Getting Started with Embedded OS

Embedded OS Implementation

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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?

Example 1

- 13 tasks run concurrently
  - 2 internal tasks:
    - The idle task and the statistic task
  - 11 user tasks:
    - Randomly print numbers onto 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)

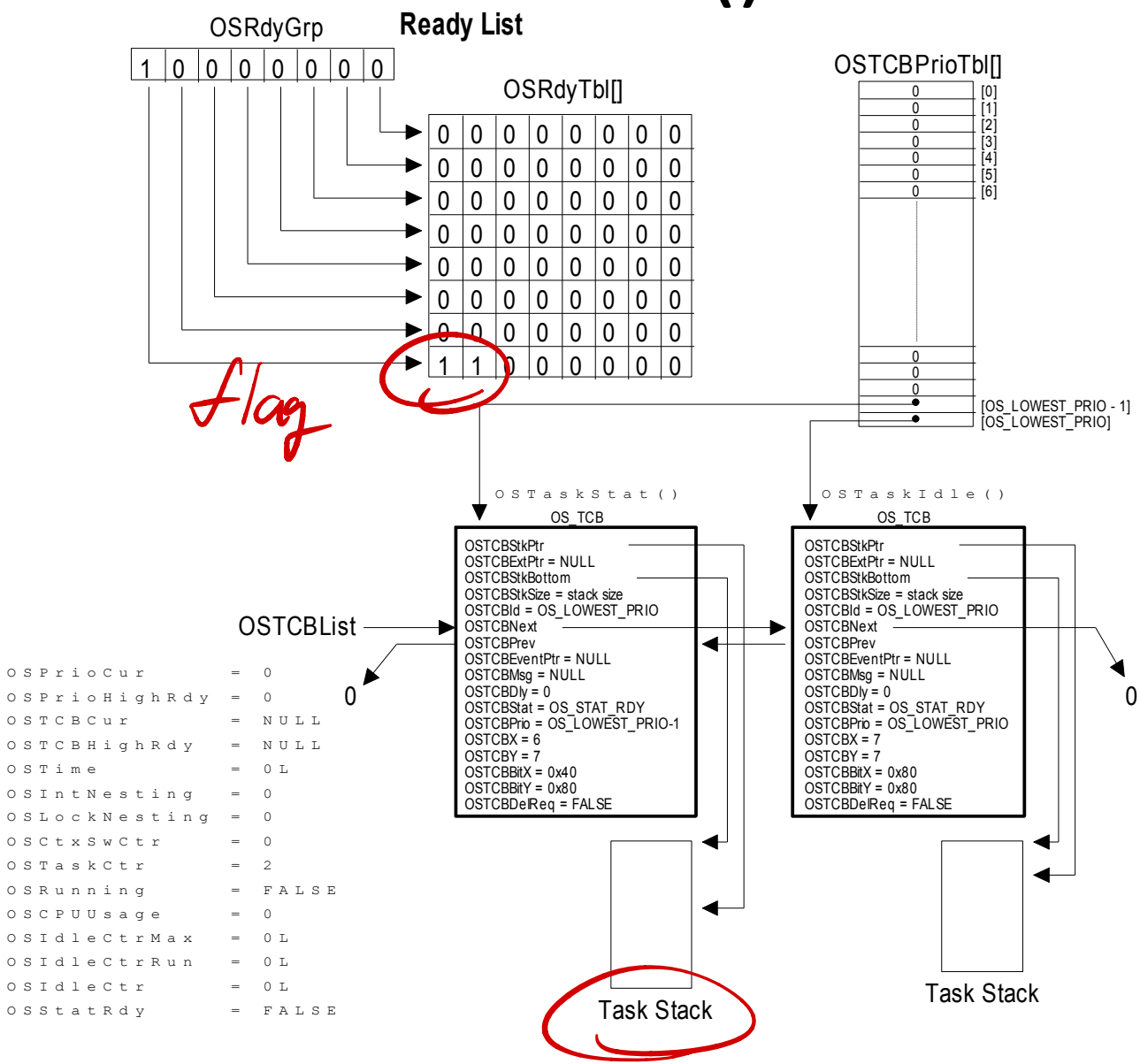
Main()

