uC/OS-II Part 1: Getting Started with uC/OS-II

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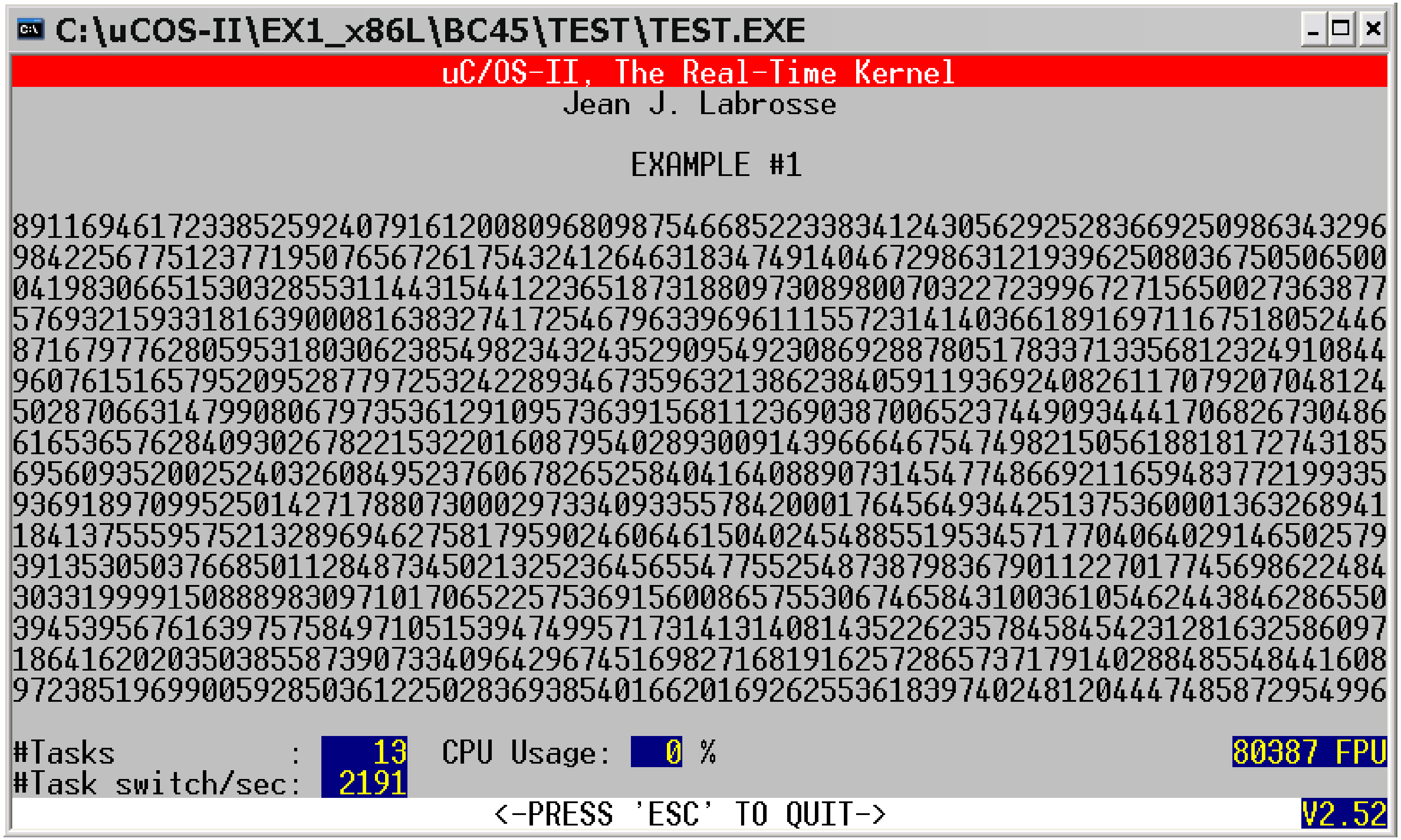
uC/OS-2

- A tiny open-source real-time kernel
  - Memory footprint is about 20k for a fully functional kernel
  - Supporting preemptive priority-driven real-time scheduling
  - Supporting many platforms: x86, 68x, ARM, MIPS…

Getting started with uC/OS-2!

- See what a uC/OS-2 program looks like
- Learn how to write a skeleton program for uC/OS-2
  - How to initialize uC/OS-2?
  - How to create tasks?
  - How to use inter-task communication mechanism?
  - How to hook on system event?

Example 1



```
                       uC/OS-II, The Real-Time Kernel
                             Jean J. Labrosse

                               EXAMPLE #1

89116946172338525924079161200809680987546685223383412430562925283669250986343296
98422567751237719507656726175432412646318347491404672986312193962508036750506500
04198306651530328553114431544122365187318809730898007032272399672715650027363877
57693215933181639000816383274172546796339696111557231414036618916971167518052446
87167977628059531803062385498234324352909549230869288780517833713356812324910844
96076151657952095287797253242289346735963213862384059119369240826117079207048124
50287066314799080679735361291095736391568112369038700652374490934441706826730486
61653657628409302678221532201608795402893009143966646754749821505618818172743185
69560935200252403260849523760678265258404164088907314547748669211659483772199335
93691897099525014271788073000297334093355784200017645649344251375360001363268941
18413755595752132896946275817959024606461504024548855195345717704064029146502579
39135305037668501128487345021325236456554775525487387983679011227017745698622484
30331999915088898309710170652257536915600865755306746584310036105462443846286550
39453956761639757584971051539474995717314131408143522623578458454231281632586097
18641620203503855873907334096429674516982716819162572865737179140288485548441608
97238519699005928503612250283693854016620169262553618397402481204447485872954996

#Tasks          :     13  CPU Usage:   0 %                               80387 FPU
#Task switch/sec:   2191
                       <-PRESS 'ESC' TO QUIT->                                V2.52
```

Example 1

- Files needed:
  - The main program (test.c)
  - The configuration for uC/OS-2(os_cfg.h)
  - The big include file (includes.h)
  - The kernel source

- Tools needed:
  - Borland C++ compiler (V3.1+)
  - DOSBox (x86 real mode + DOS/BIOS emulator)
  - Windows (tested) or MacOS (not tested)

Example 1

- Install software
  - Install DOSBox
  - Put Borland C files in <dir>\bc45
  - Put uc/OS-II files in <dir>\software
- Run DOSBox and do the following in DOSBox
  - mount c <dir>
  - cd c:\SOFTWARE\uCOS-II\EX1_x86L\BC45\test
  - maketest.bat
  - test.exe

Example 1

- Before we start…
  - Source tree structure
  - Makefile

Example 1

- 13 tasks run concurrently
  - 2 internal tasks:
    - The idle task and the statistic task
  - 11 user tasks:
    - 1 startup task
    - 10 worker tasks randomly print numbers on the screen

- Focus: System initialization and task creation

Example 1

```
#include "includes.h"

/*
*********************************************************************************************************
*                                               CONSTANTS
*********************************************************************************************************
*/

#define  TASK_STK_SIZE                 512       /* Size of each task's stacks (# of WORDs)            */
#define  N_TASKS                        10       /* Number of identical tasks                          */

/*
*********************************************************************************************************
*                                               VARIABLES
*********************************************************************************************************
*/

OS_STK        TaskStk[N_TASKS][TASK_STK_SIZE];        /* Tasks stacks                                  */
OS_STK        TaskStartStk[TASK_STK_SIZE];
char          TaskData[N_TASKS];                      /* Parameters to pass to each task               */
OS_EVENT     *RandomSem;
```

A semaphore (to be explained later)

