

# EE445M/EE380L.12 Embedded and Real-Time Systems/ Real-Time Operating Systems

## Lecture 13: Commercial RTOS, Final Exam, Review

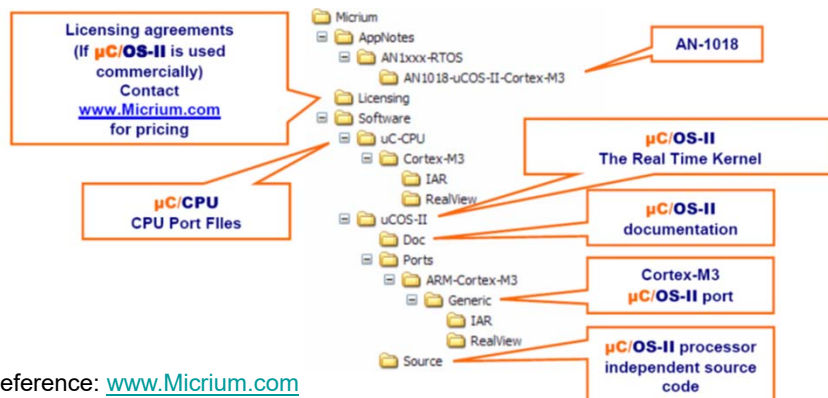
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## Putting it All Together

- Micrium  $\mu$ COS-II

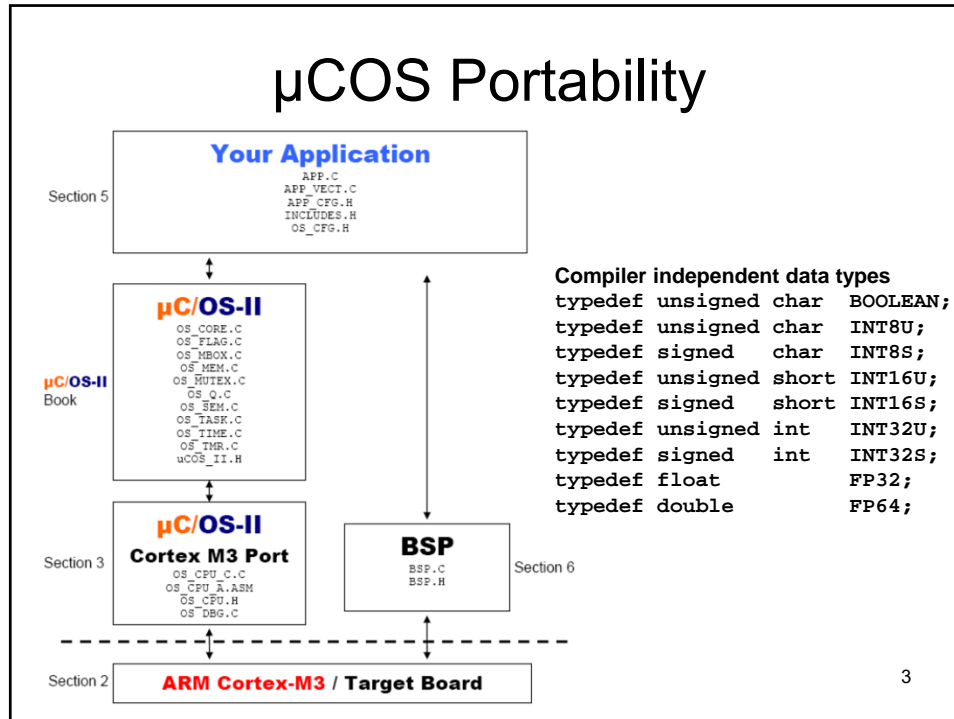


Reference: [www.Micrium.com](http://www.Micrium.com)  
Application Note AN-1018 (Cortex-M3)  
 $\mu$ C/OS-II and  $\mu$ C/OS-III by Jean J. Labrosse

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## Hooks

- Run user supplied code at strategic places
- Allows you to
  - Extend the OS
  - Implement debugging
  - Implement performance testing
  - Implement black box recording
- Collect run-time performance data