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

Main()

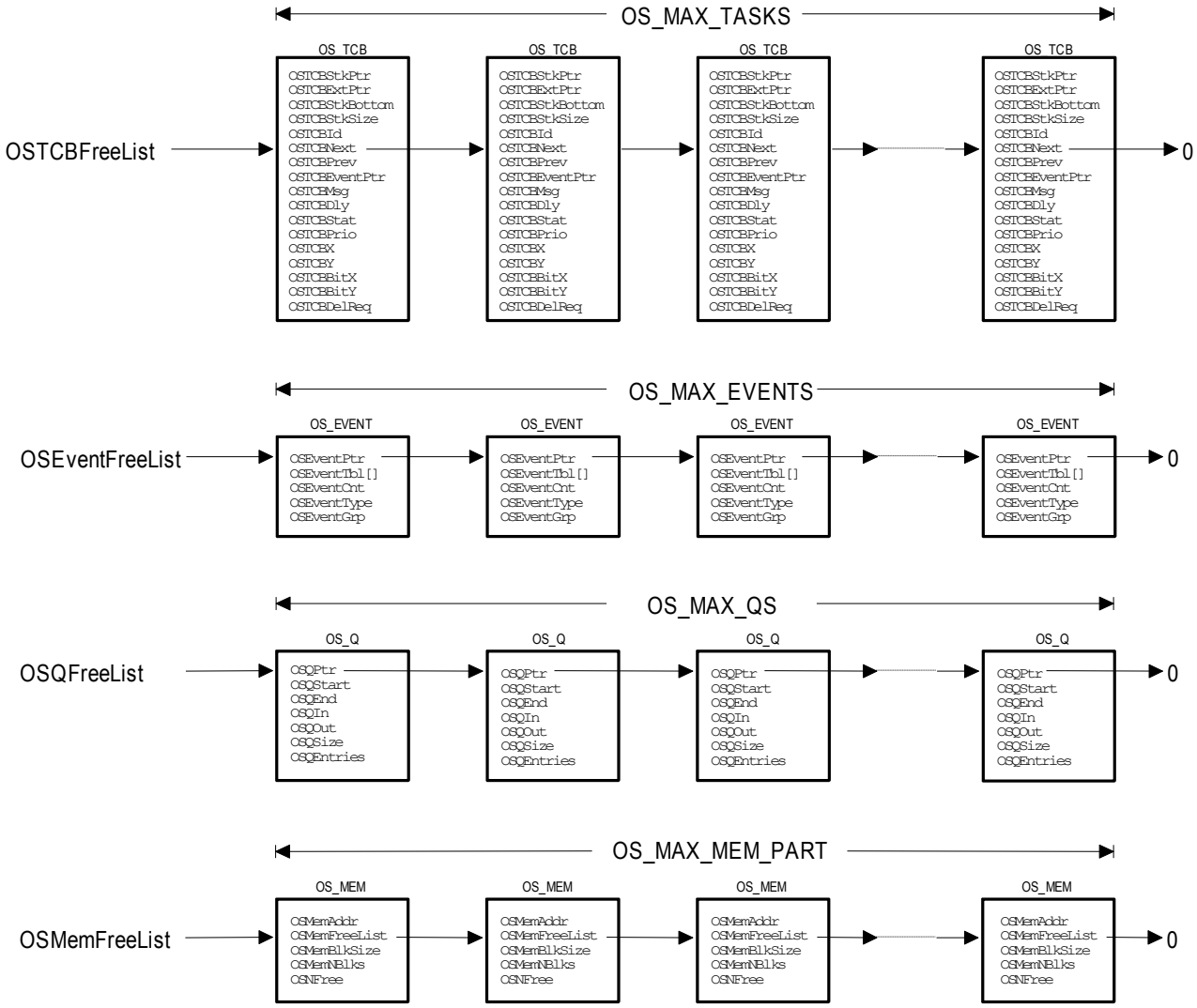
- OSinit():
  - Init internal structures of uC/OS-2.
    - Task ready list f lag
    - Priority table for task
    - Task control blocks (TCB)
    - Free pool
  - Create housekeeping tasks.
    - The idle task 不可略 → CPU不懂
    - The statistics task 可略

