Functional Architectures

Structure and Mechanisms of the MicroC/OS-II Microkernel

NOTE:

Some aspects are specific to MicroC/OS-II and are implemented differently in other microkernels

Integrating different functionality on a processor

- **Different applications** executing **on** the **same processor** may
  - Cause **resource conflicts**
    - CPU time
    - Memory
    - Peripherals
    - …
  - Require **arbitration** for these conflicts
    - Scheduler
    - Memory Management
    - Semaphores
    - …
- Often these conflicts are resolved by an operating system or runtime environment

What does a microkernel do?

- Task Scheduling
- Interrupt Handling
- Provide Communication Primitives
- Provide Synchronization Primitives
- Memory Management
- Provide Timebase

„The kernel is the part of a multitasking system responsible for management of tasks (i.e., for managing the CPU‘s time) and communication between tasks.“

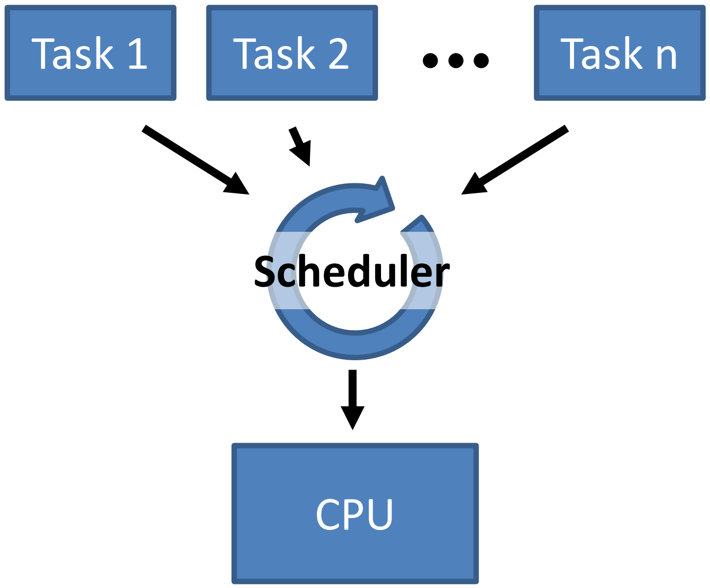
MicroC/OS-II – The Real-Time Kernel

SCHEDULING

Task Scheduling

„A task, also called thread, is a simple program that thinks it has the CPU all to itself.“ *MicroC/OS-II – The Real-Time Kernel*

„The scheduler, also called the dispatcher, is the part of the kernel responsible for determining which task runs next.“ *MicroC/OS-II – The Real-Time Kernel*



Writing a task in MicroC/OS-II

- Writing a task

```
void task(void *pTaskArg){
while(1){
  OSTimeDly(5);
  // do something periodically
}
} // here be dragons
```

- A task is a C function
  - needs to have a given signature
- Implements a while(1) loop
  - **never stops executing until explicitly shut down via OSTaskDelete**
- Has at least one blocking function call to allow other tasks to execute, otherwise it will prevent the execution of tasks with a lower priority

