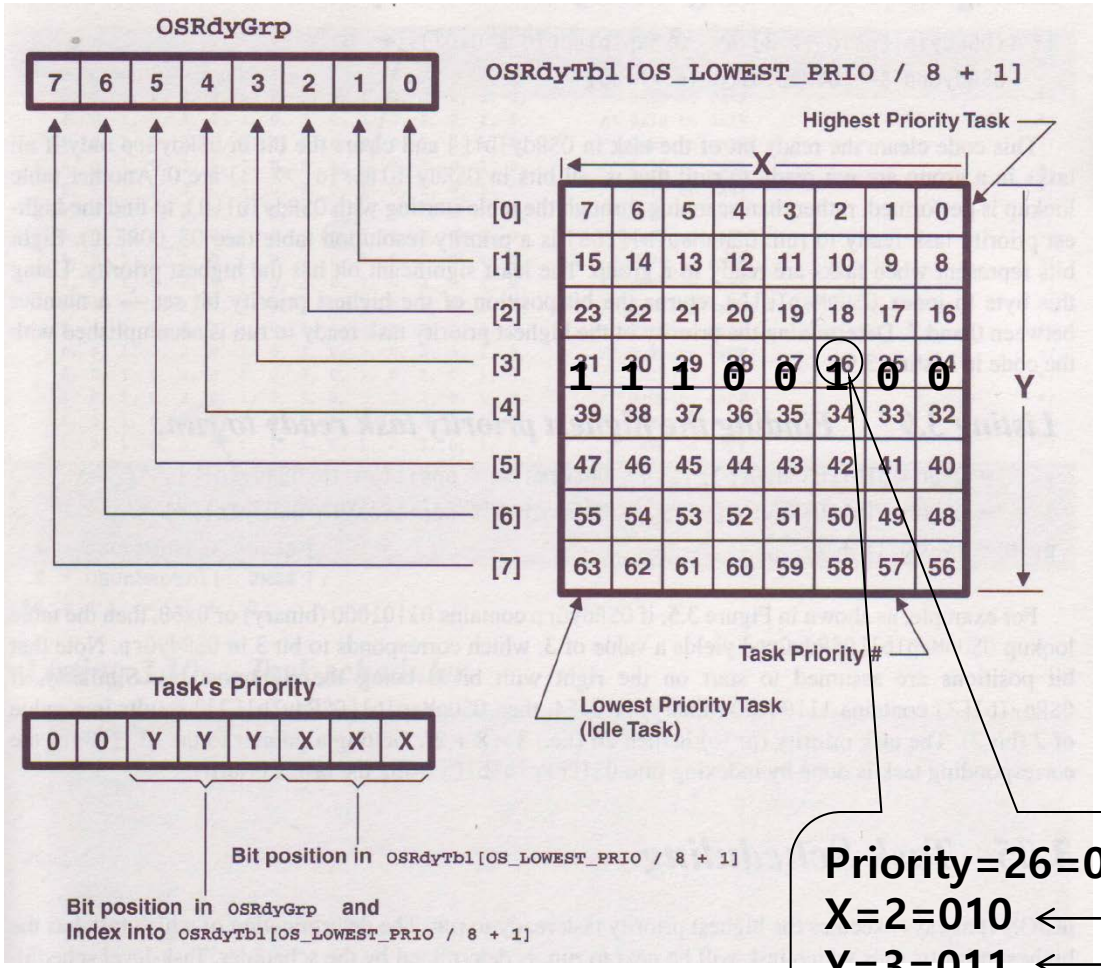
INT8U OS_TCBInit()

- `OS_TCB` is initialized by this function
- `OSTaskCreate()` or `OSTaskCreateExt()` calls this function
- `OS_TCBInit()` has seven arguments
  - `INT8U prio`: the task priority
  - `OS_STK *ptos`: a pointer to the top of stack
  - `OS_STK *pbos`: a pointer to the bottom of stack
  - `INT16U id`: task identifier
  - `INT32U stk_size`: total size of stack
  - `void *pext`: value of `OSTCBExtPtr`
  - `INT16U opt`: value of `OSTCBOpt`

Ready List

- Each task has unique priority level between 0 and `OS_LOWEST_PRIO`(=63) inclusive (totally 64 tasks)
- Ready list is maintained by two variables
  - `INT8U OSRdyGrp`
  - `INT8U OSRdyTbl[8]`

Ready List - Figure



INT8U OSMapTbl[]

Index	*Bit Mask*
0	00000001
1	00000010
2	00000100
3	00001000
4	00010000
5	00100000
6	01000000
7	10000000

Priority=26=00011010
X=2=010
Y=3=011
BitX=0000 0100
BitY=0000 1000

Operations on Ready List

Listing 3.7 Making a task ready to run.

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

OSRdyGrp |= BitY
OSRdyTbl[Y] |= BitX

Listing 3.8 Removing a task from the ready list.

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

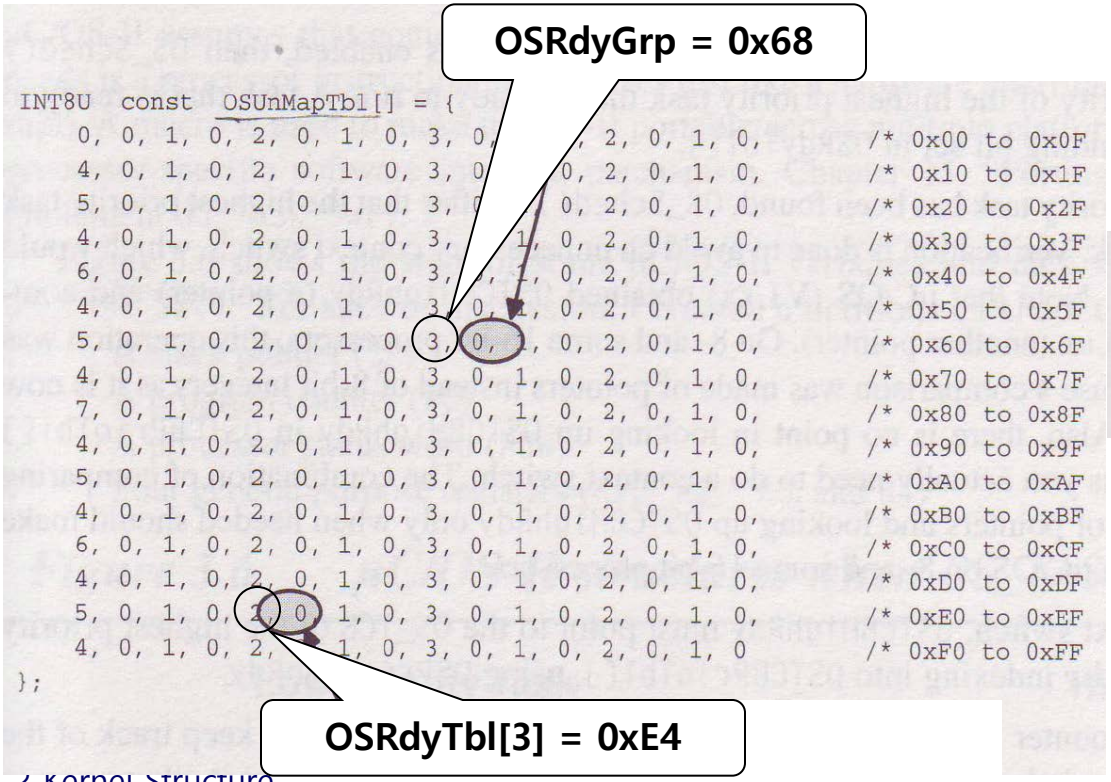
if((OSRdyTbl[Y] &= ~BitX) == 0)
OSRdyGrp &= ~BitY;

