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A. Zuepke

AUTOBEST:

A United AUTOSAR-OS And ARINC 653 Kernel

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Motivation

- Automotive and Avionic industry begin to face similar challenges:
  - Hyper integration: increasing HW & SW complexity
  - Energy consumption
  - Certification effort
  - Cost pressure
  - Security issues

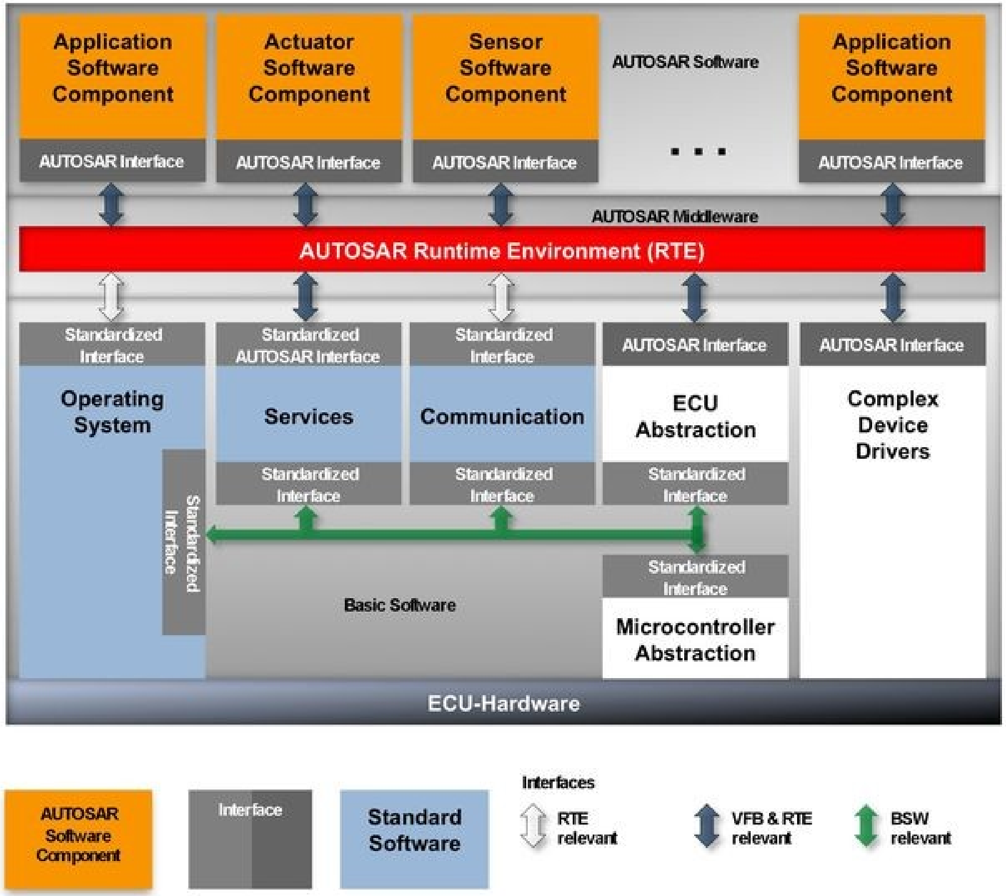
Motivation

- Automotive and Avionic industry begin to face similar challenges:
  - Hyper integration: increasing HW & SW complexity
  - Energy consumption
  - Certification effort
  - Cost pressure
  - Security issues
- But both industries use different OS standards!
  - Can't we challenge this with a single, unified operating system?
  - Combine avionics safety with the resource-efficiency of automotive systems?
  - And (probably) make it faster than existing systems?