## μCOS Runs with PSP

```

OS_CPU_PendSVHandler
  CPSID   I           ; Prevent interruption during context switch
  MRS     R0, PSP      ; PSP is process stack pointer
  CBZ     R0, OS_CPU_PendSVHandler_nosave ; Skip save the
                                           ; first time

  SUBS    R0, R0, #0x20 ; Save remaining regs r4-11
                                           ; on process stack

  STM     R0, {R4-R11}

  LDR     R1, =OSTCBCur ; OSTCBCur->OSTCBStkPtr = SP;
  LDR     R1, [R1]
  STR     R0, [R1]      ; R0 is SP of process being
                                           ; switched out

  ...

```

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## User Can Hook into μCOS

```

... (context switch continued)
  PUSH   {R14}          ; Save LR exc_return value
  LDR    R0, =OSTaskSwHook ; OSTaskSwHook();
  BLX   R0
  POP   {R14}

```

Many hooks provided:

```

OSInitHookBegin()
OSInitHookEnd()
OSTaskCreateHook()
OSTaskDelHook()
OSTaskIdleHook()
OSTaskStatHook()
OSTaskStkInit()
OSTaskSwHook()
OSTCBInitHook()
OSTimeTickHook()

```

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## Board Support Package (BSP)

- Hardware abstraction layer (HAL)
  - I/O abstraction for anything OS needs
  - Encapsulate functionality of target hardware
    - Timer initialization
    - ISR Handlers
    - LED control functions
    - Reading switches
    - Setting up the interrupt controller
    - Setting up communication channel
    - CAN, I2C, ADC, DAC, SPI, serial, graphics

```
void LED_Init(void);
void LED_On(CPU_INT08U led_id);
void LED_Off(CPU_INT08U led_id);
void LED_Toggle(CPU_INT08U led_id);
```

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## μCOS Synchronization

- Message mail box
- Message queue
- Semaphores
- Flags (software events)
  - Groups of flags
  - Names
  - pend/post, and/or

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## μCOS Mutex

```

/* Description: This function waits for a mutual exclusion semaphore.
Arguments  : pevent pointer to event control block associated with mutex.
             timeout optional timeout period (in clock ticks).
             If non-zero, your task will wait up to the specified time
             If you specify 0, however, will wait forever for resource
perr      pointer to where an error message will be deposited.
OS_ERR_NONE           successful and your task owns the mutex
OS_ERR_TIMEOUT       not available within the 'timeout'.
OS_ERR_PEND_ABORT    mutex was aborted.
OS_ERR_EVENT_TYPE    If you didn't pass a pointer to a mutex
OS_ERR_PEVENT_NULL   'pevent' is a NULL pointer
OS_ERR_PEND_ISR      called from an ISR
OS_ERR_PIP_LOWER     task priority that owns is HIGHER
OS_ERR_PEND_LOCKED   called when the scheduler is locked

* Returns    : none
* Note(s)1) The task that owns the Mutex MUST NOT pend on any other event while it
*            owns the mutex.
*            2) You MUST NOT change the priority of the task that owns the mutex
*/
void  OSMutexPend (OS_EVENT *pevent, INT16U timeout, INT8U *perr)
INT8U OSMutexPost (OS_EVENT *pevent)

```

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## Other μCOS Features

- Memory manager
- Time delay (sleep)
- Priority resolution table
- Debugger aware

Reference: [www.Micrium.com](http://www.Micrium.com)  
 μC/OS-II and μC/OS-III books by Jean J. Labrosse

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## Final Exam

- Wednesday, May 13, 7-10pm, online
  - Open book, open notes, open web
  - No electronic devices (except calculator with small B/W screen)
  - All phones off
- Comprehensive (see Study Guide)
  - Book Chapters 1-9
  - Lectures 1-12
  - Labs 1-7