means no ready task in the row

Finding the Highest Priority Task

Listing 3.9 Finding the highest priority task ready to run.

```
y    = OSUnMapTbl[OSRdyGrp];    /* Determine Y position in OSRdyTbl[]  */
x    = OSUnMapTbl[OSRdyTbl[y]]; /* Determine X position in OSRdyTbl[Y] */
prio = (y << 3) + x;
```



OSRdyGrp = 0110 1000

```
 3 = OSUnMapTbl[  0x68 ];
 2 = OSUnMapTbl[  0xE4 ];
26 = ( 3 << 3) +  2;
```

OSRdyTbl[3] = 1110 0100

Task Scheduler - void OS_Sched()

```
void OS_Sched(void)
{
#if OS_CRITICAL_METHOD == 3
  OS_CPU_SR  cpu_sr;
#endif
  INT8U y;

  OS_ENTER_CRITICAL();
                              /* if all ISRs done & not locked */
  if ((OSIntNesting == 0) && (OSLockNesting == 0)) {
    y = OSUnMapTbl[OSRdyGrp];
    OSPrioHighRdy = (INT8U)((y << 3) + OSUnMapTbl[OSRdyTbl[y]]);
    if (OSPrioHighRdy != OSPrioCur) {
      OSTCBHighRdy = OSTCBPrioTbl[OSPrioHighRdy];
      OSCtxSwCtr++;           /* Increment context switch counter */
      OS_TASK_SW();           /* Perform a context switch */
    }
  }
  OS_EXIT_CRITICAL();
}
```

OS_TASK_SW( ) - 1/3

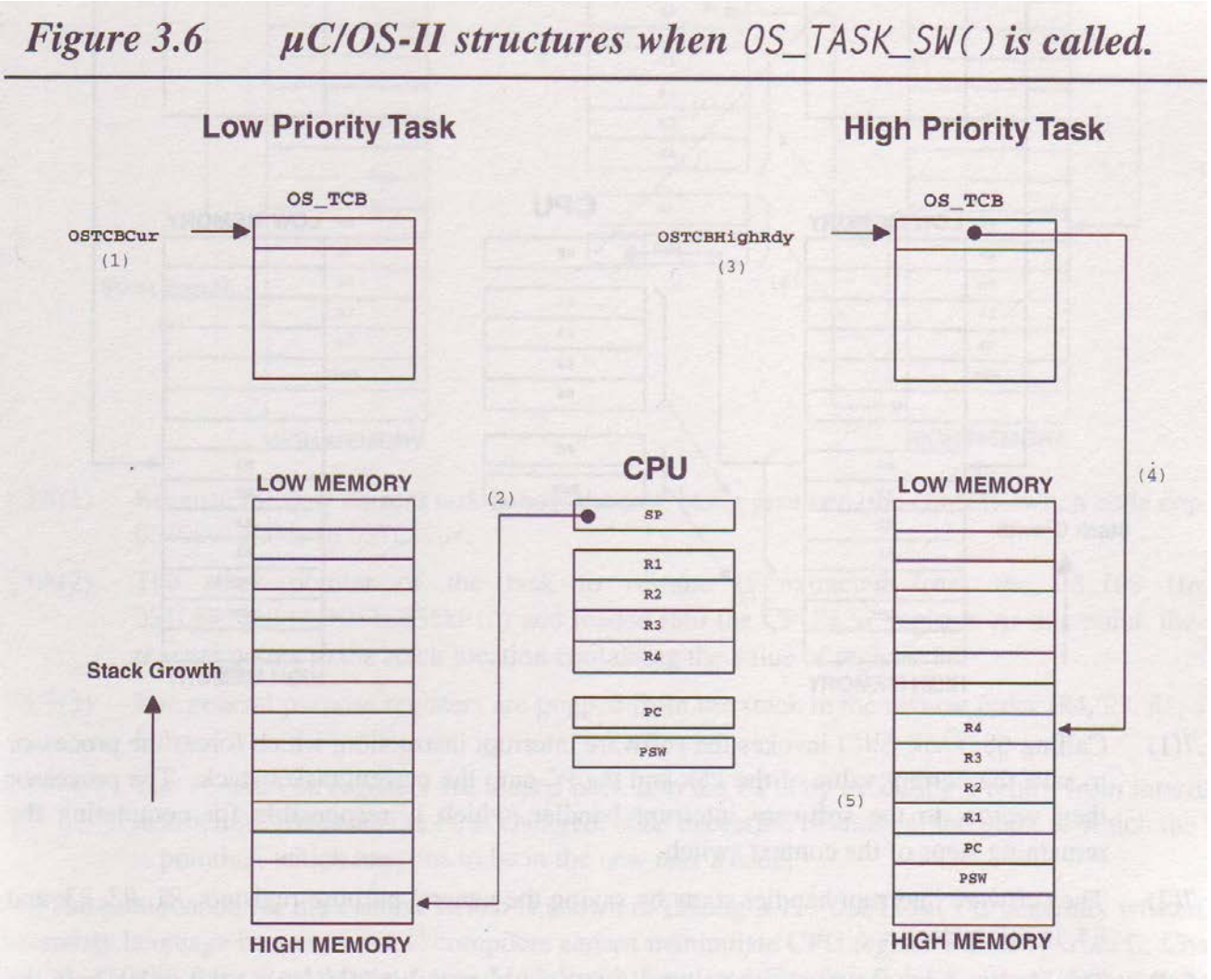


Figure 3.6 µC/OS-II structures when OS_TASK_SW( ) is called.
Low Priority Task
High Priority Task
OS_TCB
OSTCBCur
(1)
OS_TCB
OSTCBHighRdy
(3)
CPU
LOW MEMORY
(2)
SP
R1
R2
R3
R4
PC
PSW
Stack Growth
(4)
LOW MEMORY
R4
R3
R2
R1
PC
PSW
(5)
HIGH MEMORY
HIGH MEMORY