Outline

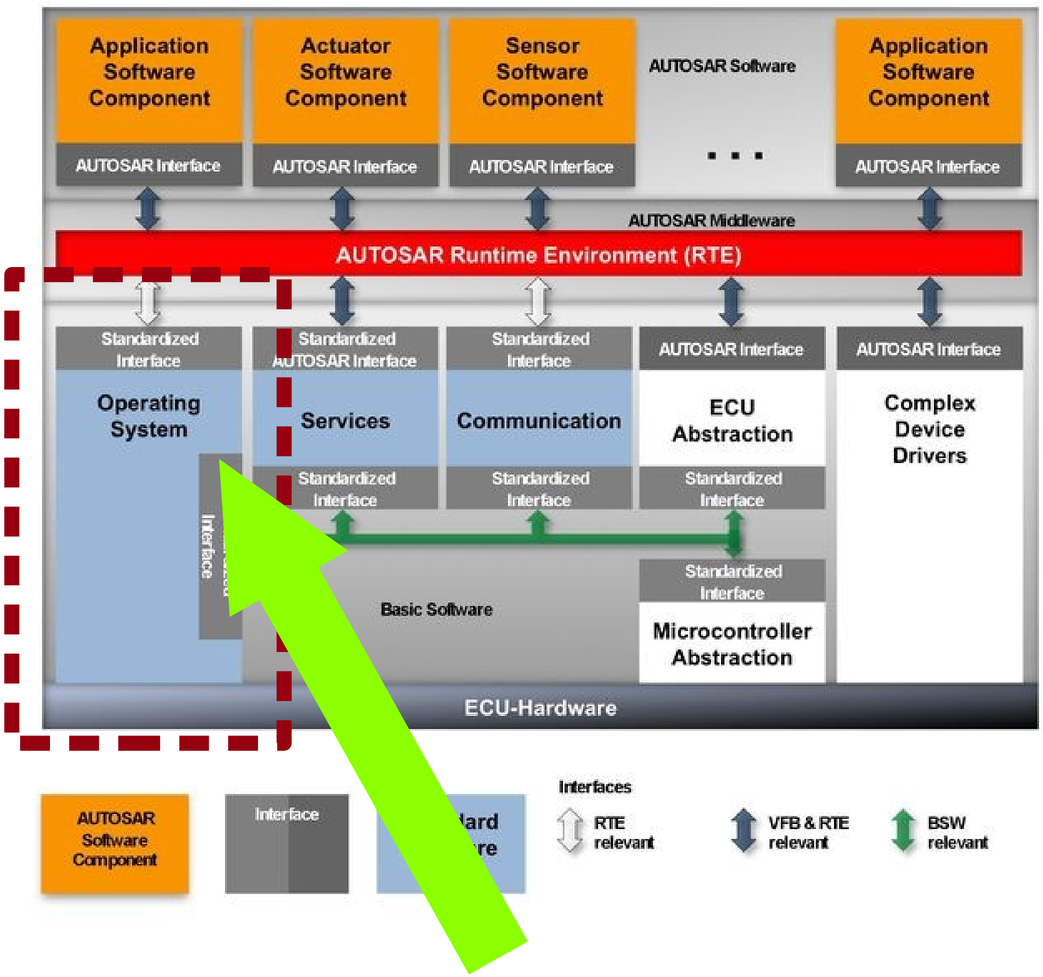
- AUTOSAR and ARINC 653
  - Short introduction
  - Task models
  - Partitioning concepts
  - Challenges
- AUTOBEST
  - Architecture
  - Lazy priority switching
  - Static Futexes
- Conclusions & Outlook

AUTOSAR



Source: http://www.autosar.org

AUTOSAR



OS Concepts:

- Tasks
- ISRs
- Event driven
- Fixed-priority scheduling
- Statically configured at compile time
- Isolation: group tasks into OS-Applications