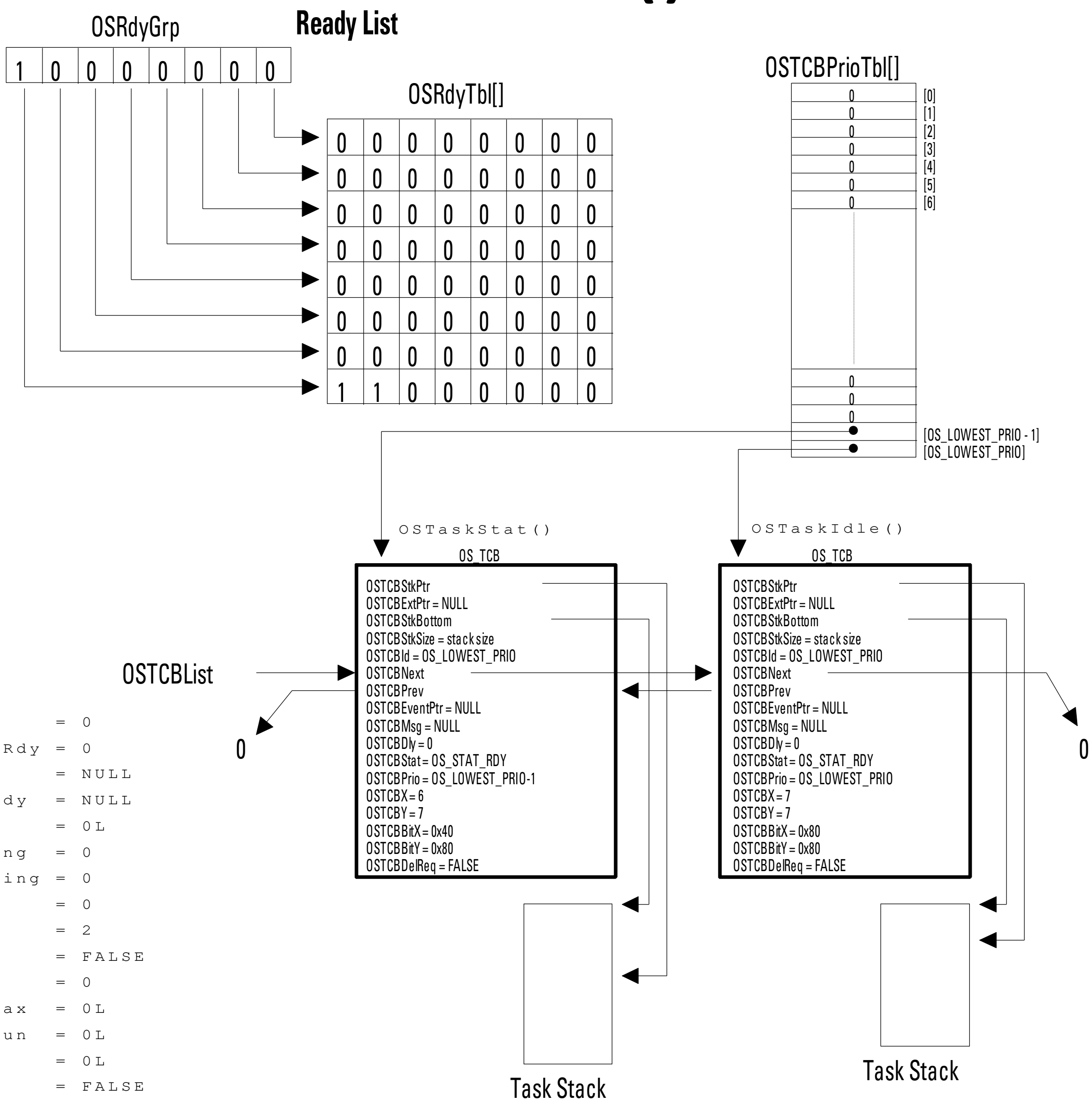
Main()

```
void main (void)
{
    PC_DispClrScr(DISP_FGND_WHITE + DISP_BGND_BLACK);          (1)
    OSInit();                                                  (2)
    PC_DOSSaveReturn();                                        (3)
    PC_VectSet(uCOS, OSCtxSw);                                 (4)
    RandomSem = OSSemCreate(1);                                (5)
    OSTaskCreate(TaskStart,                                    (6)
                 (void *)0,
                 (void *)&TaskStartStk[TASK_STK_SIZE-1],
                 0);
    OSStart();                                                 (7)
}
```

Main()

- OSinit():
  - Init internal structures of uC/OS-2
    - Task ready list
    - Priority table
    - Task control blocks (TCB)
    - Free pool
  - Create housekeeping tasks
    - The idle task
    - The statistics task

OSinit()



0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
1	1	0	0	0	0	0	0

OSTaskStat() OS_TCB:

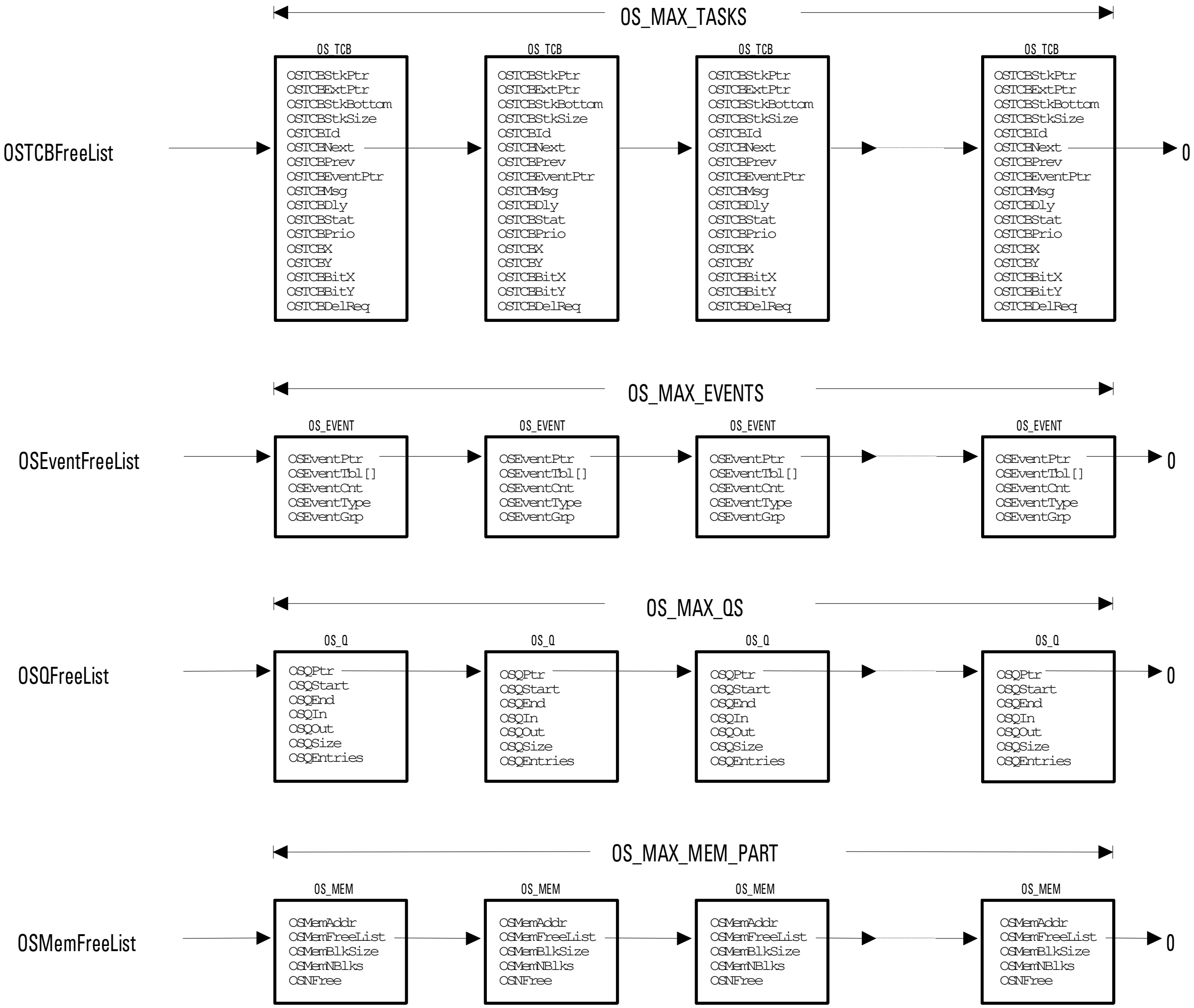
OSTCBStkPtr
OSTCBExtPtr = NULL
OSTCBStkBottom
OSTCBStkSize = stack size
OSTCBId = OS_LOWEST_PRIO
OSTCBNext
OSTCBPrev
OSTCBEventPtr = NULL
OSTCBMsg = NULL
OSTCBDly = 0
OSTCBStat = OS_STAT_RDY
OSTCBPrio = OS_LOWEST_PRIO-1
OSTCBX = 6
OSTCBY = 7
OSTCBBitX = 0x40
OSTCBBitY = 0x80
OSTCBDelReq = FALSE

