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Improving the performance of execution time control by using a hardware Time Management Unit

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Summary

- Ada 2012 brings execution time control for interrupt handling

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- Makes low overhead even more important

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- Makes low overhead even more important
- Designed specialized Time Management Unit (TMU)
- Shown to significantly reduce execution time control overhead

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Outline

Background and motivation

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Execution time control for interrupt handling

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Execution time control for interrupt handling

Implementation of Ada 2012 execution time control

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Time Management Unit (TMU)

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Conclusion

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Worst-case execution time (WCET)

- Need WCET for scheduling analysis

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- Branch-prediction and speculative execution
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- Using WCET as budget $\implies$ low utilization

Execution time control

— Dynamic control – not just static analysis

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- *Mechanism*:
  - Execution time measurement and monitoring
  - Handler called when timer expires

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  - Support advanced scheduling policies. . .

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- *Policy*:
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    - Support advanced scheduling policies. . .
- Still need some timing analysis for budgets

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Ada 2005 execution time control

— Execution time measurement for tasks:

- Package Ada.Execution_Time
- Type CPU_Time and function Clock

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- Ravenscar – no timers or group budgets

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  - Implementations charge interrupted task
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— Also apply to other languages, POSIX…

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Interrupt execution time control

— Is it right to charge interrupted task?

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Interrupt execution time control

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- Separate execution time measurement:
  - Improves accuracy for tasks
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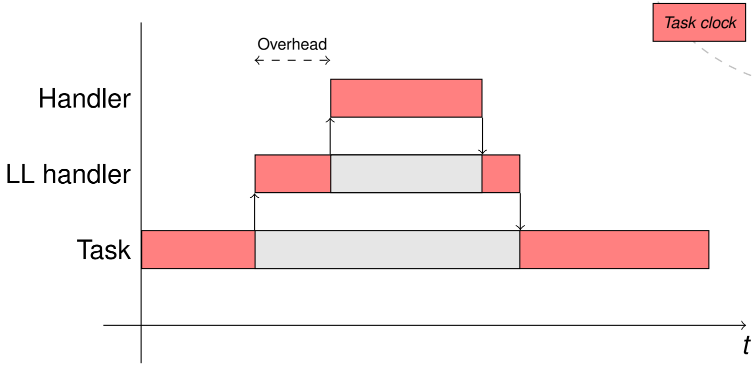
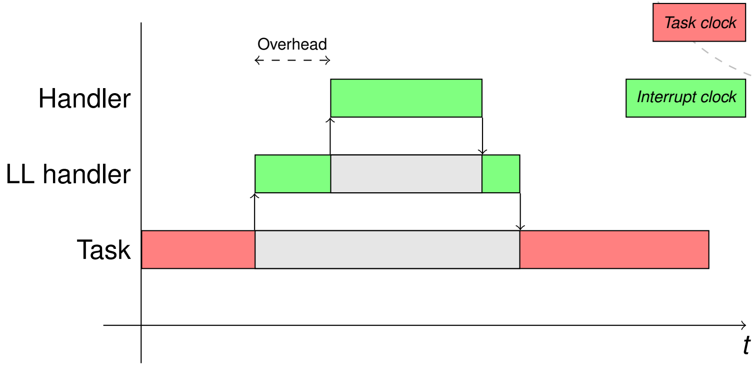
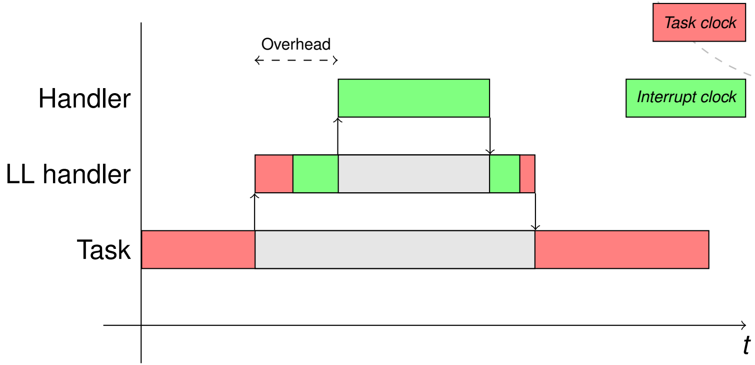
Interrupt handling



Interrupt handling – ideal



Interrupt handling – reality



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Ada 2012 execution time control

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- Implemented on GNATforAVR32
- Initially used interrupt *priorities*
- Updated to Interrupt_Id after discussion

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- Workshop forwarded both proposals
- Now in draft for ISO-standard **Ada 2012**!