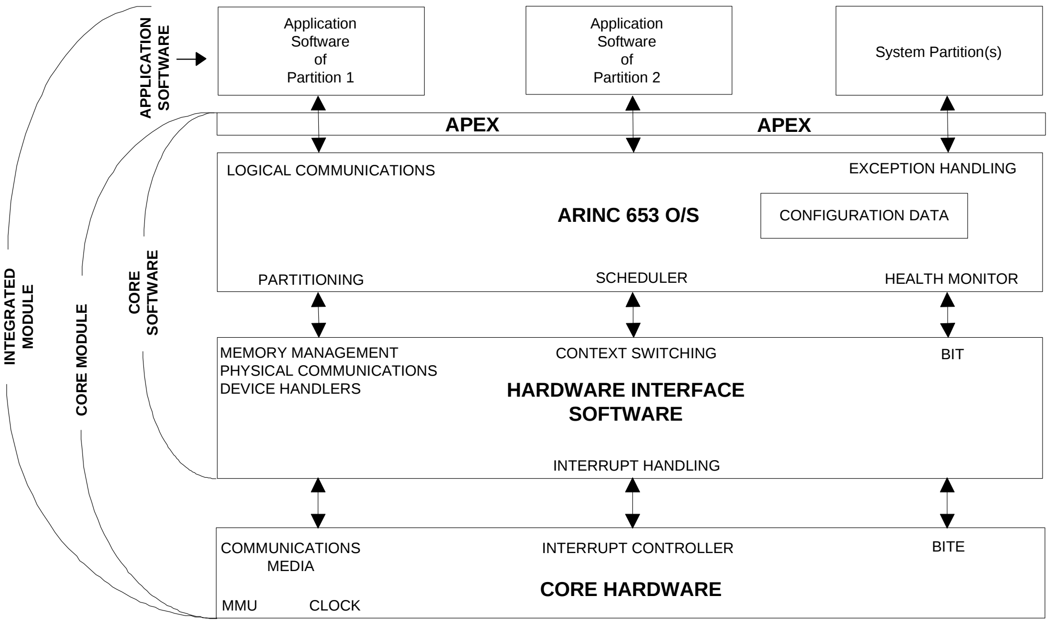
Here: focus on AUTOSAR-OS, the OS kernel

Source: http://www.autosar.org

ARINC 653

ARINC 653 Standard:

- Part 1 - Required Services
- Part 2 - Extended Services
- Part 3 - Conformity
- Part 4 - Subset Services