OS_TASK_SW( ) - 2/3

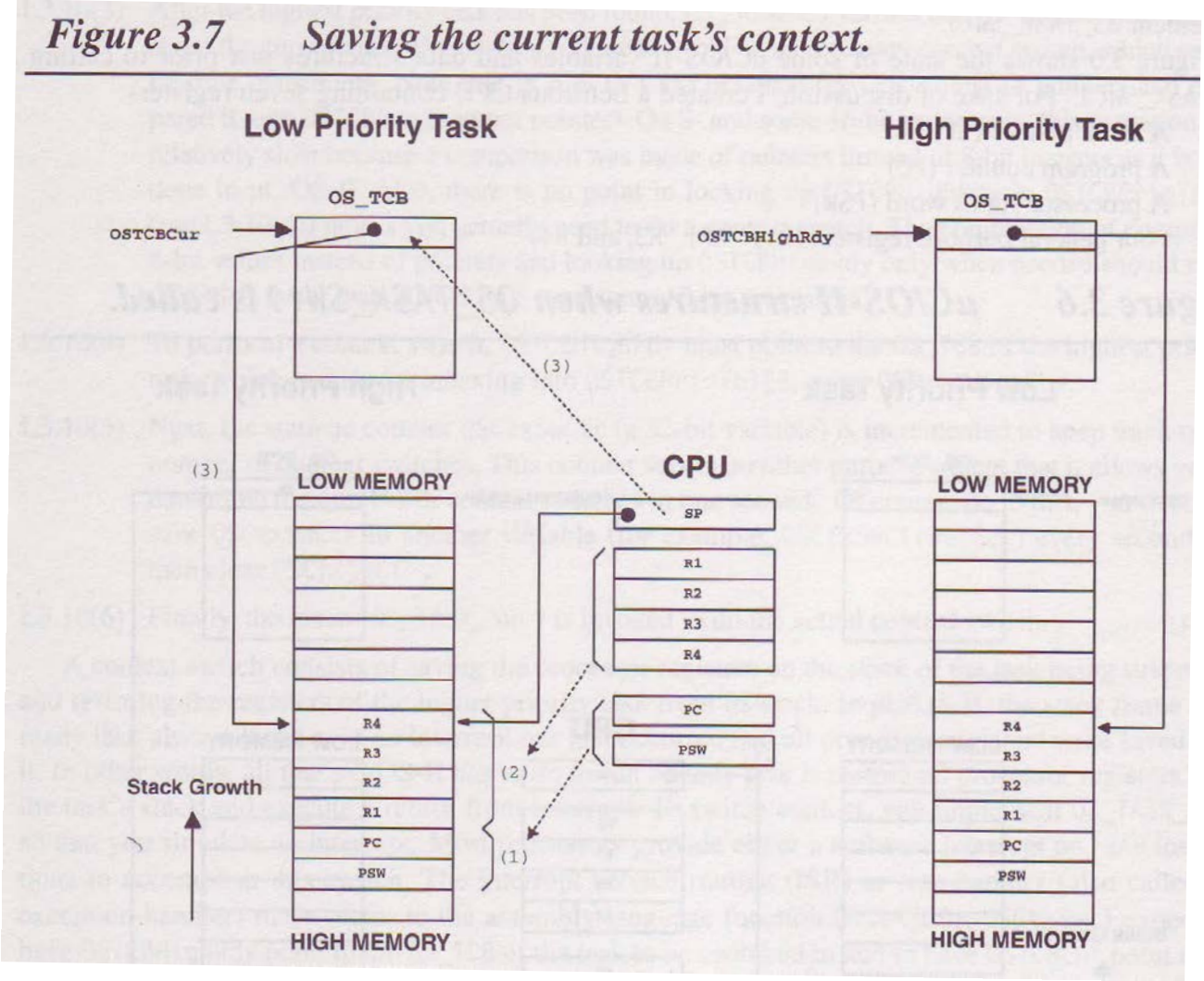


Figure 3.7 Saving the current task's context.
Low Priority Task
High Priority Task
OS_TCB
OSTCBCur
OSTCBHighRdy
(3)
(3)
CPU
LOW MEMORY
SP
R1
R2
R3
R4
PC
PSW
R4
R3
R2
R1
PC
PSW
(2)
(1)
Stack Growth
HIGH MEMORY