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Ada 2012 execution time control

```
package Ada.Execution_Time is

    ...

    Interrupt_Clocks_Supported : constant Boolean :=
        implementation−defined;

    Separate_Interrupt_Clocks_Supported : constant Boolean :=
        implementation−defined;

    function Clock_For_Interrupts return CPU_Time;

private
     ...
end Ada.Execution_Time;
```

Ada 2012 execution time control

```
with Ada.Interrupts;

package Ada.Execution_Time.Interrupts is

    function Clock (Interrupt  :  Ada.Interrupts. Interrupt_Id )
         return CPU_Time;

    function Supported (Interrupt :  Ada.Interrupts. Interrupt_Id )
         return Boolean;

end Ada.Execution_Time.Interrupts;
```

Interrupt timer proposal

```
with Ada.Execution_Time.Timers;

package Ada.Execution_Time.Interrupts.Timers is

   type Interrupt_Timer (I  :  Ada.Interrupts. Interrupt_Id )
      is  new Ada.Execution_Time.Timers.Timer
     (Ada.Task_Identification.Null_Task_Id'Access)
     with private;

private
    ...
end Ada.Execution_Time.Interrupts.Timers;
```

— Implemented in GNATforAVR32

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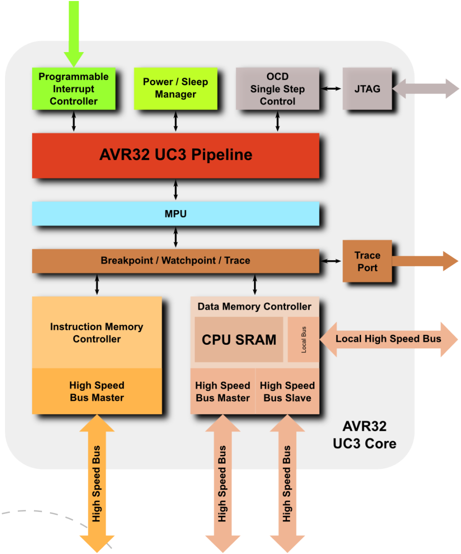
— Not to be included in Ada 2012…

Atmel AVR32 UC3 series



— Atmel AVR32 architecture:

- 32-bit RISC
- Efficient ISA
- 4 interrupt levels
- Atmel Norway

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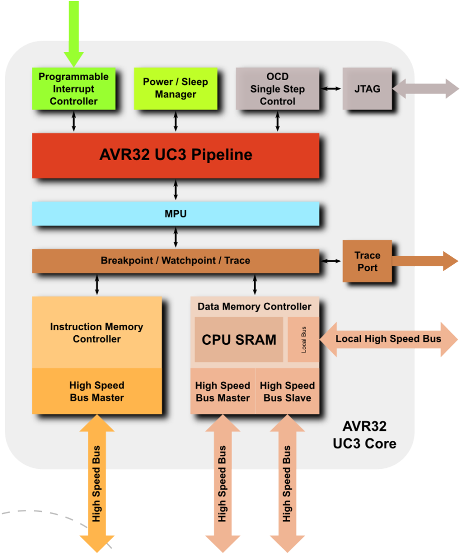

- Atmel AVR32 architecture:
  - 32-bit RISC
  - Efficient ISA
  - 4 interrupt levels
  - Atmel Norway
- UC3 microcontroller series:
  - Second implementation
  - Embedded control apps.
  - Integrated SRAM
  - 16 to 64 KB SRAM
  - Up to 60 MHz

GNATforAVR32

— GNU Ada Compiler (GNAT) for AVR32 architecture:

- GNU Compiler Collection (GCC)
- GNAT front-end → AVR32 back-end

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- Bare-board Ravenscar run-time environment:
  - Open Ravenscar Kernel by UPM
  - Used by ESA’s LEON space application processor
  - Real-time kernel integrated with GNARL
  - Ported to UC3 microcontroller series

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  - Ported to UC3 microcontroller series
- Small code size – low memory requirements

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Ada 2012 implementation

— Similarities between RTC and execution time clocks:

- Same clock and alarm abstraction
- Use the COUNT / COMPARE timer for both clocks
- Reset and reprogram on clock change
- Tick-less clocks

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— Low overhead – *can it be further reduced?*

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Time Management Unit (TMU)

— HW timer specialized for execution time control:

- 64-bit COUNT / COMPARE registers
- Interrupt line asserted when COUNT $\geq$ COMPARE
- Atomic swapping of COUNT / COMPARE values
- Triggered by write to final swap register

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- Functional specification in SystemC