Creating Tasks and Starting the Scheduler

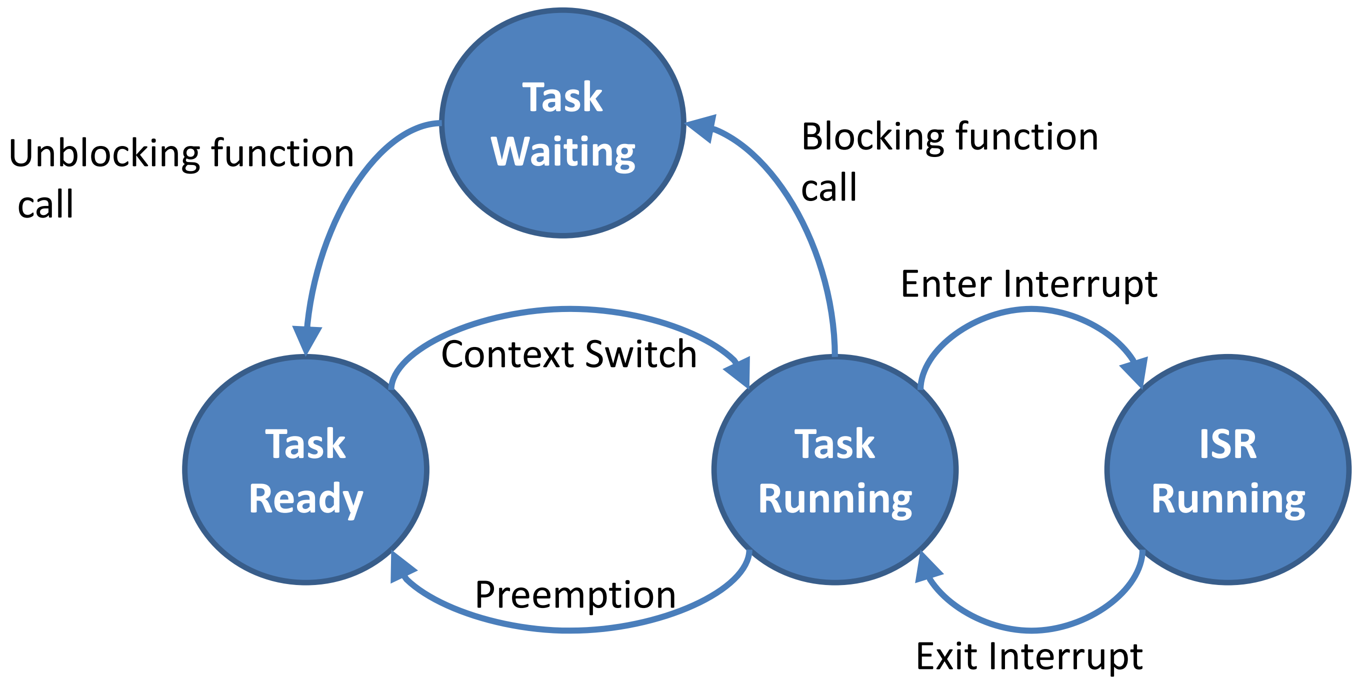
```
OS_STK stack[stacksize];          // declare stack of stacksize bytes
INT8U prio = 3;                   // declare task priority
void *pTaskArg = 0;               // no task arguments used

OSInit();                         // init OS
err8 = OSTaskCreate (
          task,                   // pointer to task function
          pTaskArg,               // pointer to task arguments
          &stack[stacksize - 1],// pointer to stack
          prio);                  // task priority
OSStart();                        // start the scheduler
```

Open Questions:

- How does a scheduler determine which task should run next?
- How does the scheduler start, stop and switch tasks, i.e. perform a context switch?
- Why does each task need a stack?

Task States (simplified)

- **Only** tasks in the **running and ready** state may be chosen by the scheduler **for execution**
- **Waiting** tasks are in a **blocking function** call, e.g. OSTimeDly or OSQPend, and have to wait for a condition to become ready



Required Steps for Context Switches

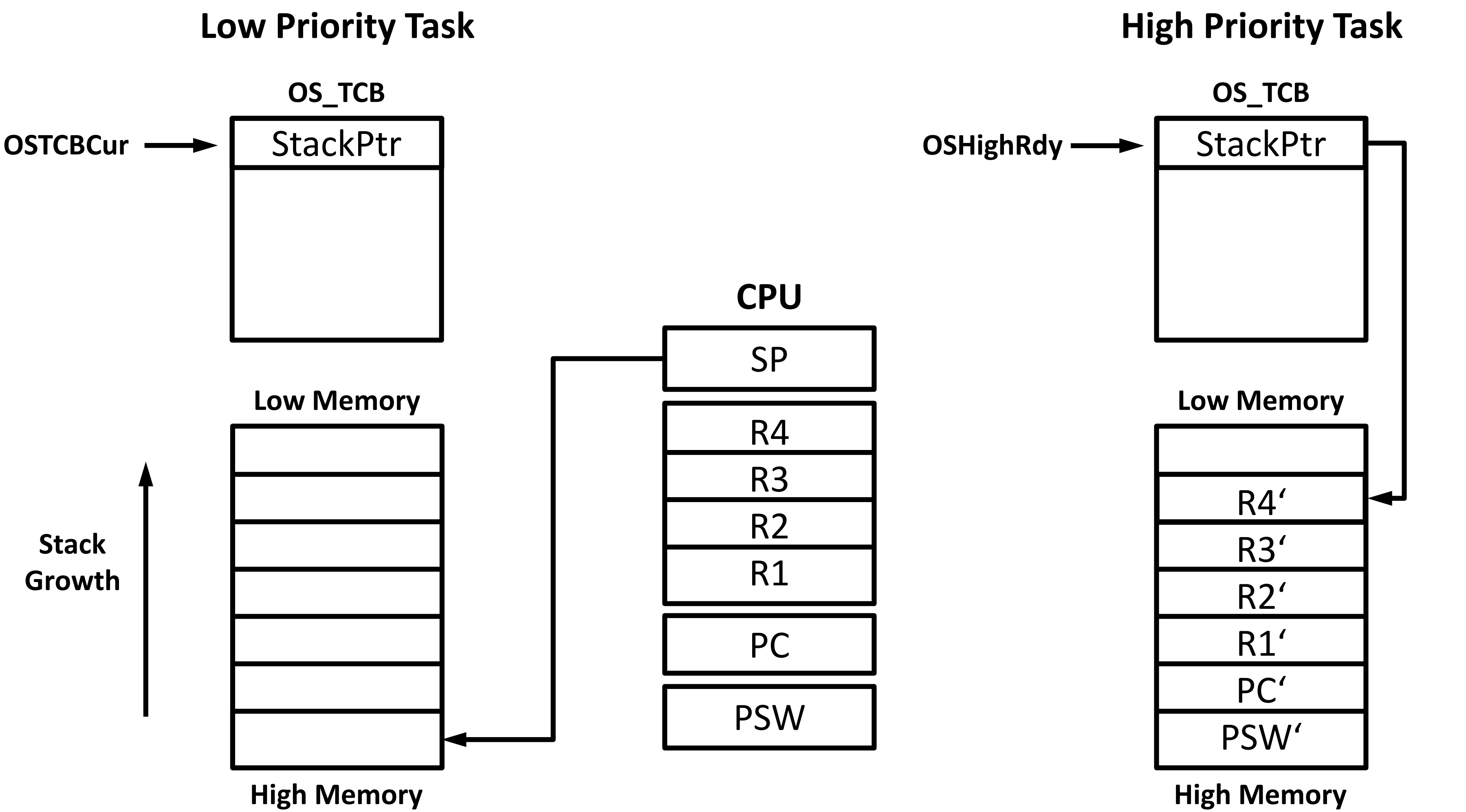
- **Interrupt** currently executing task
- **Save** the **registers** of the task to be suspended to memory
  - Program counter (PC)
  - processor status word (PSW)
  - Registers
  - Stack Pointer (SP)
- **Restore** the **registers** of the task to be resumed
- **Resume execution**