OS_TASK_SW( ) - 3/3

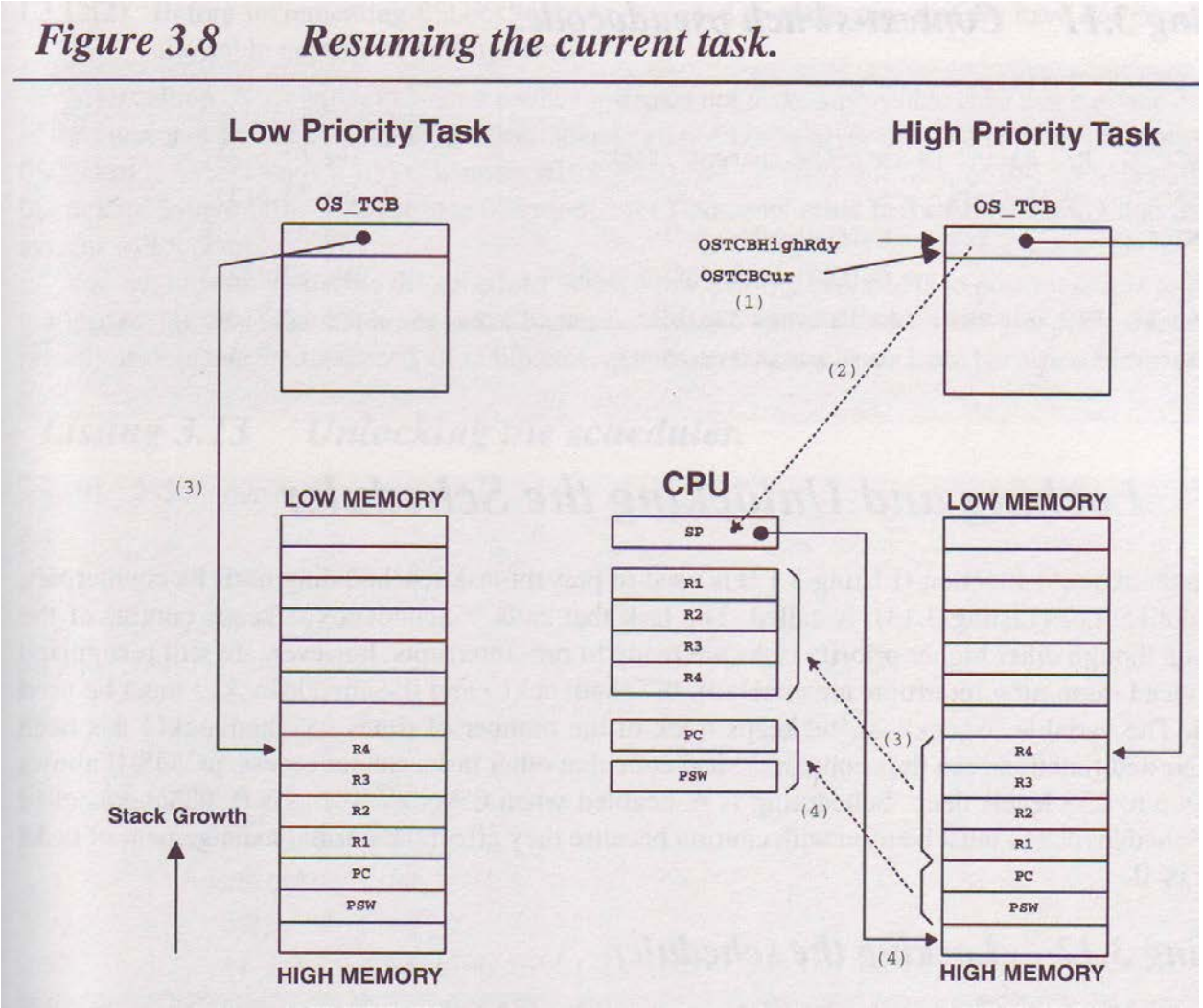


Figure 3.8 Resuming the current task.
Low Priority Task
High Priority Task
OS_TCB
OS_TCB
OSTCBHighRdy
OSTCBCur
(1)
(2)
(3)
CPU
LOW MEMORY
LOW MEMORY
SP
R1
R2
R3
R4
PC
PSW
(3)
(4)
(4)
R4
R3
R2
R1
PC
PSW
Stack Growth
HIGH MEMORY
HIGH MEMORY

Macro OS_TASK_SW( )

```
#define OS_TASK_SW() OSCtxSw()
```

```
OSCtxSw:
  // push current task's context
  STMFD SP!, {LR}       // PC
  STMFD SP!, {LR}       // LR
  STMFD SP!, {R0-R12} // R0-R12
  MRS R4,  CPSR         // CPSR
  STMFD SP!, {R4}

  // OSTCBCur->OSTCBStkPtr = SP
  LDR R4, __OS_TCBCur
  LDR R5, [R4]
  STR SP, [R5]

  // OSPrioCur = OSPrioHighRdy
  LDR R4, __OS_PrioCur
  LDR R5, __OS_PrioHighRdy
  LDRB R6, [R5]
  STRB R6, [R4]

  // OSTCBCur  = OSTCBHighRdy
  LDR R4, __OS_TCBCur
  LDR R6, __OS_TCBHighRdy
  LDR R6, [R6]
  STR R6, [R4]

  // SP = OSTCBHighRdy->OSTCBStkPtr
  LDR SP, [R6]

  // pop new task's context
  LDMFD SP!, {R4}  // CPSR
  MSR SPSR_cxsf, R4
  LDMFD SP!, {R0-R12,LR,PC}^  // R0-R12, LR, PC
```

Locking the Scheduler - OSSchedLock( )

Listing 3.12 Locking the scheduler.

```
void  OSSchedLock (void)
{
#if OS_CRITICAL_METHOD == 3
    OS_CPU_SR  cpu_sr;
#endif


    if (OSRunning == TRUE) {
        OS_ENTER_CRITICAL();
        if (OSLockNesting < 255) {
            OSLockNesting++;
        }
        OS_EXIT_CRITICAL();
    }
}
```

OSLockNesting > 0 when scheduler is locked

Unlocking the Scheduler - OSSchedUnlock()

Listing 3.13 Unlocking the scheduler.

```
void  OSSchedUnlock (void)
{
#if OS_CRITICAL_METHOD == 3
    OS_CPU_SR  cpu_sr;
#endif


    if (OSRunning == TRUE) {
        OS_ENTER_CRITICAL();
        if (OSLockNesting > 0) {
            OSLockNesting--;
            if ((OSLockNesting == 0) && (OSIntNesting == 0))
                OS_EXIT_CRITICAL();
                OS_Sched();
            } else {
                OS_EXIT_CRITICAL();
            }
        } else {
            OS_EXIT_CRITICAL();
        }
    }
}
```

Idle Task - void OS_TaskIdle(void *pdata)

Listing 3.14 The µC/OS-II idle task.

```
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();
    }
}
```

a lowest priority task OS_LOWEST_PRI

32 bits counter

user supplied function

Statistic Task

- uC/OS-II provides a task with `OS_LOWEST_PRIO-1` that provides run-time statistic called `OS_TaskStat()` when `OS_TASK_STAT_EN` macro is 1
- This task executes every second and computes the percentage of CPU usage
- The computed value is placed in the variable `INT8U OSCPUUsage`
- If you use the statistic task, you must call `OSStatInit()` from the first and only task created before calling `OSStart()`

Initializing the Statistic Task

```
void main (void)
{
    OSInit();                    /* Initialize uC/OS-II
    /* Install uC/OS-II's context switch vector */
    /* Create your startup task (for sake of discussion, TaskStart())
    OSStart();                   /* Start multitasking
}


void TaskStart (void *pdata)
{
    /* Install and initialize µC/OS-II's ticker
    OSStatInit();                /* Initialize statistics task
    /* Create your application task(s) */
    for (;;) {
        /* Code for TaskStart() goes here! */
    }
}
```

void OSStatInit(void)

```
void  OSStatInit (void)
{
#if OS_CRITICAL_METHOD == 3
  OS_CPU_SR  cpu_sr;
#endif

  OSTimeDly(2);                    /* Synchronize with clock tick */
  OS_ENTER_CRITICAL();
  OSIdleCtr = 0L;                  /* Clear idle counter */
  OS_EXIT_CRITICAL();
                /* Determine MAX. idle counter value for 1 second */
  OSTimeDly(OS_TICKS_PER_SEC);
  OS_ENTER_CRITICAL();
  OSIdleCtrMax = OSIdleCtr;
  OSStatRdy = TRUE;
  OS_EXIT_CRITICAL();
}
```