OSTaskIdle() OS_TCB:

OSTCBStkPtr
OSTCBExtPtr = NULL
OSTCBStkBottom
OSTCBStkSize = stack size
OSTCBId = OS_LOWEST_PRIO
OSTCBNext
OSTCBPrev
OSTCBEventPtr = NULL
OSTCBMsg = NULL
OSTCBDly = 0
OSTCBStat = OS_STAT_RDY
OSTCBPrio = OS_LOWEST_PRIO
OSTCBX = 7
OSTCBY = 7
OSTCBBitX = 0x80
OSTCBBitY = 0x80
OSTCBDelReq = FALSE

OSPrioCur	=	0
OSPrioHighRdy	=	0
OSTCBCur	=	NULL
OSTCBHighRdy	=	NULL
OSTime	=	0L
OSIntNesting	=	0
OSLockNesting	=	0
OSCtxSwCtr	=	0
OSTaskCtr	=	2
OSRunning	=	FALSE
OSCPUUsage	=	0
OSIdleCtrMax	=	0L
OSIdleCtrRun	=	0L
OSIdleCtr	=	0L
OSStatRdy	=	FALSE

OSinit()



OS_MAX_TASKS

OSTCBFreeList

OS_TCB
OSTCBStkPtr
OSTCBExtPtr
OSTCBStkBottom
OSTCBStkSize
OSTCBId
OSTCBNext
OSTCBPrev
OSTCBEventPtr
OSTCBMsg
OSTCBDly
OSTCBStat
OSTCBPrio
OSTCBX
OSTCBY
OSTCBBitX
OSTCBBitY
OSTCBDelReq

OS_TCB
OSTCBStkPtr
OSTCBExtPtr
OSTCBStkBottom
OSTCBStkSize
OSTCBId
OSTCBNext
OSTCBPrev
OSTCBEventPtr
OSTCBMsg
OSTCBDly
OSTCBStat
OSTCBPrio
OSTCBX
OSTCBY
OSTCBBitX
OSTCBBitY
OSTCBDelReq

OS_TCB
OSTCBStkPtr
OSTCBExtPtr
OSTCBStkBottom
OSTCBStkSize
OSTCBId
OSTCBNext
OSTCBPrev
OSTCBEventPtr
OSTCBMsg
OSTCBDly
OSTCBStat
OSTCBPrio
OSTCBX
OSTCBY
OSTCBBitX
OSTCBBitY
OSTCBDelReq

OS_TCB
OSTCBStkPtr
OSTCBExtPtr
OSTCBStkBottom
OSTCBStkSize
OSTCBId
OSTCBNext
OSTCBPrev
OSTCBEventPtr
OSTCBMsg
OSTCBDly
OSTCBStat
OSTCBPrio
OSTCBX
OSTCBY
OSTCBBitX
OSTCBBitY
OSTCBDelReq

0

OS_MAX_EVENTS

OSEventFreeList

OS_EVENT
OSEventPtr
OSEventTbl[]
OSEventCnt
OSEventType
OSEventGrp

OS_EVENT
OSEventPtr
OSEventTbl[]
OSEventCnt
OSEventType
OSEventGrp

OS_EVENT
OSEventPtr
OSEventTbl[]
OSEventCnt
OSEventType
OSEventGrp

OS_EVENT
OSEventPtr
OSEventTbl[]
OSEventCnt
OSEventType
OSEventGrp

0

OS_MAX_QS

OSQFreeList

OS_Q
OSQPtr
OSQStart
OSQEnd
OSQIn
OSQOut
OSQSize
OSQEntries

OS_Q
OSQPtr
OSQStart
OSQEnd
OSQIn
OSQOut
OSQSize
OSQEntries

OS_Q
OSQPtr
OSQStart
OSQEnd
OSQIn
OSQOut
OSQSize
OSQEntries

OS_Q
OSQPtr
OSQStart
OSQEnd
OSQIn
OSQOut
OSQSize
OSQEntries

0

OS_MAX_MEM_PART

OSMemFreeList

OS_MEM
OSMemAddr
OSMemFreeList
OSMemBlkSize
OSMemNBlks
OSNFree

OS_MEM
OSMemAddr
OSMemFreeList
OSMemBlkSize
OSMemNBlks
OSNFree

OS_MEM
OSMemAddr
OSMemFreeList
OSMemBlkSize
OSMemNBlks
OSNFree

OS_MEM
OSMemAddr
OSMemFreeList
OSMemBlkSize
OSMemNBlks
OSNFree

0

Main()

- PC_DOSSaveReturn()
  - Save the current status of DOS for the later restoration
    - Interrupt vectors and the RTC tick rate.
  - Set a global returning point using setjmp()
    - uC/OS-2 can come back here on OS termination
    - PC_DOSReturn()

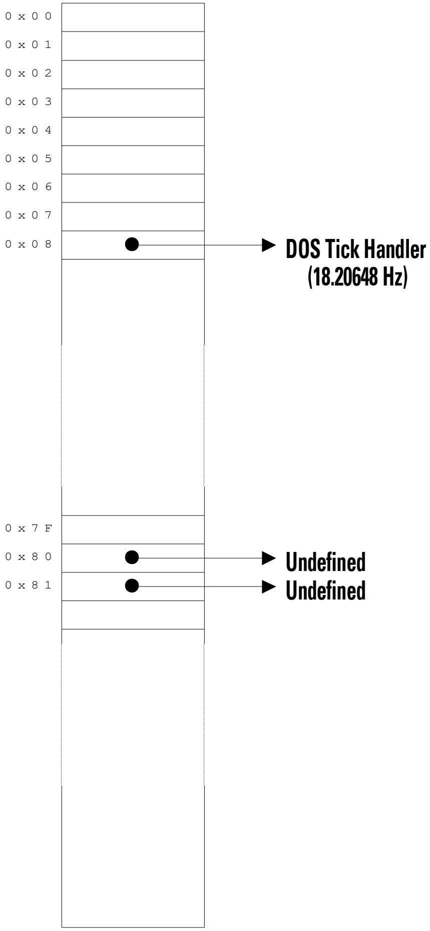
PC_DOSSaveReturn()

```
void PC_DOSSaveReturn (void)
{
    PC_ExitFlag  = FALSE;                                          (1)
    OSTickDOSCtr =     8;                                          (2)
    PC_TickISR   = PC_VectGet(VECT_TICK);                          (3)

    OS_ENTER_CRITICAL();
    PC_VectSet(VECT_DOS_CHAIN, PC_TickISR);                        (4)
    OS_EXIT_CRITICAL();

    setjmp(PC_JumpBuf);                                            (5)
    if (PC_ExitFlag == TRUE) {
        OS_ENTER_CRITICAL();
        PC_SetTickRate(18);                                        (6)
        PC_VectSet(VECT_TICK, PC_TickISR);                         (7)
        OS_EXIT_CRITICAL();
        PC_DispClrScr(DISP_FGND_WHITE + DISP_BGND_BLACK);          (8)
        exit(0);                                                   (9)
    }                                                             *
}
```

(4): backup DOS tick ISR (entry point) to another interrupt vector. Later when we install a new tick ISR, the old DOS tick ISR can be called immediately after our new tick ISR.