Task Control Block

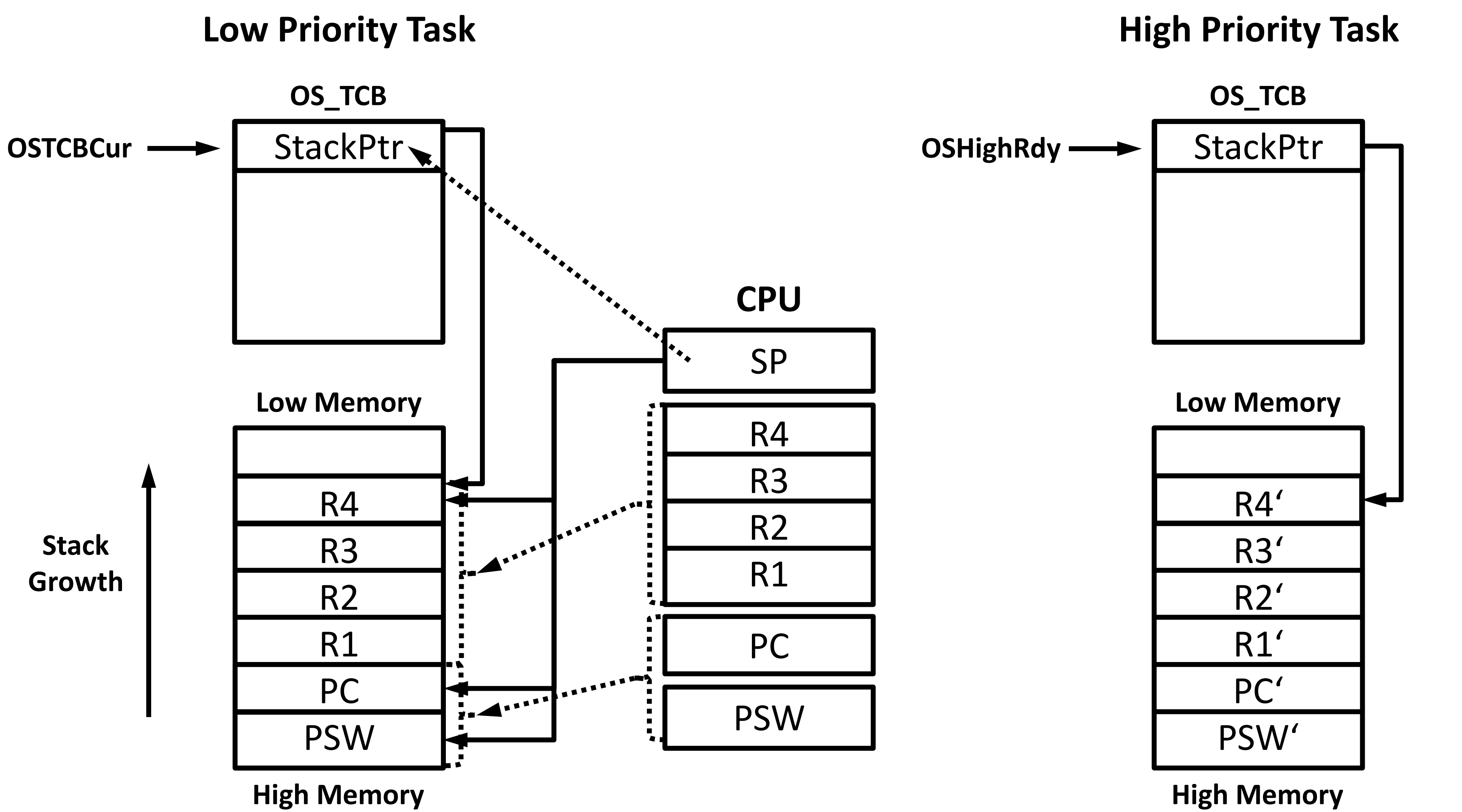
- Task Control Blocks (OS_TCB) hold a task‘s state and parameters

```
typedef struct os_tcb {
  struct os_tcb *OSTCBNext;   // Pointer to next TCB in TCB list
  struct os_tcb *OSTCBPrev;   // Pointer to previous TCB in TCB list
  INT8U OSTCBStat;            // Task state
  INT8U OSTCBPrio;            // Task priority (0 == highest)
  INT16U OSTCBDly;            // Delay ticks or timeout when waiting
  BOOLEAN OSTCBPendTO;        // Flag indicating PEND timed out
  OS_STK *OSTCBStkPtr;        // Pointer to current top of stack

  …
} OS_TCB;
```