OSinit()


OSRdyGrp
Ready List
1 0 0 0 0 0 0 0
OSRdyTbl[]
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
flag
OSTCBPrioTbl[]
0 [0]
0 [1]
0 [2]
0 [3]
0 [4]
0 [5]
0 [6]
0
0
0
[OS_LOWEST_PRIO - 1]
[OS_LOWEST_PRIO]
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
OSTCBList
0
0
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
Task Stack
Task Stack

*

OSinit()


OS_MAX_TASKS
OS_TCB
OSTCBStkPtr
OSTCBExtPtr
OSTCBStkBottom
OSTCBStkSize
OSTCBId
OSTCBNext
OSTCBPrev
OSTCBEventPtr
OSTCBMsg
OSTCBDly
OSTCBStat
OSTCBPrio
OSTCBX
OSTCBY
OSTCBBitX
OSTCBBitY
OSTCBDelReq
OSTCBFreeList
0
OS_MAX_EVENTS
OS_EVENT
OSEventPtr
OSEventTbl[]
OSEventCnt
OSEventType
OSEventGrp
OSEventFreeList
0
OS_MAX_QS
OS_Q
OSQPtr
OSQStart
OSQEnd
OSQIn
OSQOut
OSQSize
OSQEntries
OSQFreeList
0
OS_MAX_MEM_PART
OS_MEM
OSMemAddr
OSMemFreeList
OSMemBlkSize
OSMemNBlks
OSNFree
OSMemFreeList
0

*

Main()

- PC_VectSet(uCOS,OSCtxSw)

切換task 多工中斷

  - Install the context switch handler
  - Interrupt # 0x80 of 80x86 family
    - Later invoked by int instruction

*

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
    - It is non-reentrant. To be explained later.

*

Main()

- OSTaskCreate()
  - Create tasks with the supplied arguments
  - Tasks become “ready” after created

- Task control block = manager task
  - An active entity which could do some computations
  - **Priority, CPU registers, stack, text, housekeeping status**
  - uC/OS-2 allows maximum 63 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

Priority (0=hightest)

Top of Stack

Main()

- OSStart() at least one user task before OS start

  Do idel task
  ↓ wait
  new task (interrupt)
  ↓ cotext switch
  Do new task

  – Start multitasking of uC/OS-2

  – It never returns to main()

  – uC/OS-2 is terminated if PC_DOSReturn() is called

TaskStart() for close interrput enable

→ System will be handled

can't be added new task (interrpute)

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

    pdata = pdata;                                   /* Prevent compiler warning                 */

    TaskStartDispInit();                             /* Initialize the display                   */

    OS_ENTER_CRITICAL();
    PC_VectSet(0x08, OSTickISR);      太小 CPU 負擔太大  /* Install uC/OS-II's clock tick ISR        */
    PC_SetTickRate(OS_TICKS_PER_SEC); 太大 User 體感差  /* 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                          */
    }
}
```

防止被其它中斷

TaskStart()

- OS_ENTER(EXIT)_CRITICAL
  - Enable/disable most interrupts
  - An alternative way to accomplish mutual exclusion
    - No rescheduling is possible during the disabling of interrupts
    - Different from semaphores
  - Processor specific
    - CLI/STI (x86 real mode)
    - Interrupt descriptors (x86 protected mode)

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

Priority

Stack

Task()

可中斷控制
for keyboard, timer