Before (DOS only)

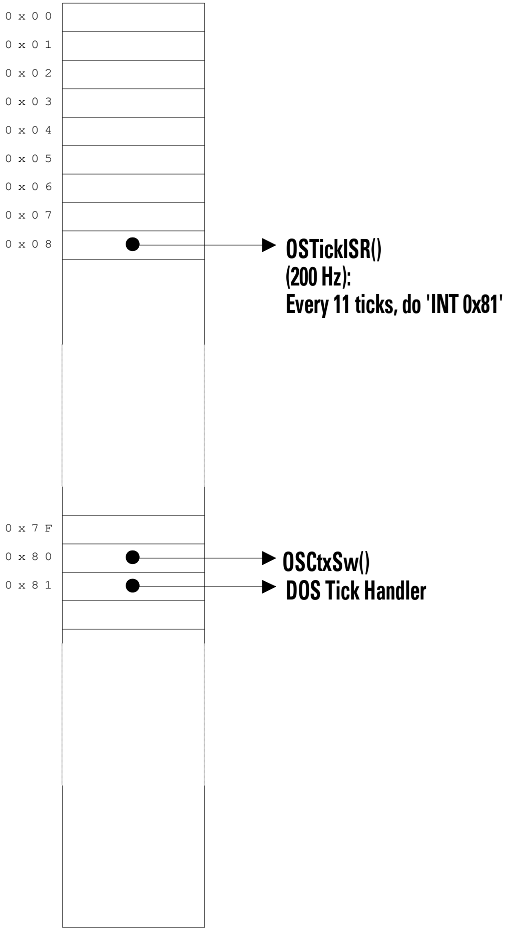
Interrupt Vector Table (IVT)



0x00
0x01
0x02
0x03
0x04
0x05
0x06
0x07
0x08 → DOS Tick Handler (18.20648 Hz)
0x7F
0x80 → Undefined
0x81 → Undefined

After (潛/OS-II installed)

Interrupt Vector Table (IVT)



0x00
0x01
0x02
0x03
0x04
0x05
0x06
0x07
0x08 → OSTickISR() (200 Hz): Every 11 ticks, do 'INT 0x81'
0x7F
0x80 → OSCtxSw()
0x81 → DOS Tick Handler

Copied from part 5

Main()

- PC_VectSet(uCOS,OSCtxSw)
  - Install the context switch handler
    - Interrupt # 0x80 of 80x86 family
  - Context switches are handled during ISR!
    - Voluntary CXTSW via executing an INT instruction
    - Involuntary CXTSW during the return of a timer ISR

*

Main()

- OSSemCreate()
  - Create a semaphore for IPC
    - To protect non-reentrant codes and shared resources
  - The semaphore is initialized as a binary semaphore
    - For mutual exclusion
  - In this example, a semaphore is created to protect “random()” in the standard C library
    - random() hides a global variable
    - Linear Congruential Generator
    - $a_n=(a_{n-1}*p +q) \%m$

Main()

- OSTaskCreate()
  - Create tasks with the supplied arguments
  - Tasks become “ready” after being created
- Task
  - An active entity which does computation
  - **Priority, CPU registers, stack, text, housekeeping status**
  - uC/OS-2 allows maximum 62 tasks to be created
- uC/OS-2 picks up the highest-priority task for execution on rescheduling points
  - Clock ticks, interrupt return, and semaphore operations…
  - We shall see more in RTC ISR.

OSTaskCreate()

```
OSTaskCreate(
   TaskStart,
   (void *)0,
   &TaskStartStk[TASK_STK_SIZE - 1],
    0
   );
```

Entry point of the task (a pointer to function)

User-specified data

Top of Stack

Priority (0=hightest)

Enabling multitasking after you created the first user task!

TaskStart()

Cxtsw begins as soon as the new tick ISR is installed. OSStart() launches the first task. So install the tick ISR after OSStart() is called

Install new Tick ISR and change the ticking rate from 18.2HZ too 200HZ

```
void  TaskStart (void *pdata)
{
#if OS_CRITICAL_METHOD == 3                                  /* Allocate storage            status register */
    OS_CPU_SR  cpu_sr;
#endif
    char       s[100];
    INT16S     key;

    pdata = pdata;                                                ent compiler warning             */

    TaskStartDispInit();                                     /* Initialize the display                */

    OS_ENTER_CRITICAL();
    PC_VectSet(0x08, OSTickISR);                             /* Install uC/OS-II's clock tick ISR     */
    PC_SetTickRate(OS_TICKS_PER_SEC);                        /* Reprogram tick rate                   */
    OS_EXIT_CRITICAL();

    OSStatInit();                                            /* Initialize uC/OS-II's statistics      */

    TaskStartCreateTasks();                                  /* Create all the application tasks      */

    for (;;) {
        TaskStartDisp();                                    /* Update the display                    */


        if (PC_GetKey(&key) == TRUE) {                       /* See if key has been pressed           */
            if (key == 0x1B) {                               /* Yes, see if it's the ESCAPE key       */
                PC_DOSReturn();                              /* Return to DOS                         */
            }
        }

        OSCtxSwCtr = 0;                                      /* Clear context switch counter          */
        OSTimeDlyHMSM(0, 0, 1, 0);                           /* Wait one second                       */
    }
}
```

TaskStart()

- OS_ENTER(EXIT)_CRITICAL
  - Enable/disable maskable interrupts
  - A solution of critical section in uniprocessor systems
    - No preemption is possible until interrupt is re-enabled
    - Different from semaphores
  - Processor specific
    - CLI/STI (x86 real mode)
    - CPSID/CPSIE (ARM)

TaskStartCreateTasks()

```
static  void  TaskStartCreateTasks (void)
{
    INT8U  i;


    for (i = 0; i < N_TASKS; i++) {

        TaskData[i] = '0' + i;

        OSTaskCreate(
        Task,
        (void *)&TaskData[i],
        &TaskStk[i][TASK_STK_SIZE - 1],
        i + 1);
    }
}
```

Entry point of the created task

Argument: character to print

Stack

Priority

Task()

Semaphore operations.

```
void  Task (void *pdata)
{
    INT8U  x;
    INT8U  y;
    INT8U  err;


    for (;;) {
        OSSemPend(RandomSem, 0, &err);/* Acquire semaphore to perform random numbers   */
        x = random(80);               /* Find X position where task number will appear */
        y = random(16);               /* Find Y position where task number will appear */
        OSSemPost(RandomSem);         /* Release semaphore                             */
                                      /* Display the task number on the screen         */
        PC_DispChar(x, y + 5, *(char *)pdata, DISP_FGND_BLACK + DISP_BGND_LIGHT_GRAY);
        OSTimeDly(1);                 /* Delay 1 clock tick                            */
    }
}
```