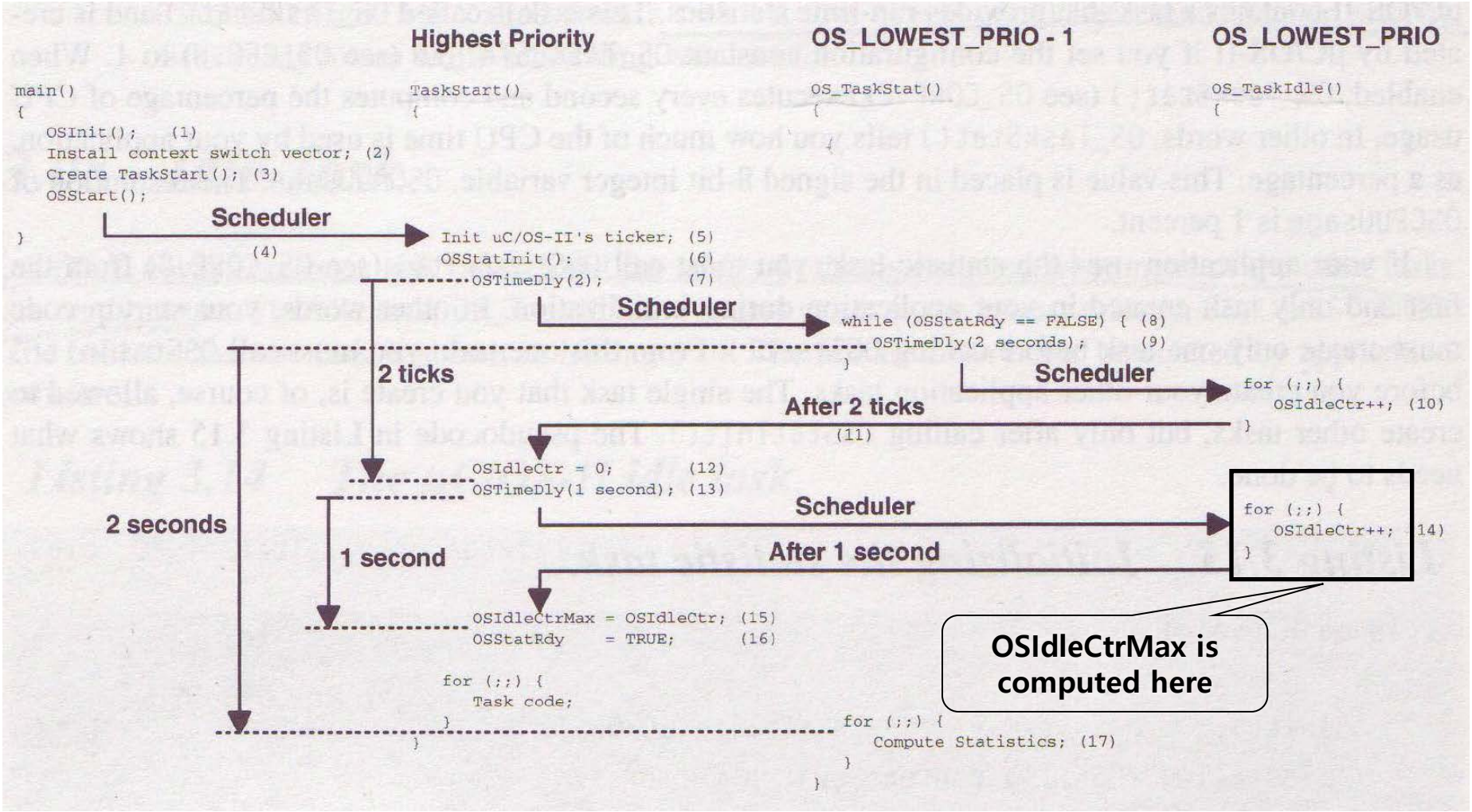
Statistic Task

```
void  OS_TaskStat (void *pdata)
{
#if OS_CRITICAL_METHOD == 3
    OS_CPU_SR  cpu_sr;
#endif
    INT32U     run;
    INT32U     max;
    INT8S      usage;


    pdata = pdata;
    while (OSStatRdy == FALSE) {
        OSTimeDly(2 * OS_TICKS_PER_SEC);
    }
    max = OSIdleCtrMax / 100L;
```