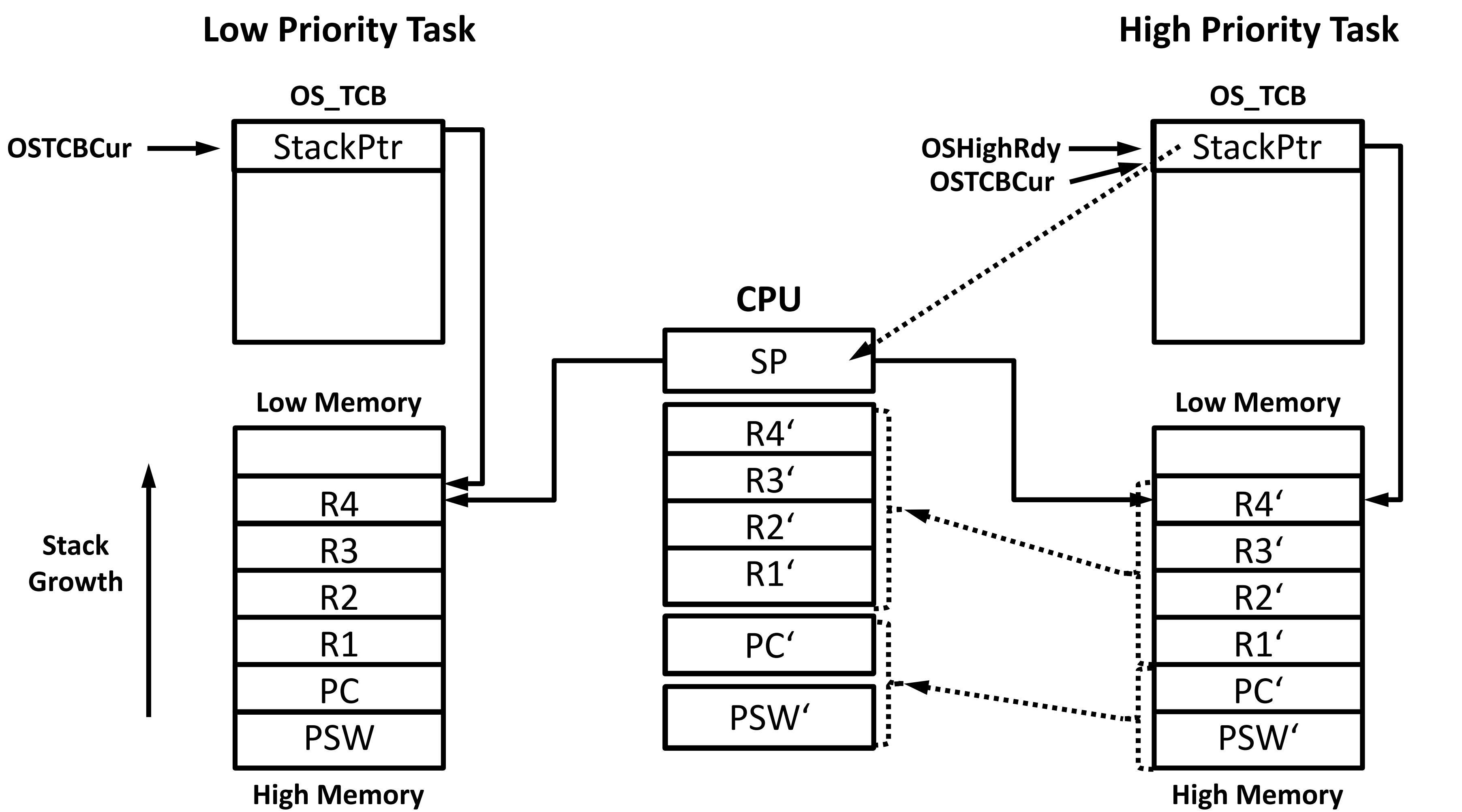
Performing a Context Switch (Preconditions)