Semaphores

- OSSemPend() / OSSemPost()
- A semaphore consists of a wait list and an integer counter
- OSSemPend:
  - Counter--;
  - If the value of the semaphore <0, the task is blocked and moved to the wait list immediately
  - A time-out value can be specified
- OSSemPost:
  - Counter++;
  - If the value of the semaphore >= 0, a task in the wait list is removed from the wait list
  - Reschedule if needed

Main()

- OSStart()
  - Start multitasking of uC/OS-2 by “context switching” to the highest priority task
  - It never returns to main()
  - ucOS’s tick ISR should be installed after OSStart() is called, so it is called in the Startup task, which is the highest priority task upon calling OSStart()
  - uC/OS-2 is terminated if PC_DOSReturn() is called

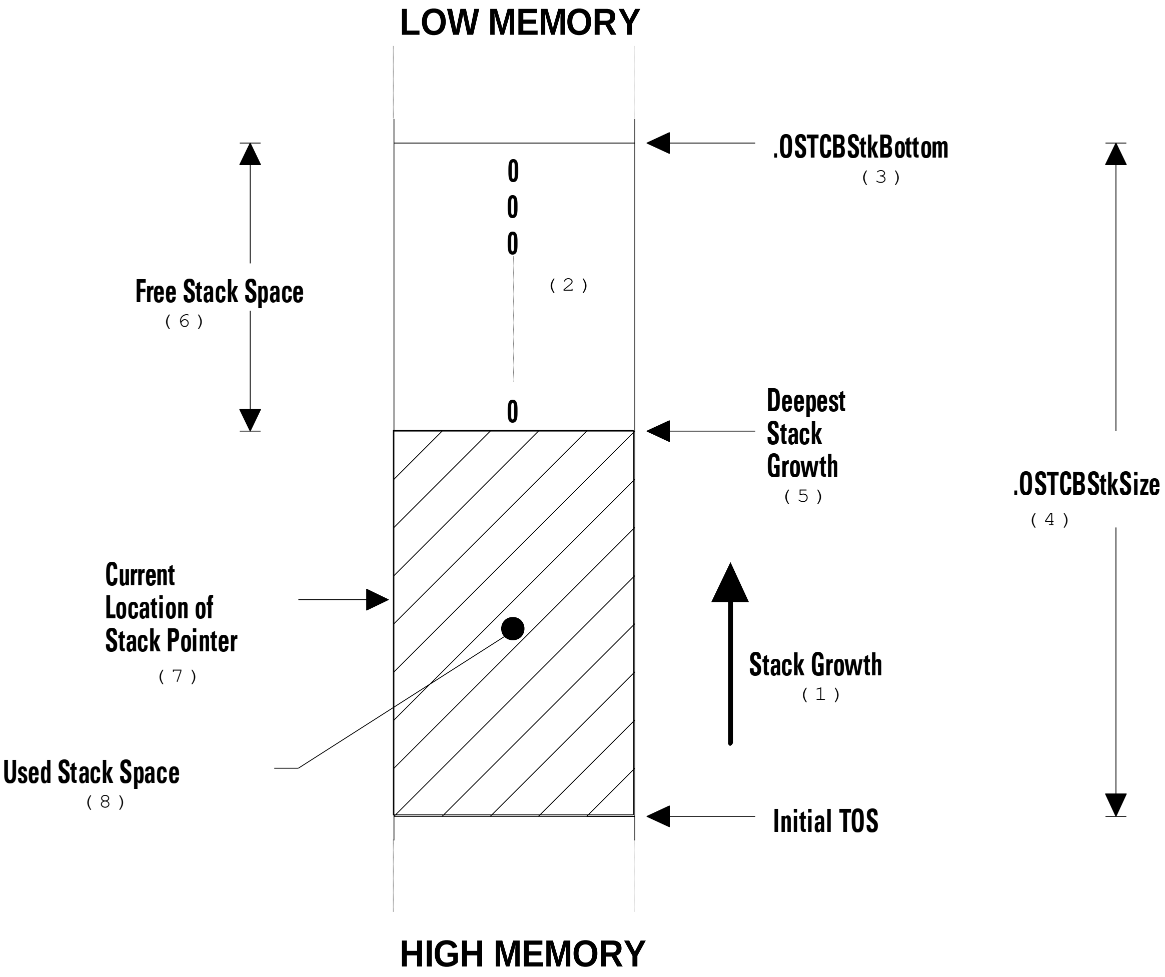
Summary: Example 1

- uC/OS-2 is initialized and started by calling OSInit() and OSStart(), respectively
- Before uC/OS-2 is started,
  - DOS status is saved by calling PC_DOSSaveReturn()
  - Context switch handler is installed by calling PC_VectSet()
  - User tasks must be created by OSTaskCreate()
- Shared resources must be protected by semaphores
  - OSSemPend(),OSSemPost()