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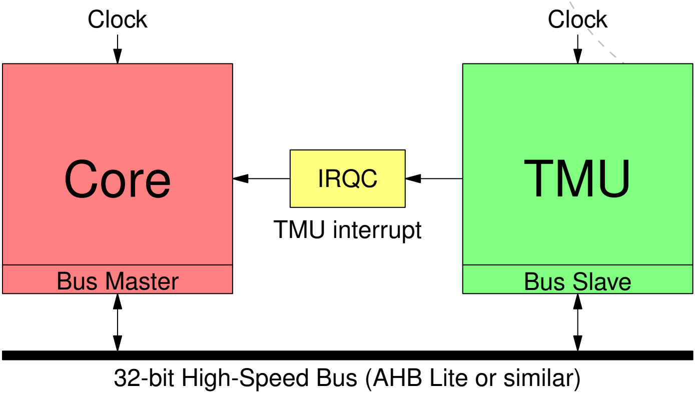
Overview



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Memory map

Offset	Register	Reset state
0x00	TMU_COMPARE_HI	0xffffffff
0x04	TMU_COMPARE_LO	0xffffffff
0x08	TMU_COUNT_HI	0
0x0c	TMU_COUNT_LO	0
0x10	TMU_SWAP_COMPARE_HI	0xffffffff
0x14	TMU_SWAP_COMPARE_LO	0xffffffff
0x18	TMU_SWAP_COUNT_HI	0
0x1c	TMU_SWAP_COUNT_LO	0

TMU implementation for UC3

— Implemented for UC3 by master student:

- High-speed bus → peripheral bus
- Bound to peripheral bus clock for synchronous design
- Interface like other AVR32 peripherals
- Interrupt control registers
- Disabled by default

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— Possible to use local CPU bus

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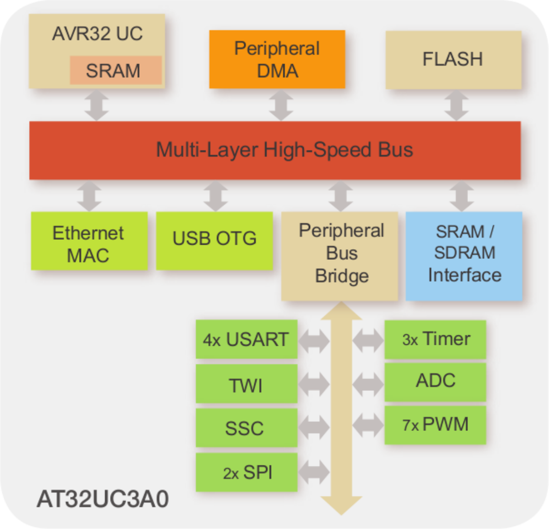

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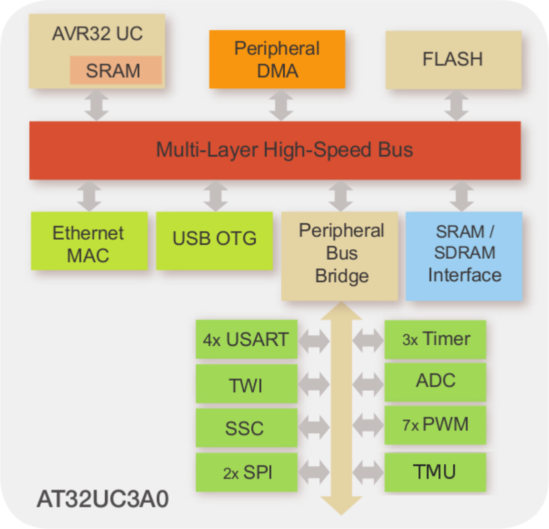

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Ada 2012 implementation with TMU

- Take advantage of powerful AVR32 instructions:
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  - Atomic access to COUNT / COMPARE
  - Load / store several registers
  - Efficient swap operation

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— Only few changes needed in run-time environment:

- Interface to TMU
- Clock interface → two HW clocks
- Context switch

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- Only few changes needed in run-time environment:
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  - Clock interface → two HW clocks
  - Context switch
- Tested with synthesizable UC3 code

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Performance improvements

Test	Improvement	
	CPU cycles	Reduction (%)
Context switch	65	54
Interrupt handler	30	25
Timing event	4	4
Interruption cost	42	21

— Compared to implementation without TMU

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- Compared to implementation without TMU
- Significant overhead reductions

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— Time Management Unit:

- Specialized 64-bit timer for execution time control
- Implemented and tested with AVR32 UC3
- Significantly reduces overhead

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