Source: ARINC 653 specification

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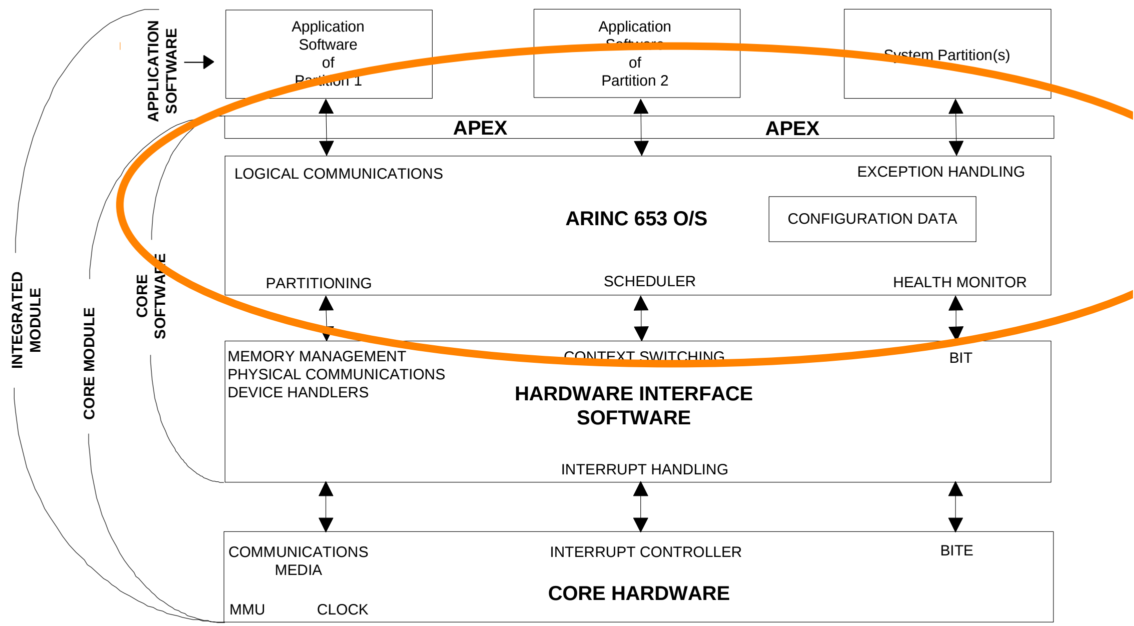
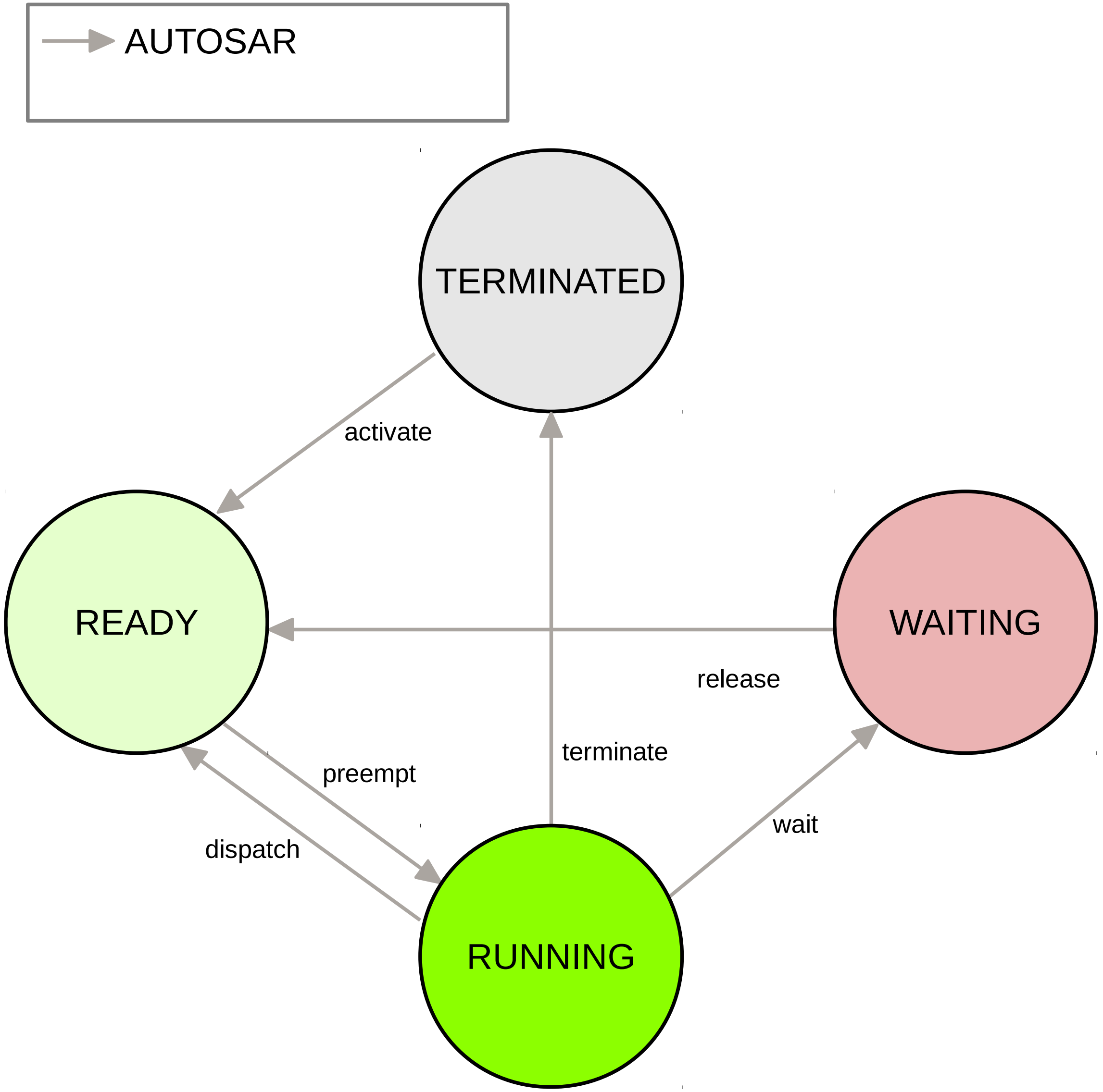


OS Concepts:

- Robust partitioning in space and time
- *Processes* (=Tasks) as executing entities
- Time driven and event driven
- Fixed-priority task scheduling, TDMA partition scheduling
- Task synchronization and partition communication means