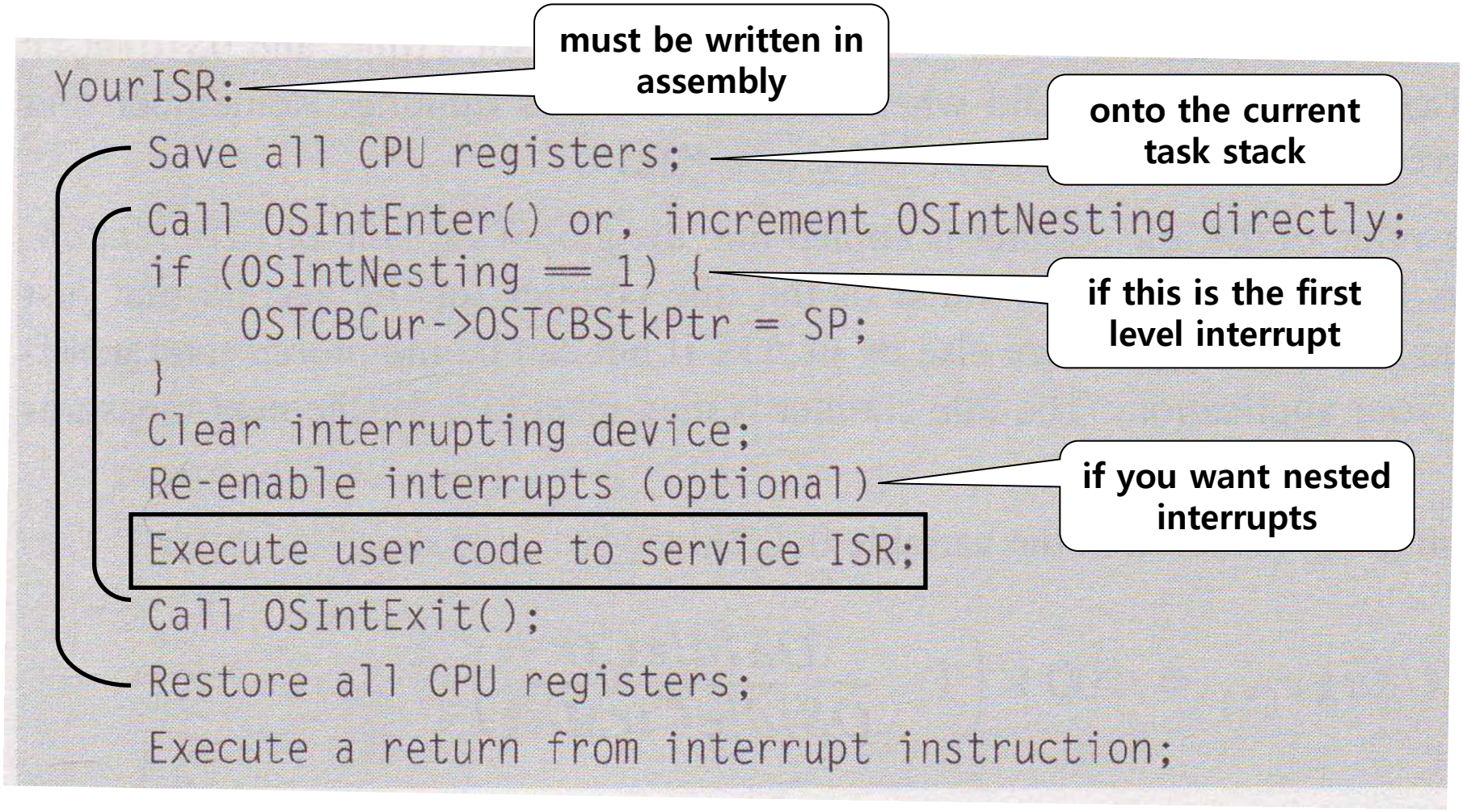
OSCPUUsage =
100*(1-(OSIdleCtr
/OSIdleCtrMax))

```
    for (;;) {
        OS_ENTER_CRITICAL();
        OSIdleCtrRun = OSIdleCtr;
        run          = OSIdleCtr;
        OSIdleCtr    = 0L;
        OS_EXIT_CRITICAL();
        if (max > 0L) {
            usage = (INT8S)(100L - run / max);
            if (usage >= 0) {
                OSCPUUsage = usage;
            } else {
                OSCPUUsage = 0;
            }
        } else {
            OSCPUUsage = 0;
            max        = OSIdleCtrMax / 100L;
        }
        OSTaskStatHook();
        OSTimeDly(OS_TICKS_PER_SEC);
    }
}
```