```
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                            */
    }
}
```

Semaphore operations.

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.

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()

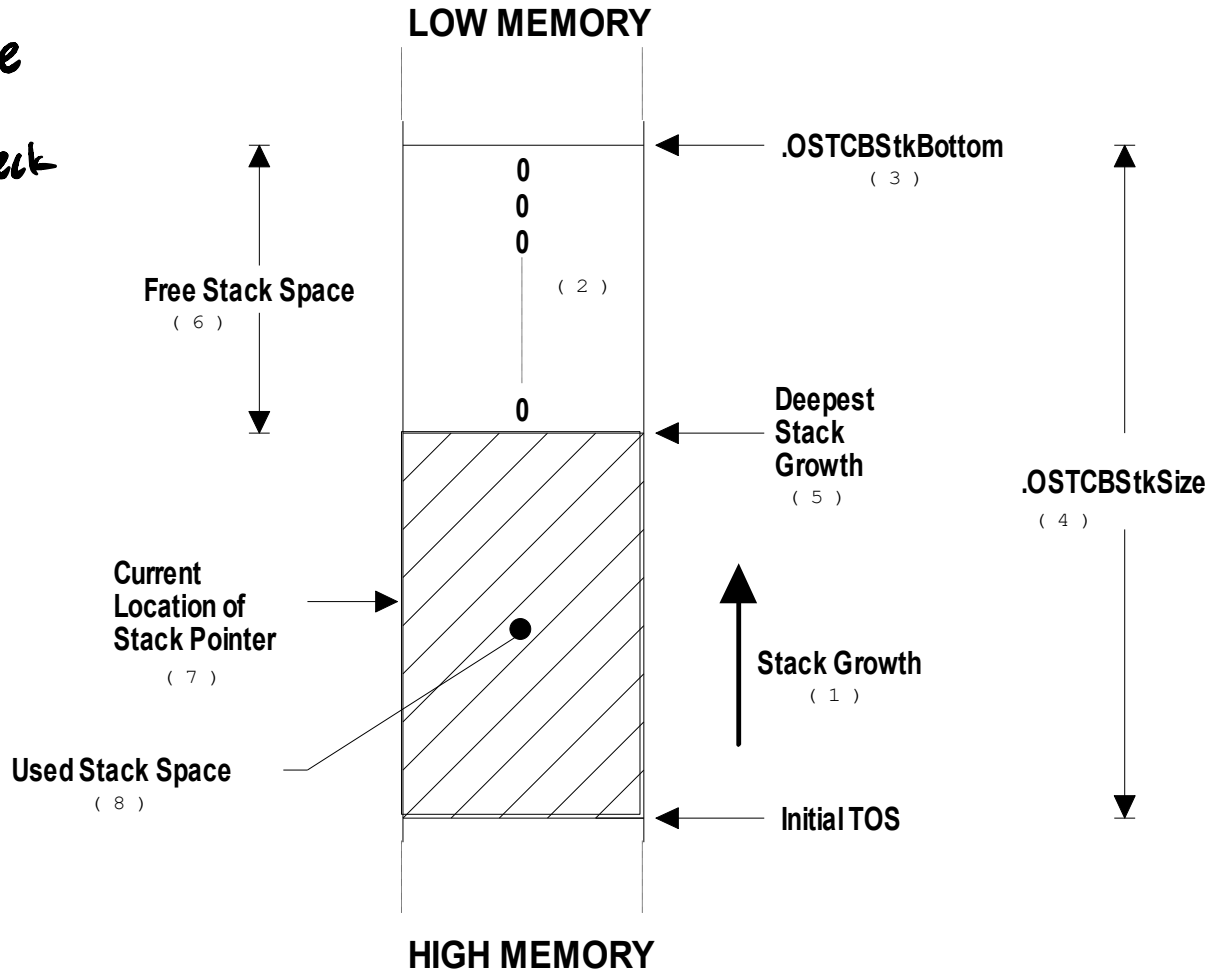
Example 2

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

Stack Usage of a Task

① 全部都給 same size

② 各自的 size
+
check stack



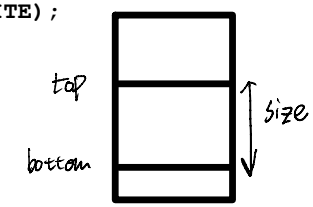
```
• #define        TASK_STK_SIZE     512          /* Size of each task's stacks (# of WORDs)      */

