Advanced Robot Control
Real-Time Operating System

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Presentation compiled for taking notes during lecture

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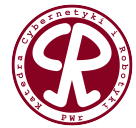

Outline

1. Operating system
   - OS support features
   - Real-Time Operating System
   - Shadowed stack pointer
   - Supervised and unsupervised mode
   - Context switching
   - Exclusive accesses
2. FreeRTOS
   - Introduction
   - Tasks
   - Mutexes
   - Queues
   - Event groups
   - Software timers
   - Heap management
3. Quiz

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Operating System (1/2)

What is an operating system?

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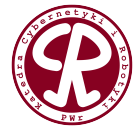

Operating System (2/2)

It is a specific software that runs in kernel mode (supervised mode) [3].

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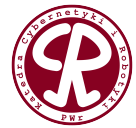

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OS support features in Cortex-M3/M4 core (1/1)

Cortex-M3/M4 support following features to facilitate the implementation of an embedded OS [4]:

- **Shadowed stack pointer**
- **SysTick timer**
- **Supervisor Call (SVC) and Pendable Service Call (PendSV) exceptions**
- **Unprivileged execution level**
- **Exclusive accesses**

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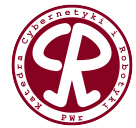

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Real-Time Operating System

The RTOS is a special kind of an operating system which focuses on time. Two groups of RTOS can be specified:

- soft real-time operating system,
- hard real-time operating system.

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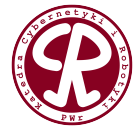

Hard RTOS

Hard real-time operating system is a specific branch of RTOS which has to meet strict time constrains.

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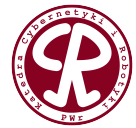

Soft RTOS

In contrast to Hard RTOS a Soft RTOS is an operating system where occasional violation of strict time regime is undesirable but will not lead to any permanent damage.

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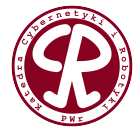

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Main Stack Pointer and Processor Stack Pointer

Figure: Stack pointer in a task [4]

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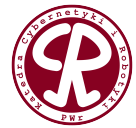

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Memory Protection Unit (1/2)

The MPU is a programmable device that can be used to define memory access permissions (e.g., privileged access only or full access) and memory attributes (e.g., bufferable, cacheable) for different memory regions [4].

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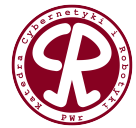

Memory Protection Unit (2/2)

The MPU can be used to make an embedded system more robust .

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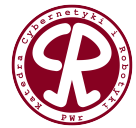

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Starting task with SVC

Figure: Initialization of a task [4]

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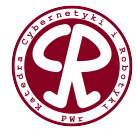

Switching task with PendSV

Figure: Context switching [4]

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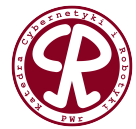

Switching task during interrupt (1/2)

Figure: Improper task switching [4]

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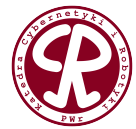

Switching task during interrupt (2/2)

Figure: Proper task switching [4]

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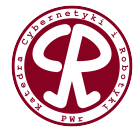

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Hardware Mutex support (1/1)

A common way to limit the access to a resource is a semaphore. It can be represented as a counter which holds a number of resource.

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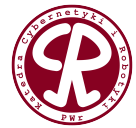

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Introduction

FreeRTOS is a real-time kernel on top of which embedded applications can be built to meet their hard real-time requirements [1].

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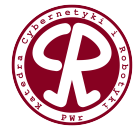

Fatures (1/1)

- Abstracting away timing information
- Maintainability/Extensibility
- Modularity
- Team development
- Easier testing
- Code reuse
- Improved efficiency
- Idle time
- Power Management
- Flexible interrupt handling
- Mixed processing requirements

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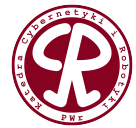

ISR dedicated API

ISR specific API

It is worthy of note that not all API can be called in ISR routines.

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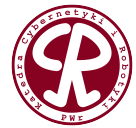

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Task states

Figure: Task switching [1]

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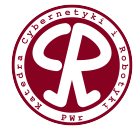

Task creation

```
1 BaseType_t xTaskCreate( TaskFunction_t pvTaskCode,
2                         const char * const pcName,
3                         uint16_t usStackDepth,
4                         void *pvParameters,
5                         UBaseType_t uxPriority,
6                         TaskHandle_t *pxCreatedTask );
```

```
1 vTaskStartScheduler();
```

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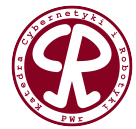

Delaying task execution

```
1 void vTaskDelay( TickType_t xTicksToDelay );
```

```
1 void vTaskDelayUntil( TickType_t * pxPreviousWakeTime,
2                       TickType_t xTimeIncrement );
```

```
1 TickType_t xLastWakeTime;
2 xLastWakeTime = xTaskGetTickCount();
```

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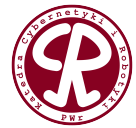

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Mutexes (1/2)

A mutex can be created using [2]

```
1 SemaphoreHandle_t xSemaphoreCreateMutex( void );
```

```
1 BaseType_t xSemaphoreTake( SemaphoreHandle_t xSemaphore,
      TickType_t xTicksToWait );
```

```
1 BaseType_t xSemaphoreGive( SemaphoreHandle_t xSemaphore );
```

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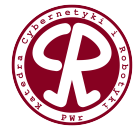

Mutexes (2/2)

During usage of mutexes a situation called *Deadlock* can arise.