Performing a Context Switch (Saving Context)



Performing a Context Switch (Restoring Context)



Context Switch Pseudo-Code

- Implemented as **Software-Interrupt**
  - Calling **ISR** automatically **pushes PSW** and **PC to stack**
  - **Returning** from ISR automatically **pops PSW** and **PC from stack**
- Remaining part implemented in ISR
  - Platform-dependent implementation
  - Usually written in assembly

```
PUSH R1, R2, R3, R4 onto the current stack;
OSTCBCur->OSTCBStkPtr  = SP;
OSTCBCur               = OSTCBHighRdy;
SP                     = OSTCBCur->OSTCBStkPtr;
POP R4, R3, R2, R1 from the new stack;
Execute „return from interrupt" instruction
```

Determining highest priority task ready to run

How do we determine the highest priority task, which is ready to execute?

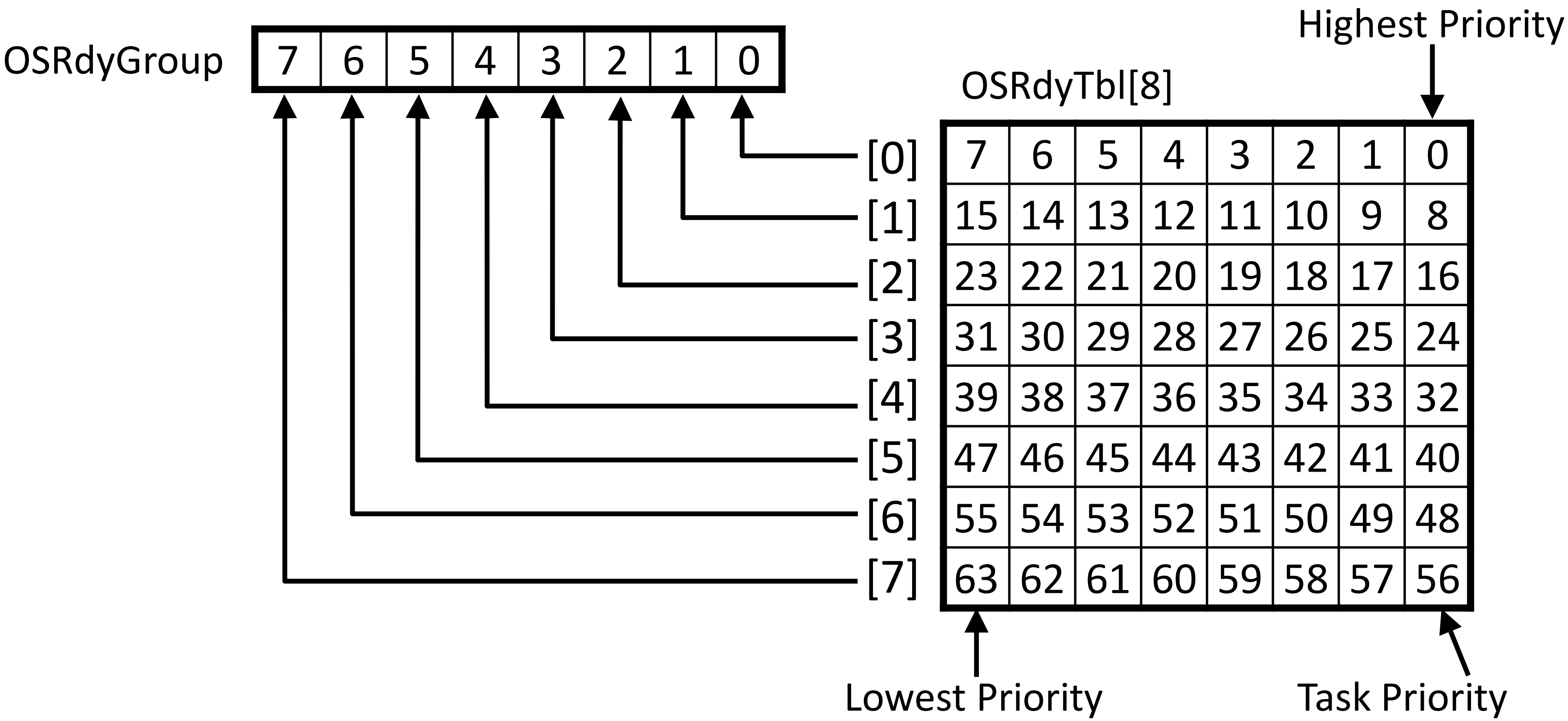
- MicroC/OS-II is targeted at real-time applications
- Determining highest priority ready task has to fulfill timing requirements
  - Time must not depend on the number of tasks → O(1)