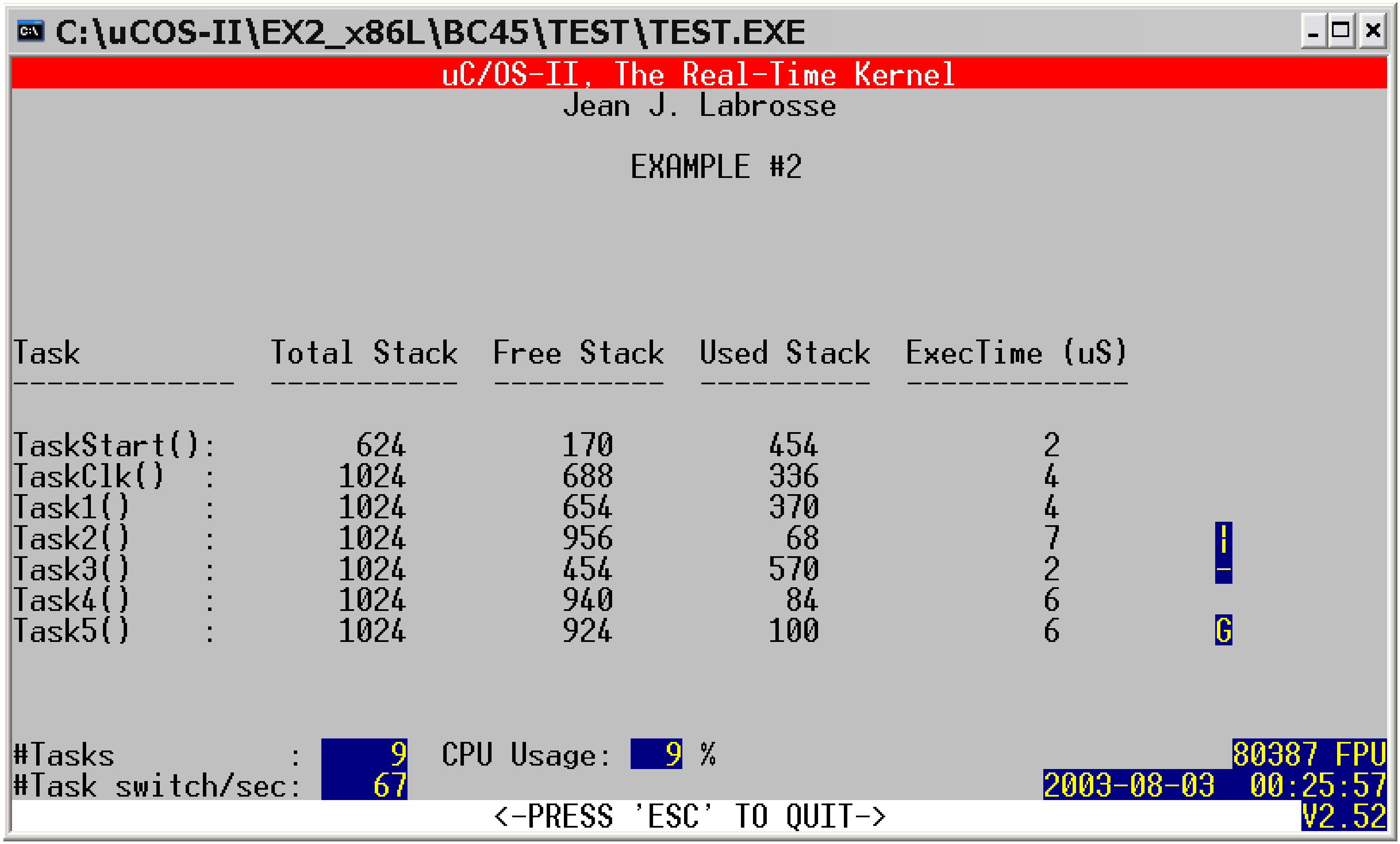
Example 2

- Example 2 focuses on:
  - More task creation options
  - **Stack usage** of each task
  - **Floating point** operations
  - IPC via **mailboxes**

Stack Usage of a Task



Example 2



```
                         uC/OS-II, The Real-Time Kernel
                                Jean J. Labrosse

                                    EXAMPLE #2




Task           Total Stack  Free Stack  Used Stack  ExecTime (uS)
-------------  -----------  ----------  ----------  -------------

TaskStart():        624         170         454             2
TaskClk()  :       1024         688         336             4
Task1()    :       1024         654         370             4
Task2()    :       1024         956          68             7         |
Task3()    :       1024         454         570             2         -
Task4()    :       1024         940          84             6
Task5()    :       1024         924         100             6         G



#Tasks          :     9  CPU Usage:   9 %                              80387 FPU
#Task switch/sec:    67                                     2003-08-03  00:25:57
                            <-PRESS 'ESC' TO QUIT->                        V2.52
```

```
#define          TASK_STK_SIZE     512                /* Size of each task's stacks (# of WORDs)       */

#define          TASK_START_ID       0                /* Application tasks IDs                         */
#define          TASK_CLK_ID         1
#define          TASK_1_ID           2
#define          TASK_2_ID           3
#define          TASK_3_ID           4
#define          TASK_4_ID           5
#define          TASK_5_ID           6

#define          TASK_START_PRIO    10                /* Application tasks priorities                  */
#define          TASK_CLK_PRIO      11
#define          TASK_1_PRIO        12
#define          TASK_2_PRIO        13
#define          TASK_3_PRIO        14
#define          TASK_4_PRIO        15
#define          TASK_5_PRIO        16

OS_STK        TaskStartStk[TASK_STK_SIZE];            /* Startup    task stack                         */
OS_STK        TaskClkStk[TASK_STK_SIZE];              /* Clock      task stack                         */
OS_STK        Task1Stk[TASK_STK_SIZE];                /* Task #1    task stack                         */
OS_STK        Task2Stk[TASK_STK_SIZE];                /* Task #2    task stack                         */
OS_STK        Task3Stk[TASK_STK_SIZE];                /* Task #3    task stack                         */
OS_STK        Task4Stk[TASK_STK_SIZE];                /* Task #4    task stack                         */
OS_STK        Task5Stk[TASK_STK_SIZE];                /* Task #5    task stack                         */

OS_EVENT     *AckMbox;                                /* Message mailboxes for Tasks #4 and #5         */
OS_EVENT     *TxMbox;
```

2 Mailboxes

Main()

```
void main (void)
{
    OS_STK *ptos;
    OS_STK *pbos;
    INT32U  size;


    PC_DispClrScr(DISP_FGND_WHITE);                        /* Clear the screen                         */

    OSInit();                                              /* Initialize uC/OS-II                      */

    PC_DOSSaveReturn();                                    /* Save environment to return to DOS        */
    PC_VectSet(uCOS, OSCtxSw);                             /* Install uC/OS-II's context switch vector */

    PC_ElapsedInit();                                      /* Initialized elapsed time measurement     */

    ptos        = &TaskStartStk[TASK_STK_SIZE - 1];        /* TaskStart() will use Floating-Point      */
    pbos        = &TaskStartStk[0];
    size        = TASK_STK_SIZE;
    OSTaskStkInit_FPE_x86(&ptos, &pbos, &size);
    OSTaskCreateExt(TaskStart,
                   (void *)0,
                   ptos,
                   TASK_START_PRIO,
                   TASK_START_ID,
                   pbos,
                   size,
                   (void *)0,
                   OS_TASK_OPT_STK_CHK | OS_TASK_OPT_STK_CLR);

    OSStart();                                             /* Start multitasking                       */
}
```

TaskStart()

```
void  TaskStart (void *pdata)
{
#if OS_CRITICAL_METHOD == 3                                /* Allocate storage for CPU status register */
    OS_CPU_SR  cpu_sr;
#endif
    INT16S     key;


    pdata = pdata;                                         /* Prevent compiler warning                 */

    TaskStartDispInit();                                   /* Setup the display                        */

    OS_ENTER_CRITICAL();                                   /* Install uC/OS-II's clock tick ISR        */
    PC_VectSet(0x08, OSTickISR);
    PC_SetTickRate(OS_TICKS_PER_SEC);                      /* Reprogram tick rate                      */
    OS_EXIT_CRITICAL();

    OSStatInit();                                          /* Initialize uC/OS-II's statistics         */

    AckMbox = OSMboxCreate((void *)0);                     /* Create 2 message mailboxes               */
    TxMbox  = OSMboxCreate((void *)0);

    TaskStartCreateTasks();                                /* Create all other tasks                   */

    for (;;) {
        TaskStartDisp();                                   /* Update the display                       */

        if (PC_GetKey(&key)) {                             /* See if key has been pressed              */
            if (key == 0x1B) {                             /* Yes, see if it's the ESCAPE key          */
                PC_DOSReturn();                            /* Yes, return to DOS                       */
            }
        }

        OSCtxSwCtr = 0;                                    /* Clear context switch counter             */
        OSTimeDly(OS_TICKS_PER_SEC);                       /* Wait one second                          */
    }
}
```

Create 2 mailboxes

The dummy loop wait for 'ESC'