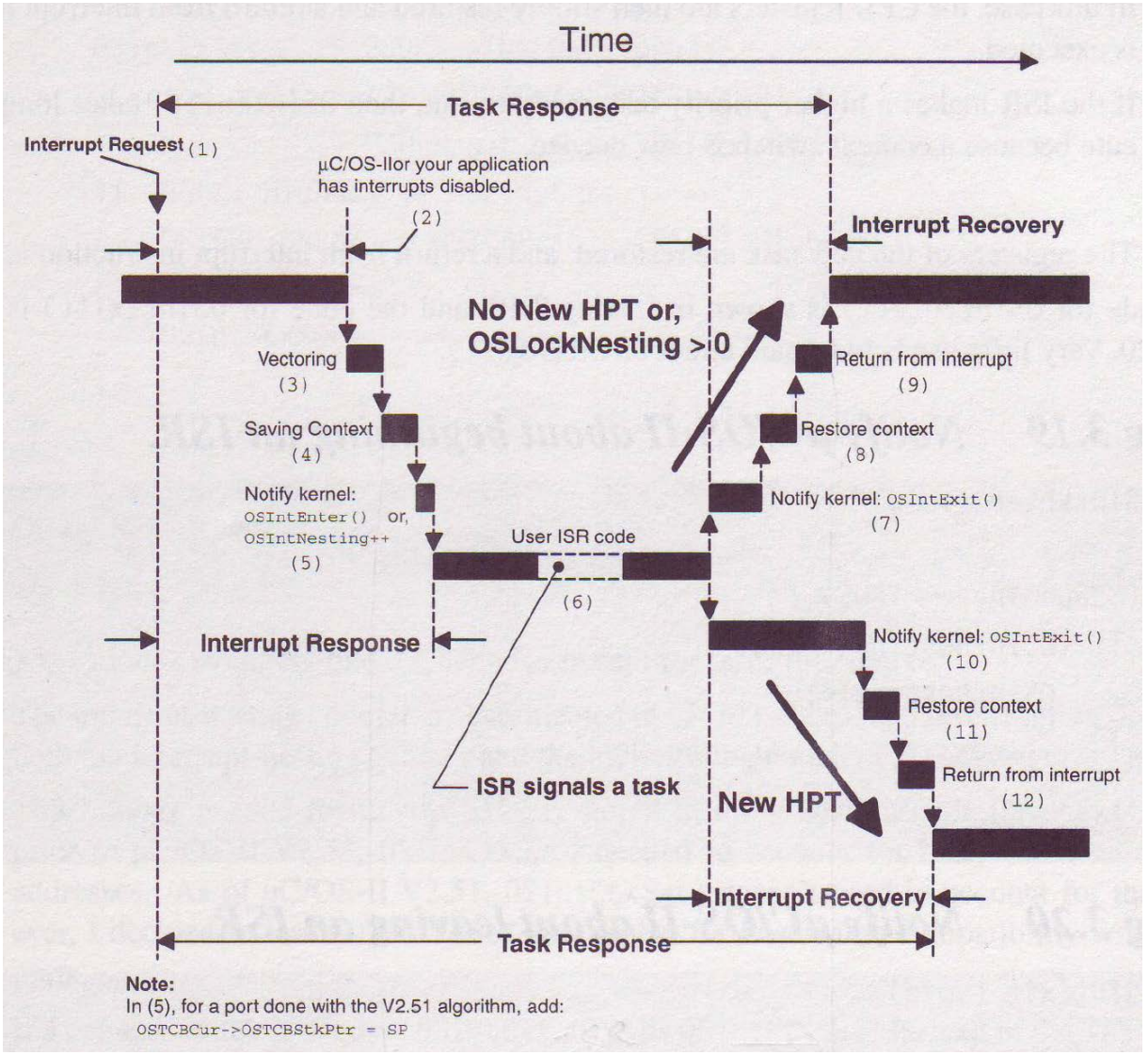
Computing OSIdleCtrMax



Interrupt Under uC/OS-II



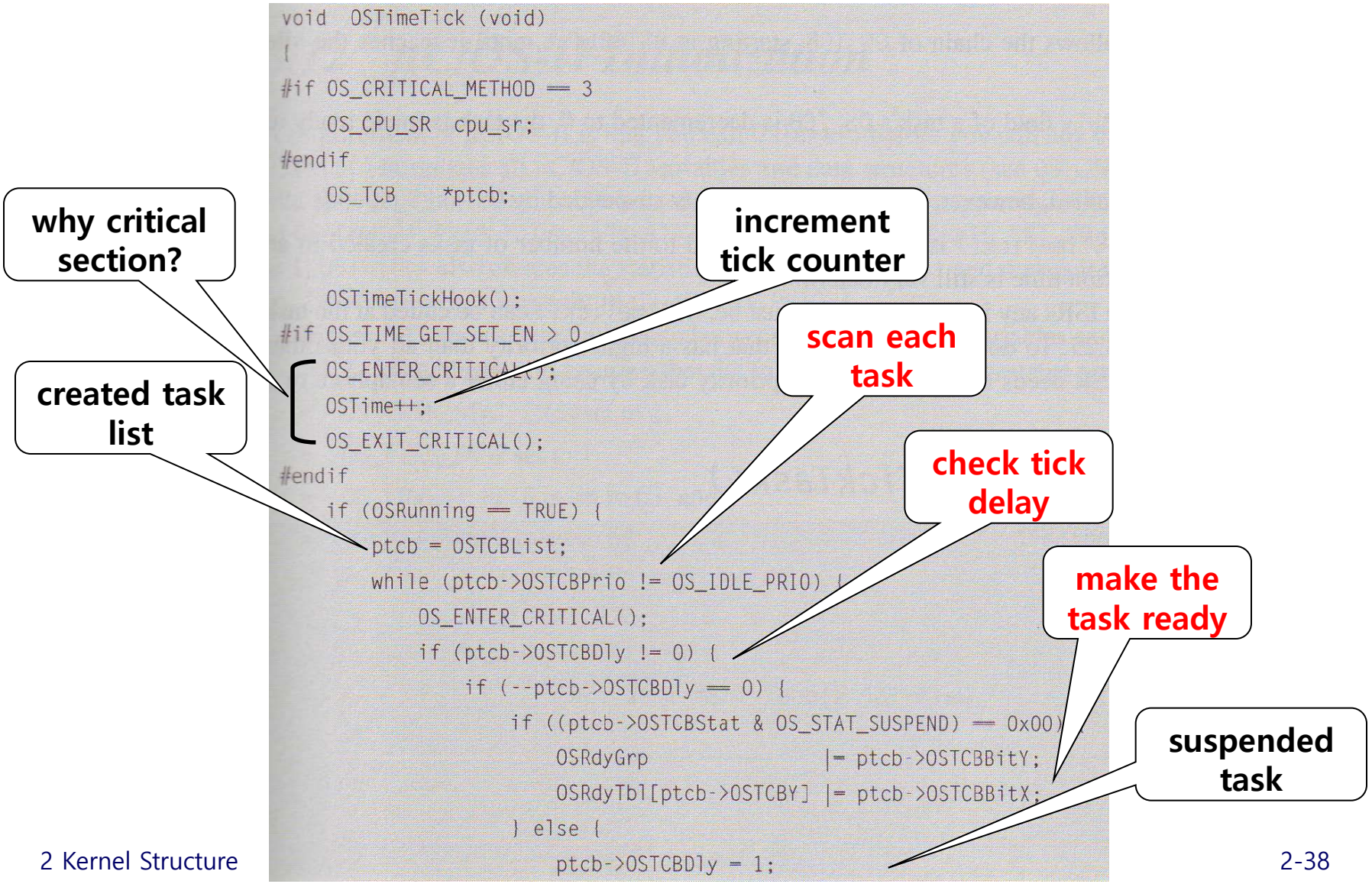
Servicing an Interrupt



Tick ISR

- uC/OS-II require you provide a periodic time source to keep track of time delay and timeout
- A tick should be between 10 to 100 times per seconds or Hertz
- Tick ISR - `void OSTimeTick()`

Tick ISR - OSTimeTick()




```
void  OSTimeTick (void)
{
#if OS_CRITICAL_METHOD == 3
    OS_CPU_SR  cpu_sr;
#endif
    OS_TCB     *ptcb;


    OSTimeTickHook();
#if OS_TIME_GET_SET_EN > 0
    OS_ENTER_CRITICAL();
    OSTime++;
    OS_EXIT_CRITICAL();
#endif
    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) == 0x00) {
                        OSRdyGrp               |= ptcb->OSTCBBitY;
                        OSRdyTbl[ptcb->OSTCBY] |= ptcb->OSTCBBitX;
                    } else {
                        ptcb->OSTCBDly = 1;
```

void TickTask(void *pdata)

- If you want a task-based tick ISR, make Tick ISR post a mail and supply `TickTask` with highest priority

```
void TickTask (void *pdata)
{
    pdata = pdata;
    for (;;) {
        OSMboxPend(...);     /* Wait for signal from Tick ISR */
        OSTimeTick();
        OS_Sched();
    }
}
```

`void OSInit(void)`

- `OSInit()`should be called before calling any uC/OS-II function
- `OSInit()` initialize all uC/OS-II variables and data structures
- `OSInit()` creates the idle task and the statistic task

Figure 3.11 Variables and data structures after calling `OSInit()`.