Determining highest priority task ready to run

- **Why not** using a **list** of ready tasks sorted by priority?
  → Sorting or list parsing **cannot be done in O(1)**
  → Would **not** be **feasible for real-time** systems as execution time would depend on the number of tasks

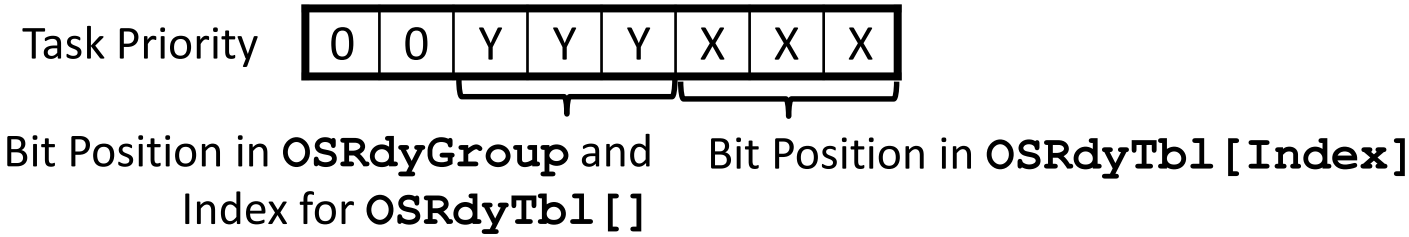
Determining highest priority task ready to run

- Each task ready to run is in a ready list consisting of two variables
  - **`INT8U OSRdyGroup`** – Bit i is set to 1 if any bit in **`OSRdyTbl[i]`** is set to 1
  - **`INT8U OSRdyTbl[8]`** – Indicates which task in the group is ready to run



Making a task ready to run

- Task's **priority** is **devided** into **2 fields**
  - 3bits for bit position in **`OSRdyGroup`** and index to **`OSRdyTbl`**
  - 3bits for bit position in **`OSRdyTbl[index]`**



- **`OSMapTbl[]`** is a precompiled table mapping **bit position to bit mask**
  - e.g. **`OSMapTbl[2]`** maps to 0b00000100

- **Code** to make a task **ready to run:**

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

Determining highest priority task ready to run

- Finding **highest priority task ready to run** through another **precompiled table**
  - `OSUnMapTbl[bitmask]` returns first bit that is one from a given bitmask
  - e.g. `OSUnMapTbl[0b00101010]` contains the value 1

- **Finding highest priority task ready to run**

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

- Some **architectures** directly **support this** technique **as assembler instructions**
  - „Count leading zeros“ -> clz
  - „Count trailing zeros“ -> ctz

OSUnMapTbl Example

```
INT8U  const  OSUnMapTbl[256] = {

    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                           */
};
```

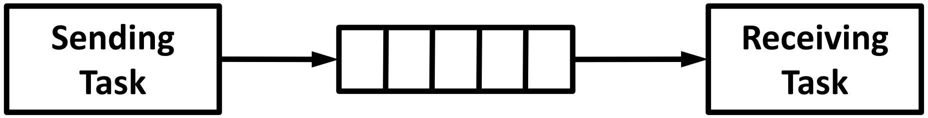
Use OSUnMapTbl to find the lowest `1` in 36

OSUnMapTbl[36] = 2
36 -> 0b00010100

COMMUNICATION

Communication through Message Queues

- Message queues allow to
  - **send** a **message** between two tasks
    i.e. pass a pointer to a memory location
  - manage messages in **FIFO** (ring buffer) and **LIFO** (stack buffer)
  - receive messages in **blocking** or **non-blocking** way



Queue Communication

- Code for message queue usage

Create Message Queue:

```
void *QMem[NumEntries];                 // memory to manage queue content
OS_EVENT MsgQ;                          // pointer to queue
MsgQ = OSQCreate(QMem, NumEntries);     // create queue
```

Sending Task:

```
void *data = &messageToSend;            // pointer to data to send
err = OSQPost(MsgQ, data);              // post pointer in queue
```

Receiving Task:

```
void *data;                             // pointer to data to receive
data = OSQPend(MsgQ, timeout, &err);    // get pointer to message
                                        // blocking method

data = OSQAccept(MsgQ,&err);            // get pointer to message
                                        // non blocking method
```

Blocking Receive from a Message Queue

- Pseudo-Code for blocking receive

```
void *OSQPend(pMsgQ, timeout, err){
if queue not empty
   acquire pointer to message from buffer
   decrement number of messages
   return message pointer
else
   set timeout for task in OS_TCB
   register queue as waiting event in OS_TCB
   call scheduler
   acquire pointer to message from buffer
   decrement number of messages
   return message pointer
}
```