Task1()

```
void  Task1 (void *pdata)
{
    INT8U       err;
    OS_STK_DATA data;                       /* Storage for task stack data                              */
    INT16U      time;                       /* Execution time (in uS)                                   */
    INT8U       i;
    char        s[80];


    pdata = pdata;
    for (;;) {
        for (i = 0; i < 7; i++) {
            PC_ElapsedStart();
            err  = OSTaskStkChk(TASK_START_PRIO + i, &data);
            time = PC_ElapsedStop();
            if (err == OS_NO_ERR) {
                sprintf(s, "%4ld        %4ld        %4ld        %6d",
                        data.OSFree + data.OSUsed,
                        data.OSFree,
                        data.OSUsed,
                        time);
                PC_DispStr(19, 12 + i, s, DISP_FGND_BLACK + DISP_BGND_LIGHT_GRAY);
            }
        }
        OSTimeDlyHMSM(0, 0, 0, 100);                       /* Delay for 100 mS                         */
    }
}
```

```
void  Task2 (void *data)
{
    data = data;
    for (;;) {
        PC_DispChar(70, 15, '|',  DISP_FGND_YELLOW + DISP_BGND_BLUE);
        OSTimeDly(10);
        PC_DispChar(70, 15, '/',  DISP_FGND_YELLOW + DISP_BGND_BLUE);
        OSTimeDly(10);
        PC_DispChar(70, 15, '-',  DISP_FGND_YELLOW + DISP_BGND_BLUE);
        OSTimeDly(10);
        PC_DispChar(70, 15, '\\', DISP_FGND_YELLOW + DISP_BGND_BLUE);
        OSTimeDly(10);
    }
}

void  Task3 (void *data)
{
    char    dummy[500];
    INT16U  i;


    data = data;
    for (i = 0; i < 499; i++) {        /* Use up the stack with 'junk'  */
        dummy[i] = '?';
    }
    for (;;) {
        PC_DispChar(70, 16, '|',  DISP_FGND_YELLOW + DISP_BGND_BLUE);
        OSTimeDly(20);
        PC_DispChar(70, 16, '\\', DISP_FGND_YELLOW + DISP_BGND_BLUE);
        OSTimeDly(20);
        PC_DispChar(70, 16, '-',  DISP_FGND_YELLOW + DISP_BGND_BLUE);
        OSTimeDly(20);
        PC_DispChar(70, 16, '/',  DISP_FGND_YELLOW + DISP_BGND_BLUE);
        OSTimeDly(20);
    }
}
```

Task4 and Task5

```
void  Task4 (void *data)
{
    char   txmsg;
    INT8U  err;


    data  = data;
    txmsg = 'A';
    for (;;) {
        OSMboxPost(TxMbox, (void *)&txmsg);       /* Send message to Task #5                            */
        OSMboxPend(AckMbox, 0, &err);             /* Wait for acknowledgement from Task #5              */
        txmsg++;                                  /* Next message to send                               */
        if (txmsg == 'Z') {
            txmsg = 'A';                          /* Start new series of messages                       */
        }
    }
}

void  Task5 (void *data)
{
    char  *rxmsg;
    INT8U  err;


    data = data;
    for (;;) {
        rxmsg = (char *)OSMboxPend(TxMbox, 0, &err);                   /* Wait for message from Task #4 */
        PC_DispChar(70, 18, *rxmsg, DISP_FGND_YELLOW + DISP_BGND_BLUE);
        OSTimeDlyHMSM(0, 0, 1, 0);                                     /* Wait 1 second                 */
        OSMboxPost(AckMbox, (void *)1);                                /* Acknowledge reception of msg  */
    }
}
```

MailBox

- A mailbox is a data exchange between tasks
  - A mailbox consists of a data pointer and a wait-list
- OSMboxPend():
  - The message in the mailbox is retrieved
  - If the mailbox is empty, the task is immediately blocked and moved to the wait-list
  - A time-out value can be specified
- OSMboxPost():
  - A message is deposited in the mailbox
  - If there is already a message in the mailbox, an error is returned (not overwritten)
  - If tasks waiting for a message from the mailbox, the task with the highest priority is removed from the wait-list and scheduled to run

OSTaskStkInit_FPE_x86()

- OSTaskStkInit_FPE_x86(&ptos, &pbos, &size)
- Passing the original top address, bottom address, and size of the stack
- On return, the arguments are modified and some stack space are reserved for floating point library
  - For context switches

OSCreateTaskExt()

```
OSTaskCreateExt(
TaskStart,
(void *)0,
ptos,
TASK_START_PRIO,
TASK_START_ID,
pbos,
size,
(void *)0,
OS_TASK_OPT_STK_CHK | OS_TASK_OPT_STK_CLR
);
```

OSTaskStkCheck()

- Check for stack overflow
  - Criteria
    - bos < (tos – stack length)
  - Who uses stacks?
    - Local variables,
    - arguments for procedure calls,
    - and temporary storage for ISR’s
  - When stacks are checked?
    - When a task is created
    - When OSTaskStkCheck() is called
    - No automatic stack checking

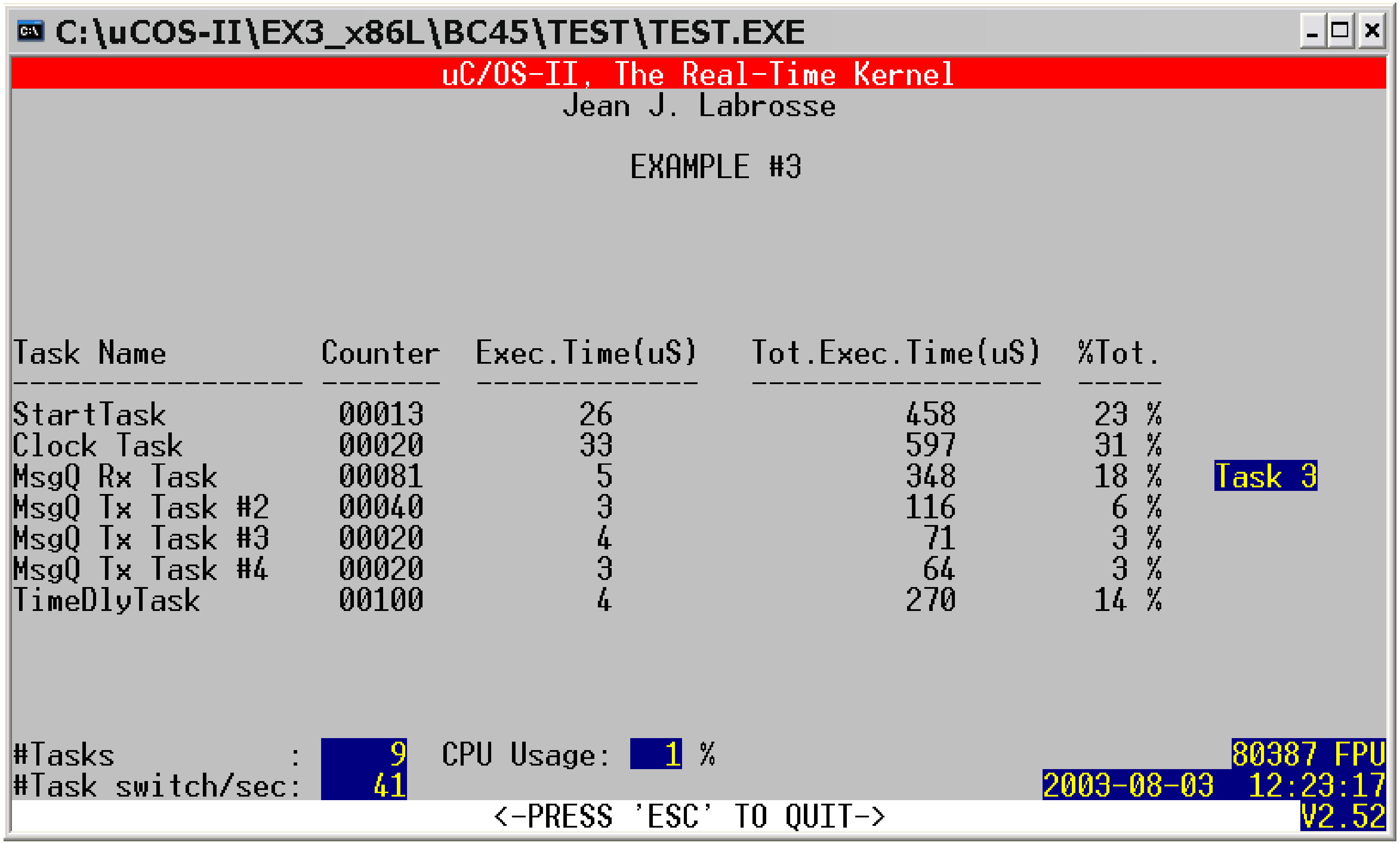
Summary: Example2

- Local variable, function calls, and ISR’s will utilize the stack space of user tasks
  - ISR will use the stack of the task being interrupted
- If floating-point operations are needed, some stack space should be reserved
- Mailbox can be used to synchronize among tasks