• #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;
```

7

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                     */
    }
}
```

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  */
    }
}
```

三方交握

MailBox

- A mailbox is a data exchange between tasks
  - A mailbox consists of a data pointer and a wait-list
- OSMboxPend(): 收
  - 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(): 送
  - 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) size top bottom
  - Who uses stacks?
    - Local variables,
    - arguments for procedure calls,
    - temporary storage for ISR's 存在被中断者下的 task stack
  - When stacks are checked?
    - When a task is created
    - When OSTaskStkCheck() is called
    - No automatic stack checking

      没那麼聰明

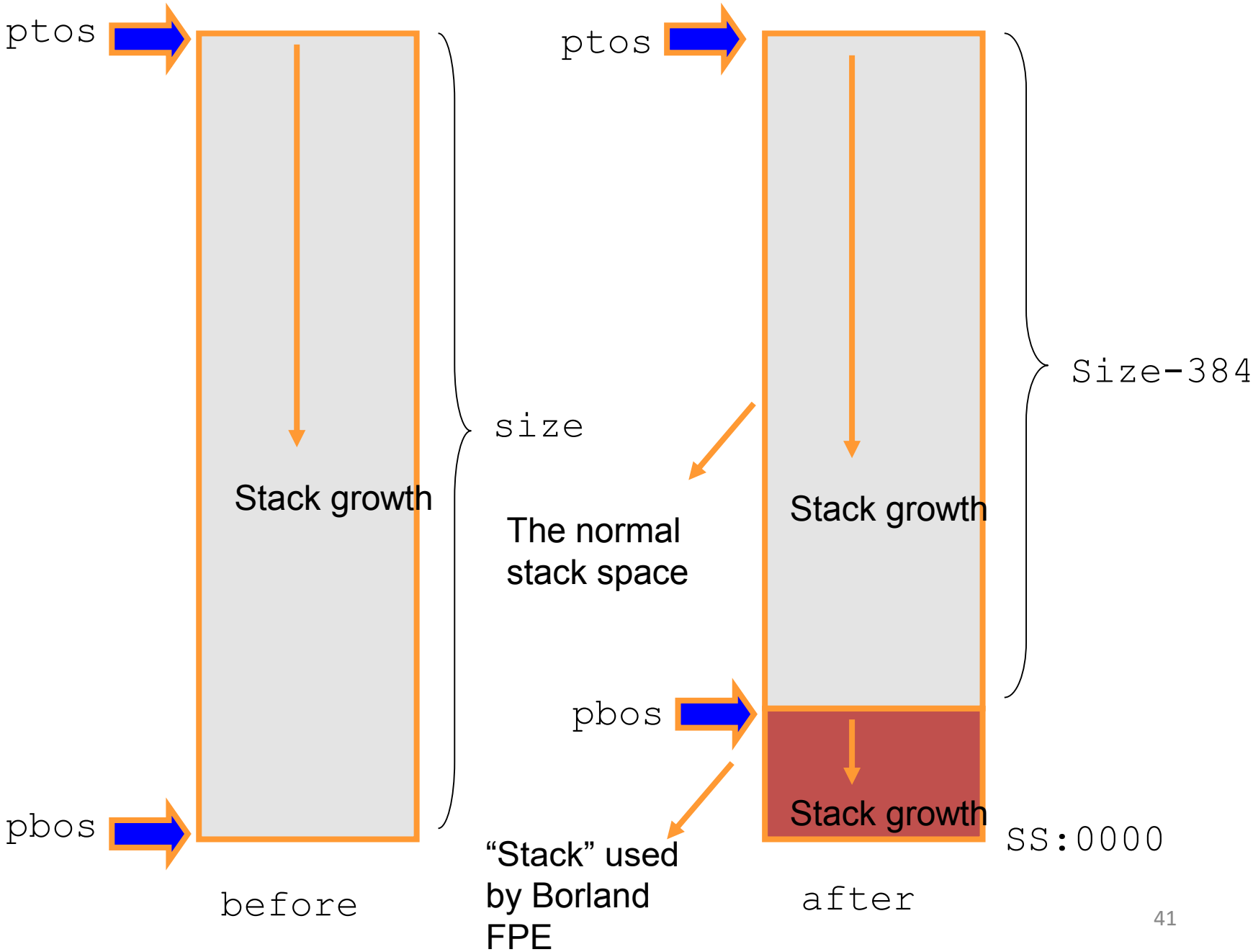
Summary: Example2

- 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 預先保留
- Mailbox can be used to synchronize among tasks

同步

OS_CPU.C – OSTaskStkInit_FPE_x86()

