Resource Sharing in Real-time Microkernels
– Training: real-time, embedded and concurrent programming –

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Outline

1. Introduction
2. Task Synchronization
3. Stack Resource Policy in microC/OS-II
4. Conclusions
An embedded system typically has:
- a simple microcontroller (e.g. TI MSP-430x1611);
- very limited resources, especially RAM (∼ 10 kB);
- peripherals to be controlled.
Introduction to Microkernels

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A RTOS provides:
- abstractions (e.g. tasks and synchronization primitives);
- interaction between hardware and application;
- simplified debugging;
- I/O libraries (support for platform hardware).
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Microkernel objective

Provide a reduced, configurable system that fits on a typical system-on-chip.
microC/OS-II Basics

microC/OS-II is

- a commercial RTOS;
- targeted at embedded systems;
- open source;

It provides

- a portable and configurable kernel;
- a fixed-priority, preemptive task scheduler;
- basic synchronization services.
The scheduler selects the *highest-priority, ready task*. 
At each time instant a task must have a unique priority.
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Disable and enable interrupts
- share variables or data structures with an ISR.

Software events:
- Mailboxes: communicate messages between tasks; FIFO or Priority-based.
- Flags: synchronize the occurrence of multiple events.
- (Counting) semaphores: e.g. signaling of tasks.
- Mutexes: resolve priority inversion.

Blocking for an event means keeping track of waiting tasks!
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Blocking for an event means keeping track of waiting tasks!
The easiest and fastest way to gain exclusive access to a shared resource is by disabling and enabling interrupts.
MicroC/OS-II: Disable and Enable Interrupts

The easiest and fastest way to gain exclusive access to a shared resource

Be careful, because:

- disabling interrupts for too long affects the response to interrupts (i.e. interrupt latency);
- a non-preemptive system becomes easily not schedulable.
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- it is the only way that a task can share variables or data structures with an ISR;
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**However,**
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*Keep interrupts disabled for as little time as possible!*
Mutual Exclusion: Priority Inversion Problem

The price of increased preemptiveness:

What really happened on Mars Rover Pathfinder?
Mutual Exclusion: Priority Inheritance Protocol

A solution:

![Diagram showing the Priority Inheritance Protocol](image-url)
Mutual Exclusion: Priority Inheritance Protocol

A solution:

Multi-resource issues:
- deadlocks;
- chained-blocking.
Priority calling is similar to *priority inheritance protocol* (PIP):

**Priority Inheritance Rule:**
when a higher-priority task blocks on a resource, the lower-priority task holding the resource inherits the higher priority;
microC/OS-II’s mutexes: Priority calling

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**It is not:** Highest Locker Protocol (HLP) or Stack Resource Policy (SRP).

- microC/OS-II: a task inherits a higher priority *only* when a higher priority task is blocked;
- in HLP/SRP a task immediately inherits a priority *when it locks a resource.
microC/OS-II’s synchronization protocol suffers from deadlock:

Legend:
- active
- holding
- mutex

Conclusion:
microC/OS-II implements a non-transparent, priority-inheritance protocol; But in other OSes...

microC/OS-II: protocol classification

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D. Polock and D. Zobel.
Conformance testing of priority inheritance protocols.
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Each resource has a statically determined *resource ceiling*:

The maximum priority of any task that could use the resource.
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A task can only be selected for execution if

1. it has the highest priority among all ready tasks;
2. its priority is higher than the current system ceiling.
SRP provides non-blocking primitives:

- blocking occurs upon an attempt to preempt, rather than upon an attempt to access a resource (no wait queues).
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- it therefore allows tasks to share their execution stack;

Sharing of the execution stack is possible, if two tasks execute non-interleaved.
Intermezzo: SRP is Non-blocking

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- Why does stack-sharing not work in microC/OS-II?
SRP is non-transparent:
- similar to microC/OS-II’s PIP-like implementation.
- each resource has a statically computed ceiling
  (represents the highest priority task that uses the resources).
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Maintaining the system ceiling can be implemented using a stack data structure:
- we stack the resource ceilings of used resources in a monotonically increasing order;
- the top of the stack represents the system ceiling.
microC/OS-II: Our SRP extension

Deadlocks are resolved when critical sections are properly nested:

Legend:
- active
- holding
- mutex

Task1
Task2
Idle

Legend:
- active
- holding
- mutex

Easy implementations (approx. 170 lines of code); Extended microC/OS-II scheduler with SRP's preemption rule.

Martijn van den Heuvel (TU/e, SAN)
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- Easy implementations (approx. 170 lines of code);
- Extended microC/OS-II scheduler with SRP’s preemption rule.
Alternative SRP implementation

Assuming fixed-priority scheduling:

Immediate Priority Ceiling exhibits the same execution behavior as SRP

Instead of changing the scheduler:

- **Lock**: raise a task’s priority equal to the resource ceiling;
- **Unlock**: restore a task’s priority.
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**Note 1:** Immediate Priority Ceiling == Highest Locker Protocol!

**Note 2:** Add the priority inheriting task in the ready queue before the blocking task!

**Note 3:** SRP/IPC/HLP do not need waiting lists of blocked tasks!
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Conclusions

We presented:

- an overview of microC/OS-II’s task-communication methods;
- a classification of microC/OS-II’s priority-inversion protocol;
- an efficient task-level SRP implementation;
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Keep in mind:

- Make a minimal number of modifications to MicroC/OS-II;
- Keep durations of disabled interrupts short and predictable;
- Be aware of the consequences of blocking.
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Extending a HSF-enabled open-source real-time operating system with resource sharing.
Questions

1. What are the disadvantages of SRP compared to PIP?

2. What are the (dis)advantages of both SRP implementation methods?

3. Implement SRP in microC/OS-II.

4. Make 3 test-cases and exchange the test-cases with your neighbor.

5. Make a test application with at least two tasks that need mutual exclusive access to the UART device, i.e. two concurrent tasks try to print a string to the serial port.