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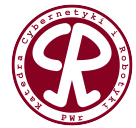

Critical section

A critical section is a region of code surrounded with

```
1  taskENTER_CRITICAL();
2  //...
3  taskEXIT_CRITICAL();
```

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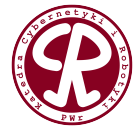

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Queues (1/3)

Queues are normally used as **First In First Out (FIFO) buffers**, where data is written to the end (tail) of the queue and removed from the front (head) of the queue.

```
1 QueueHandle_t xQueueCreate( UBaseType_t uxQueueLength,
2 UBaseType_t uxItemSize );
```

```
1 BaseType_t xQueueSendToFront( QueueHandle_t xQueue,
2 const void * pvItemToQueue,
3 TickType_t xTicksToWait );
```

```
1 BaseType_t xQueueSendToBack( QueueHandle_t xQueue,
2 const void * pvItemToQueue,
3 TickType_t xTicksToWait );
```

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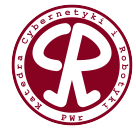

Queues (2/3)

```
1 BaseType_t xQueueReceive( QueueHandle_t xQueue,
2 void * const pvBuffer,
3 TickType_t xTicksToWait );
```

```
1 UBaseType_t uxQueueMessagesWaiting( QueueHandle_t xQueue );
```

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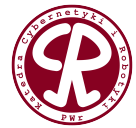

Queues (3/3)

Queue can be used as a **message box** where size of a queue is equal to 1.

```
1 BaseType_t xQueueOverwrite( QueueHandle_t xQueue,
2 const void * pvItemToQueue );
```

```
1 BaseType_t xQueuePeek( QueueHandle_t xQueue,
2 void * const pvBuffer,
3 TickType_t xTicksToWait );
```

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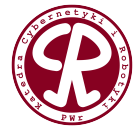

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Event groups (1/2)

Event group is a mechanism available in FreeRTOS which allows to suspend a task in a blocking state as long as a certain condition is not met.

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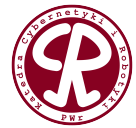

Event groups (2/2)

```
1 EventGroupHandle_t xEventGroupCreate( void );
```

```
1 EventBits_t xEventGroupSetBits( EventGroupHandle_t xEventGroup,
2 const EventBits_t uxBitsToSet );
```

```
1 EventBits_t xEventGroupWaitBits( const EventGroupHandle_t
      xEventGroup,
2 const EventBits_t uxBitsToWaitFor,
3 const BaseType_t xClearOnExit,
4 const BaseType_t xWaitForAllBits,
5 TickType_t xTicksToWait );
```

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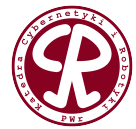

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Software timers (1/4)

Software timers can run a function (callback function) at a specific time or periodically.

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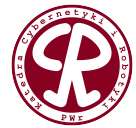

Software timers (2/4)

```
1 TimerHandle_t xTimerCreate( const char * const pcTimerName,
2 TickType_t xTimerPeriodInTicks,
3 UBaseType_t uxAutoReload,
4 void * pvTimerID,
5 TimerCallbackFunction_t pxCallbackFunction );
```

```
1 BaseType_t xTimerStart( TimerHandle_t xTimer, TickType_t
      xTicksToWait );
```

```
1 BaseType_t xTimerStop( TimerHandle_t xTimer, TickType_t
      xTicksToWait );
```

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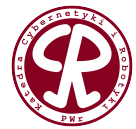

Software timers (3/4)

```
1 void vTimerSetTimerID( const TimerHandle_t xTimer, void *pvNewID
      );
```

```
1 void *pvTimerGetTimerID( TimerHandle_t xTimer );
```

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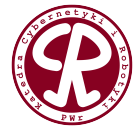

Software timers (4/4)

```
1 BaseType_t xTimerChangePeriod( TimerHandle_t xTimer,
2 TickType_t xNewTimerPeriodInTicks,
3 TickType_t xTicksToWait );
```

```
1 BaseType_t xTimerReset( TimerHandle_t xTimer, TickType_t
      xTicksToWait );
```

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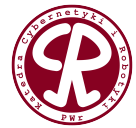

State machine for one shoot sw timer (1/1)

Figure: One-shot software timer states and transitions [1]

State machine for auto-reload sw timer (1/1)

Figure: Auto-reload software timer states and transitions [1]

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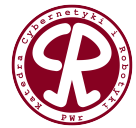

Plan

1. Operating system
   - OS support features
   - Real-Time Operating System
   - Shadowed stack pointer
   - Supervised and unsupervised mode
   - Context switching
   - Exclusive accesses
2. FreeRTOS
   - Introduction
   - Tasks
   - Mutexes
   - Queues
   - Event groups
   - Software timers
   - Heap management
3. Quiz

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Heap implementations

In FreeRTOS a number of heap implementations is available:

- **Heap_1**
- **Heap_2**
- **Heap_3**
- **Heap_4**
- **Heap_5**

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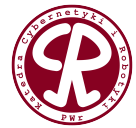

Quiz (1/1)

Calculate group number as the rest from dividing the Student ID number by 4.

Example

Student ID number is 123456, thus the group is 0.
Take last 2 digits from Student ID number (56) and calculate the rest from dividing by 4 (56 % 4 = 0).

Write down your name, Student ID number and group.

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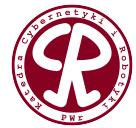

Literature (1/2)

R. Barry.
Mastering the FreeRTOS^{TM} Real Time Kernel.
Real Time Engineers Ltd., 2016.

Amazon Web Services.
The FreeRTOS^{TM} Reference Manual, API Functions and Configuration Options.
Amazon.com Inc., 2017.

A. S. Tanenbaum and H. Bos.
Moder Operating systems.
Pearson, 2014.

J. Yiu.
The Definitive Guide to ARM® Cortex®-M3 and Cortex®-M4 Processors.
Newnes, 2013.

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Literature (2/2)

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