```
OS_STK Task1Stk[1000];
OS_STK Task2Stk[1000];

void main(void) {
        OS_STK *ptos;
        OS_STK *pbos;
        OS_Init();

        ptos = &Task1Stk[999];
        pbos = &Task1st[0];
        size = 1000;

        OSTaskStkInit_FPE_x86(&ptos, &pbos, &size);
        OSTaskCreate(Task1, null, pbos, 10);

        ptos = &Task2Stk[999];
        pbos = &Task2st[0];
        size = 1000;

        OSTaskStkInit_FPE_x86(&ptos, &pbos, &size);
        OSTaskCreate(Task2, null, pbos,
                11, 11, pbos, size, null, OSTask_OPT_SAVE_FP);

        OSStart();
}
```


ptos
pbos
Stack growth
size
before
ptos
Stack growth
Size-384
The normal
stack space
pbos
Stack growth
SS:0000
"Stack" used
by Borland
FPE
after

```c
void  OSTaskStkInit_FPE_x86 (OS_STK **pptos, OS_STK **ppbos, INT32U *psize)
{
    /* 'Linear' version of top-of-stack    address   */
    INT32U   lin_tos;
    /* 'Linear' version of bottom-of-stack address   */
    INT32U   lin_bos;
    INT16U   seg;
    INT16U   off;
    INT32U   bytes;

    /* Decompose top-of-stack pointer into seg:off   */
    seg      = FP_SEG(*pptos);
    off      = FP_OFF(*pptos);
    /* Convert seg:off to linear address             */
    lin_tos  = ((INT32U)seg << 4) + (INT32U)off;
    /* Determine how many bytes for the stack        */
    bytes    = *psize * sizeof(OS_STK);
    /* Ensure paragraph alignment for BOS            */
    lin_bos  = (lin_tos - bytes + 15) & 0xFFFFFFF0L;

    /* Get new 'normalized' segment                  */
    seg      = (INT16U)(lin_bos >> 4);
    /* Create 'normalized' BOS pointer               */
    *ppbos   = (OS_STK *)MK_FP(seg, 0x0000);
    /* Copy FP emulation memory to task's stack      */
    memcpy(*ppbos, MK_FP(_SS, 0), 384);
    /* Loose 16 bytes because of alignment           */
    bytes    = bytes - 16;
    /* Determine new top-of-stack                    */
    *pptos   = (OS_STK *)MK_FP(seg, (INT16U)bytes);
    /* Determine new bottom-of-stack                 */
    *ppbos   = (OS_STK *)MK_FP(seg, 384);
    bytes    = bytes - 384;
    /* Determine new stack size                      */
    *psize   = bytes / sizeof(OS_STK);
}
```

Remarks:

FP_OFF is a macro that can get or set the offset of the far pointer *p.

FP_SEG is a macro that gets or sets the segment value of the far pointer *p.

MK_FP is a macro that makes a far pointer from its component segment (seg) and offset (ofs) parts.

See you next class!