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## Lab Topics

- Lab 1
  - Interrupts, Cortex M architecture, FIFOs, serial port, ADC
- Lab 2
  - Real time OS, semaphores, critical sections, synchronization, communication
- Lab 3
  - Priority scheduling, blocking semaphores, debugging
- Lab 4
  - File system, SPI, SD cards
- Lab 5
  - Memory & process management, process loading & linking
- Lab 6
  - CAN/Ethernet, TCP/IP, interfacing, and distributed systems
- Lab 7
  - Applications and abstraction

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## Topics Not in Labs

- DMA
- PID and ~~Fuzzy logic~~ control
- Ethernet (vs. CAN), TCP/IP
- Virtual Memory, Paging
- Synchronization & Communication
  - Monitors
  - KPNs
  - Design and implementation of thread flags  
OS\_Wait\_Event\_Or, OS\_Wait\_Event\_And,  
OS\_Trigger\_Event(Thread)

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## General Topics

- Software development
  - Data flow graphs, call graphs
- I/O
  - Device drivers
  - CPU bound, I/O bound
- Debugging
  - Intrusiveness, stabilization, profiling, dumps, monitors
- SPI/SSI, disk/flash concepts
  - Synchronization, Bandwidth, Protocol
- Networking fundamentals
  - How does CAN/Ethernet and TCP/IP work
- Memory management
  - Virtual memory, paging, page table, TLB

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## General OS Concepts

- Kernel, Hooks
- Deadlock (detection, prevention)
- Aging, Starvation
- Race condition, Critical Section
- Reentrancy, Mutual exclusion, Atomic
- Bounded waiting
- ROMable, Portability, Scalability
- CPU utilization, latency, jitter
- FIFO queue/pipe implementation, usage

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## OS Design & Implementation

- Interrupts
  - Arm, enable
  - Protocol, interrupt processing on TM4C123
  - Interrupt priority
- Context switch
  - PSP/MSP, Stack
- Scheduling
  - Round robin, priority based, rate monotonic
  - Linked list, TCB

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## Synchronization

- Semaphores
  - Binary, counting
  - Spin lock, Blocking
- Mailbox, FIFO
- Monitors
- Path expression
- Implementation, applications
  - Little book of semaphores
  - Study lecture examples, old exams

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## High-Speed I/O

- Hardware FIFOs
- Dual-port, banked memory
- DMA Concepts
  - DMA controller
  - Cycle steal, Burst
  - Single address, dual address
  - Latency, Bandwidth

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## File Systems

- SD card interface
  - Bandwidth
  - DMA
- Internal/external fragmentation
- Free space management
- Disk block allocation
  - Contiguous, linked, indexed
  - First fit, best fit, worst fit
  - Directory
- Linked, Indexed, FAT

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## Memory & Process Management

- Heap, Heap Manager
  - Dynamic memory allocation, malloc/free
- Processes (vs. threads)
  - Creation, termination, PCB
- Loading, linking, relocation
  - ELF files
  - Position-independence, dynamic linking, SVC
- Protection
- Virtual memory
  - Address translation
  - MMU, paging, swapping, TLB

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## Networking

- Framing and Messaging
- Layering
- CAN & Ethernet concepts
  - Message protocol, arbitration
  - Bandwidth, stuff bits
  - Error detection
- TCP/IP
- IoT, Application-layer protocols

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## Sensing

- Timed input capture (fundamentals)
- Measuring delay
- Measuring frequency
- Measuring pulse width
- Measuring period
  - Precision
  - Resolution
  - Range

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## Actuating, Control

- PWM
  - Range, resolution, precision
- Motor interface
  - H bridge
- PID control
  - Show how controller is run within the RTOS
- ~~Fuzzy logic control~~

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## Old Exams (See Study Guide)

- All Since Spring 2014
  - TM4C, excluding filter questions
- Spring 2013, Spring 2012, Spring 2011
  - All but filters relevant, change LM3S to TM4C
- Spring 2010
  - Change STM32 to LM4C
- Older exam topics no longer covered
  - 9S12 ports, interface, software, paging
  - Memory interfacing, Timing diagrams

<http://www.ece.utexas.edu/~valvano/EE345Moldquiz/>

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