OSQAccept (annotation covering the "if queue not empty" branch)

MEMORY MANAGEMENT

Memory Management in MicroC/OS-II

- Many Microkernels **do not provide dynamic memory allocation**, i.e. **`no malloc()`**
  - **not required** for many applications
  - generally **not real-time capable**, because allocation time often depends on the history of previous allocations
- Dynamic allocation of static memory

Creating a Memory Partition:

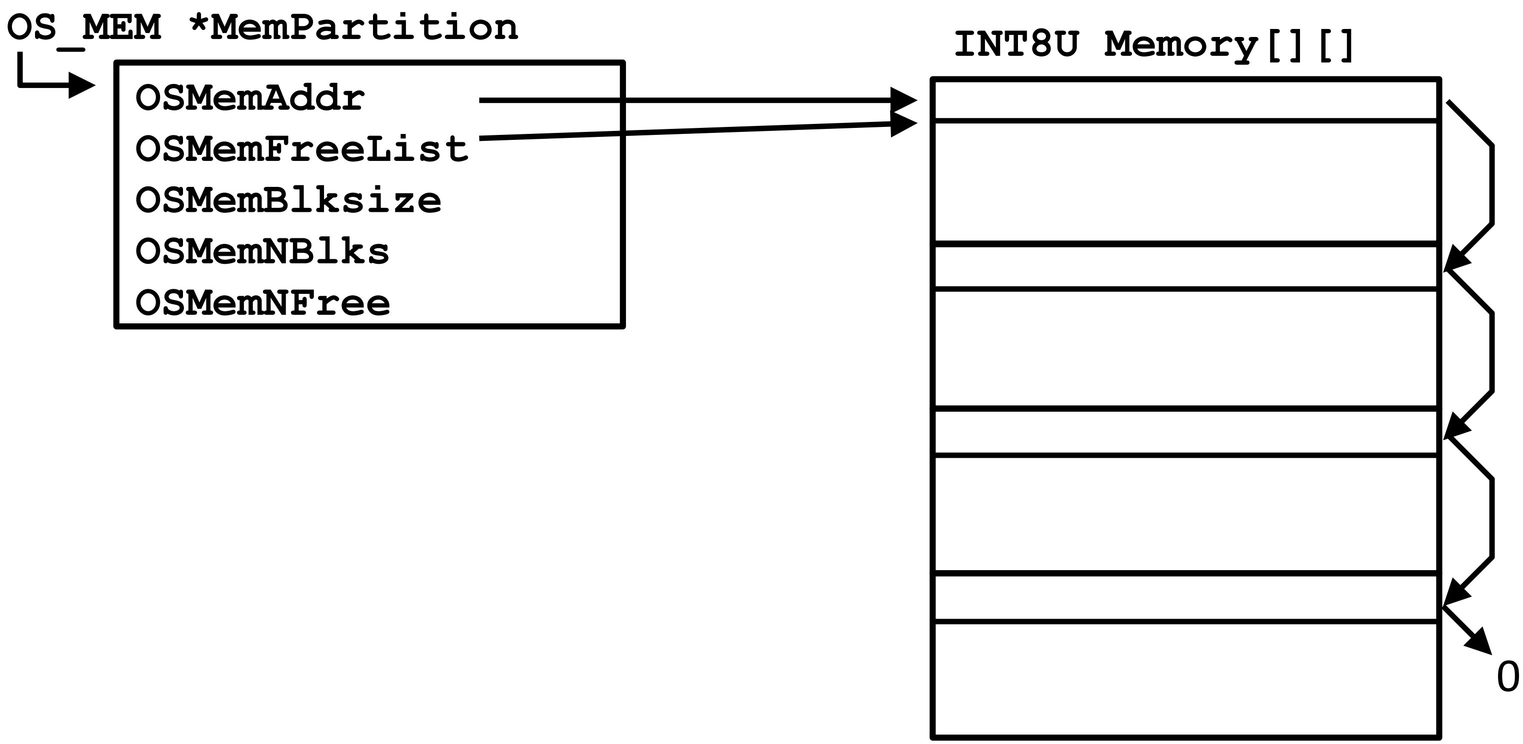
```
OS_MEM *MemPartition;                  // memory partition
INT8U  Memory[100][64];                // 6400 bytes of memory
MemPartition = OSMemCreate(Memory, 100, 64);
                                       // create memory partition with
                                       // 100 blocks of 64 byte each
```

Retrieving and Returning Memory Blocks:

```
void *memBlock;                          // pointer to memory block
memBlock = OMemGet(MemPartition, err);   // retrieve memory block
OSMemPut(MemPartition, memBlock);        // return memory block
```