Example 3

- Using message queues to pass user-defined data structures among tasks
- Demonstrating how to use OS hooks to monitor interested system events

Example 3



```
                        uC/OS-II, The Real-Time Kernel
                              Jean J. Labrosse

                                 EXAMPLE #3




Task Name         Counter  Exec.Time(uS)   Tot.Exec.Time(uS)  %Tot.
----------------- -------  -------------   -----------------  -----
StartTask          00013          26                 458       23 %
Clock Task         00020          33                 597       31 %
MsgQ Rx Task       00081           5                 348       18 %   Task 3
MsgQ Tx Task #2    00040           3                 116        6 %
MsgQ Tx Task #3    00020           4                  71        3 %
MsgQ Tx Task #4    00020           3                  64        3 %
TimeDlyTask        00100           4                 270       14 %



#Tasks          :      9  CPU Usage:   1 %                        80387 FPU
#Task switch/sec:     41                               2003-08-03  12:23:17
                     <-PRESS 'ESC' TO QUIT->                          V2.52
```

```
•    #define          TASK_STK_SIZE     512              /* Size of each task's stacks (# of WORDs)        */

•    #define          TASK_START_ID       0              /* Application tasks                              */
•    #define          TASK_CLK_ID         1
•    #define          TASK_1_ID           2
•    #define          TASK_2_ID           3
•    #define          TASK_3_ID           4
•    #define          TASK_4_ID           5
•    #define          TASK_5_ID           6

•    #define          TASK_START_PRIO    10              /* Application tasks priorities                   */
•    #define          TASK_CLK_PRIO      11
•    #define          TASK_1_PRIO        12
•    #define          TASK_2_PRIO        13
•    #define          TASK_3_PRIO        14
•    #define          TASK_4_PRIO        15
•    #define          TASK_5_PRIO        16

•    #define          MSG_QUEUE_SIZE     20              /* Size of message queue used in example          */

•    typedef struct {
•        char    TaskName[30];
•        INT16U  TaskCtr;
•        INT16U  TaskExecTime;
•        INT32U  TaskTotExecTime;
•    } TASK_USER_DATA;
```

User-defined data structure to pass to tasks

```
•    OS_STK          TaskStartStk[TASK_STK_SIZE];         /* Startup    task stack                          */
•    OS_STK          TaskClkStk[TASK_STK_SIZE];           /* Clock      task stack                          */
•    OS_STK          Task1Stk[TASK_STK_SIZE];             /* Task #1    task stack                          */
•    OS_STK          Task2Stk[TASK_STK_SIZE];             /* Task #2    task stack                          */
•    OS_STK          Task3Stk[TASK_STK_SIZE];             /* Task #3    task stack                          */
•    OS_STK          Task4Stk[TASK_STK_SIZE];             /* Task #4    task stack                          */
•    OS_STK          Task5Stk[TASK_STK_SIZE];             /* Task #5    task stack                          */

•    TASK_USER_DATA  TaskUserData[7];

•    OS_EVENT       *MsgQueue;                            /* Message queue pointer                          */
•    void           *MsgQueueTbl[20];                     /* Storage for messages                           */
```

Message queue and an array of messages

```
void  Task1 (void *pdata)
{
   char  *msg;
   INT8U  err;


   pdata = pdata;
   for (;;) {
      msg = (char *)OSQPend(MsgQueue, 0, &err);
      PC_DispStr(70, 13, msg, DISP_FGND_YELLOW + DISP_BGND_BLUE);
      OSTimeDlyHMSM(0, 0, 0, 100);
   }
}
```

```
void  Task2 (void *pdata)
{
   char  msg[20];


   pdata = pdata;
   strcpy(&msg[0], "Task 2");
   for (;;) {
      OSQPost(MsgQueue, (void *)&msg[0]);
      OSTimeDlyHMSM(0, 0, 0, 500);
   }
}
```

Task 2, 3, 4 are functionally identical.

Message Queues

- A message queue= an array of elements + a wait-list
  - Different from a mailbox, many messages are queued in a message queue in a FIFO fashion
  - As same as mailboxes, there can be multiple tasks pend/post to a message queue
- **OSQPost**():
  - Appending a message to the queue
  - The highest-priority pending task (in the wait-list) receives the message and is scheduled to run, if any
  - If queue is full, return without being blocked
- **OSQPend**():
  - Remove a message from the queue
  - If no message can be retrieved, the task is moved to the wait-list and becomes blocked

Hooks

- A hook (callback) is cascaded after its corresponding system event
  - For example, OSTaskSwHook () is called every time when context switch occurs
  - User program could do something when the interested events occur
- The hooks are specified in compile time in uC/OS-2
  - Write your code in the body of predefined hooks
  - Registration/deregistration are not available

User Customizable Hooks

- void OSInitHookBegin (void)
- void OSInitHookEnd (void)
- void OSTaskCreateHook (OS_TCB *ptcb)
- void OSTaskDelHook (OS_TCB *ptcb)
- void OSTaskIdleHook (void)
- void OSTaskStatHook (void)
- void OSTaskSwHook (void)
- void OSTCBInitHook (OS_TCB *ptcb)
- void OSTimeTickHook (void)

```
void  OSTaskStatHook (void)
{
    char    s[80];
    INT8U   i;
    INT32U  total;
    INT8U   pct;


    total = 0L;                                          /* Totalize TOT. EXEC. TIME for each task */
    for (i = 0; i < 7; i++) {
        total += TaskUserData[i].TaskTotExecTime;
        DispTaskStat(i);                                 /* Display task data                      */
    }
    if (total > 0) {
        for (i = 0; i < 7; i++) {                        /* Derive percentage of each task         */
            pct = 100 * TaskUserData[i].TaskTotExecTime / total;
            sprintf(s, "%3d %%", pct);
            PC_DispStr(62, i + 11, s, DISP_FGND_BLACK + DISP_BGND_LIGHT_GRAY);
        }
    }
    if (total > 1000000000L) {                           /* Reset total time counters at 1 billion */
        for (i = 0; i < 7; i++) {
            TaskUserData[i].TaskTotExecTime = 0L;
        }
    }
}

void  OSTaskSwHook (void)
{
    INT16U           time;
    TASK_USER_DATA  *puser;


    time  = PC_ElapsedStop();                    /* This task is done                                  */
    PC_ElapsedStart();                           /* Start for next task                                */
    puser = OSTCBCur->OSTCBExtPtr;               /* Point to used data                                 */
    if (puser != (TASK_USER_DATA *)0) {
        puser->TaskCtr++;                        /* Increment task counter                             */
        puser->TaskExecTime     = time;          /* Update the task's execution time                   */
        puser->TaskTotExecTime += time;          /* Update the task's total execution time             */
    }
}
```

Summary: Example 3

- Synchronizing tasks with message queues
  - Multiple message can be held in the queue
  - Multiple tasks can pend/post to a message queues
- Hooking interested system events via customizable hooks
  - Write your code in the body of predefined hooks

Summary: Getting Started with uC/OS-2

- Do you understand
  - how to write a dummy uC/OS-2 program?
  - how the control flows among procedures?
  - how tasks are created?
  - how tasks are synchronized by semaphore, mailbox, and message queues?
  - how the space of stacks are allocated?
  - how to hook on system events?