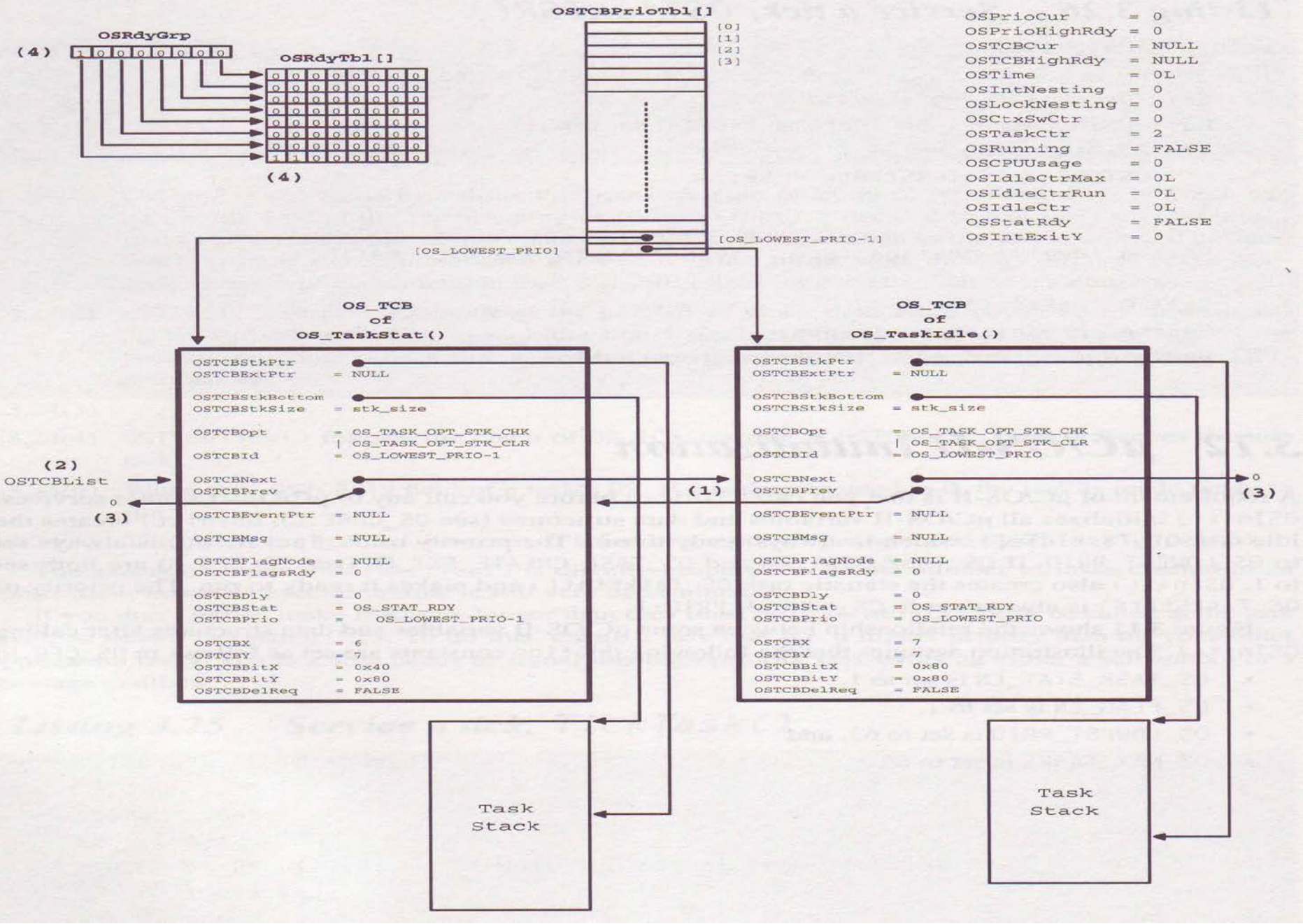
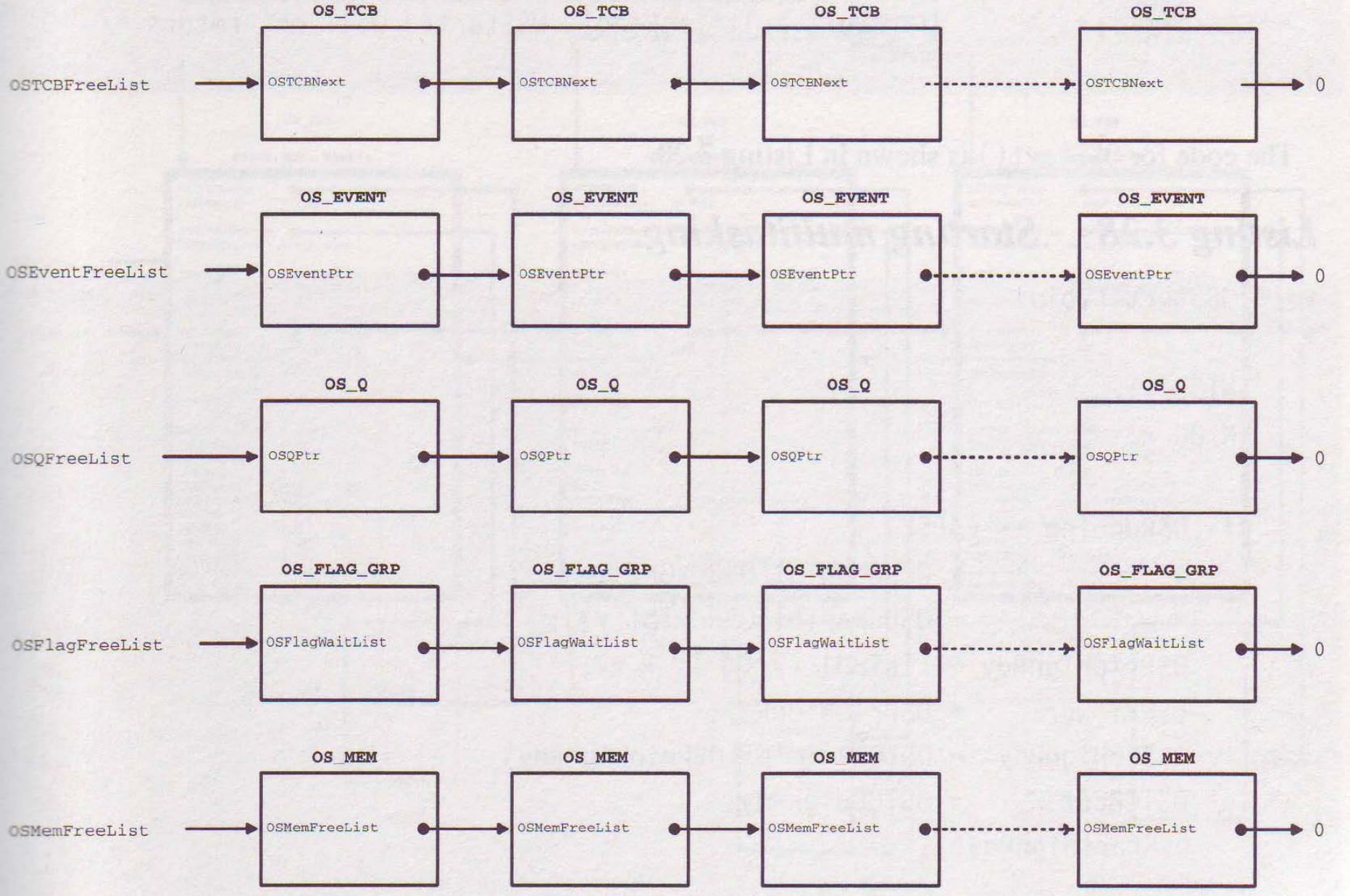


Figure 3.12 Free pools.



Starting uC/OS-II

```
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 */
}
```

Figure 3.13 Variables and data structures after calling OSStart().