Memory Management Structure

```
OS_MEM *MemPartition;                          // memory partition
INT8U  Memory[100][64];                        // 6400 bytes of memory
MemPartition = OSMemCreate(Memory, 100, 64);
                                               // create memory partition with
                                               // 100 blocks of 64 byte each
```



Properties of Memory Management

- **Static block size prevents fragmentation**
  - no defragmentation required → makes real-time implementation easier
- Management of **free blocks in list**
  - blocks are retrieved from beginning of list
  - blocks are returned to beginning of list

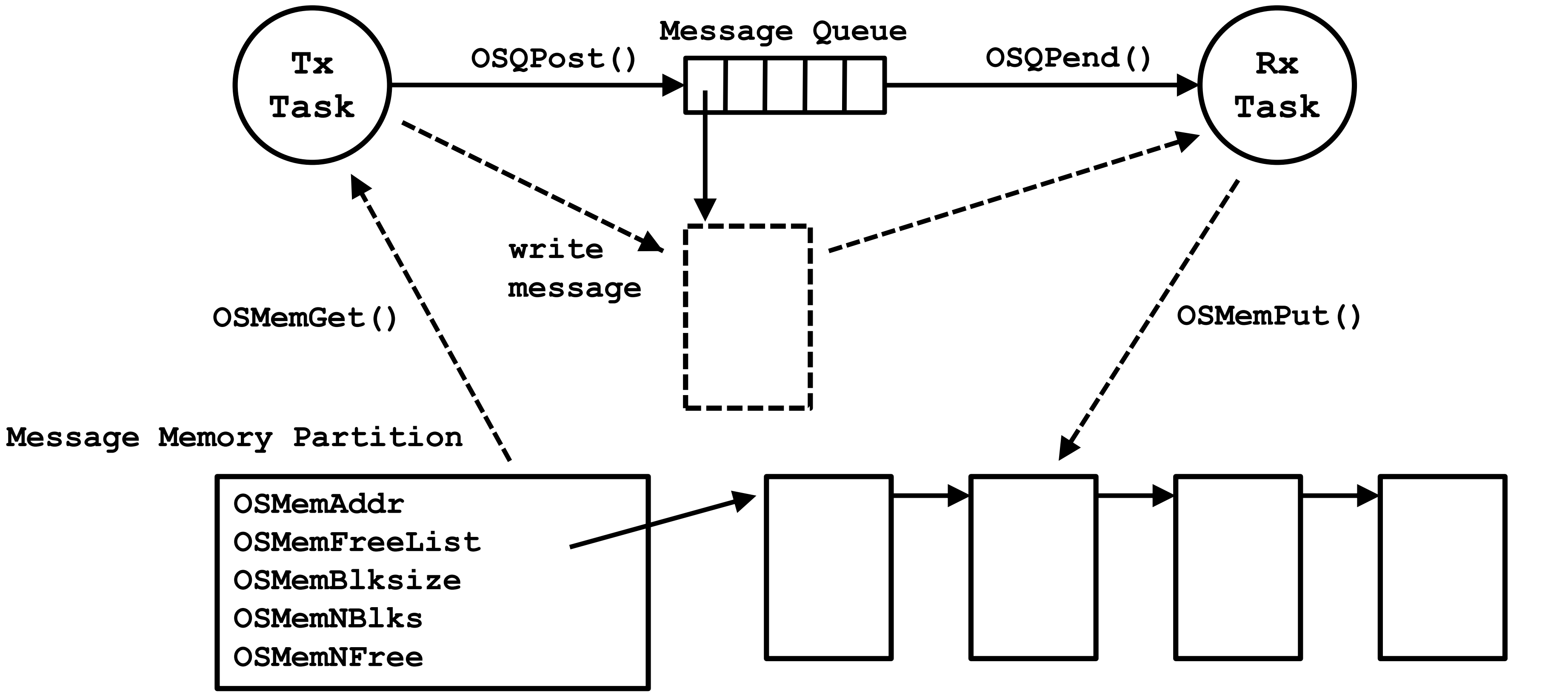
  → **O(1)** allocation and deallocation
- **Management** of blocks **within memory partition**

  → Reduction of overhead

Using Tasks, Queues and Memory Management

EXAMPLE

Example


Tx
Task
OSQPost()
Message Queue
OSQPend()
Rx
Task
write
message
OSMemGet()
OSMemPut()
Message Memory Partition
OSMemAddr
OSMemFreeList
OSMemBlksize
OSMemNBlks
OSMemNFree

Summary

- What functionality does a microkernel do?
  - Task Scheduling
  - Interrupt Handling
  - Provide Communication Primitives
  - Provide Synchronization Primitives
  - Memory Management
  - Provide Timebase
- How does scheduling in a microkernel work?
  - Performing a context switch
  - Determining highest priority task in O(1)
- Code examples on how to use a microkernel
  - Writing and starting tasks
  - Creating and using message queues
  - Creating and using memory partitions