Source: ARINC 653 specification

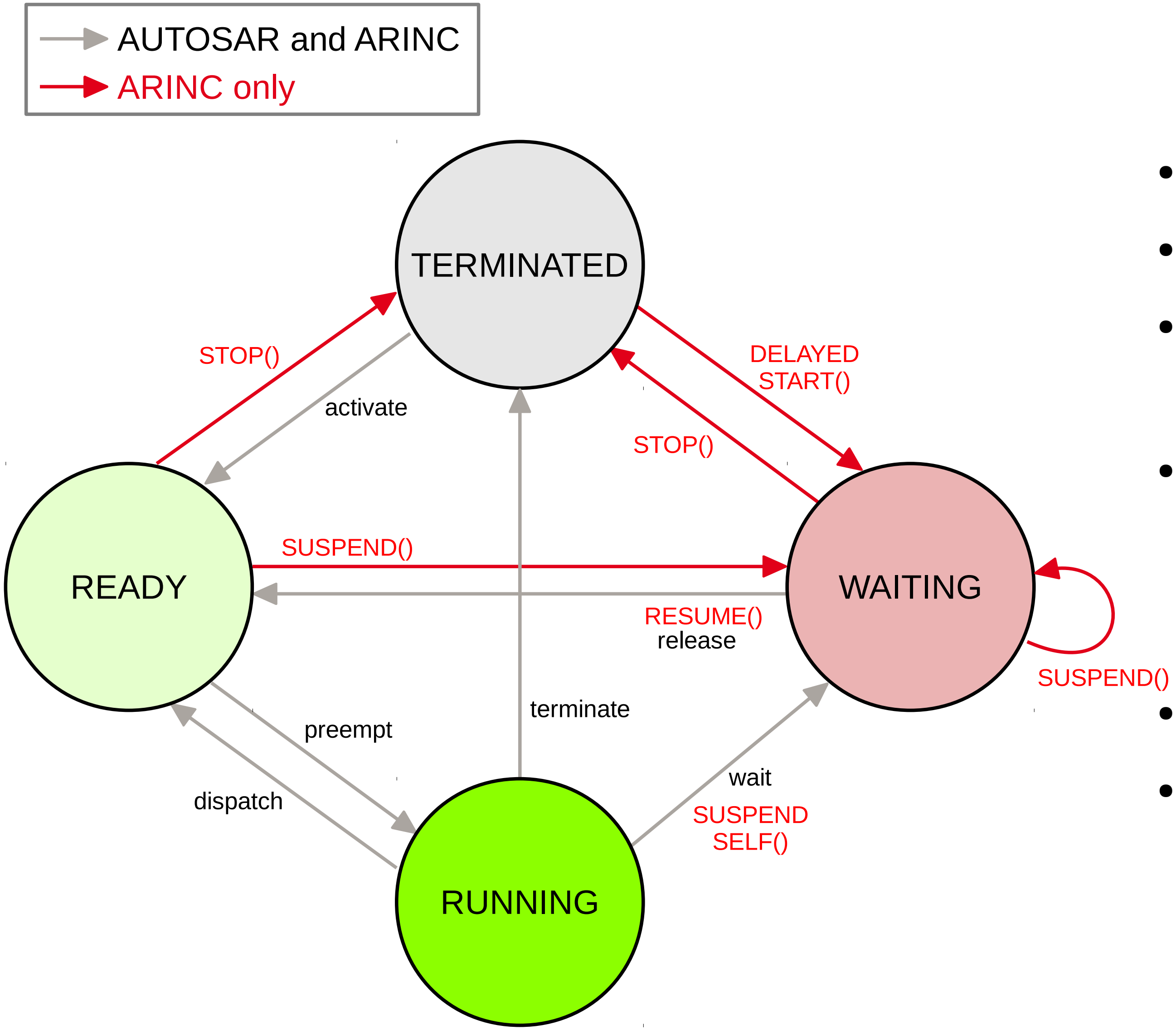
Task Model



AUTOSAR

- 4 task states
- Preemptive scheduling
- Waiting:
  - per-task event bitmask
- A task terminates when its job is complete

Task Model



AUTOSAR

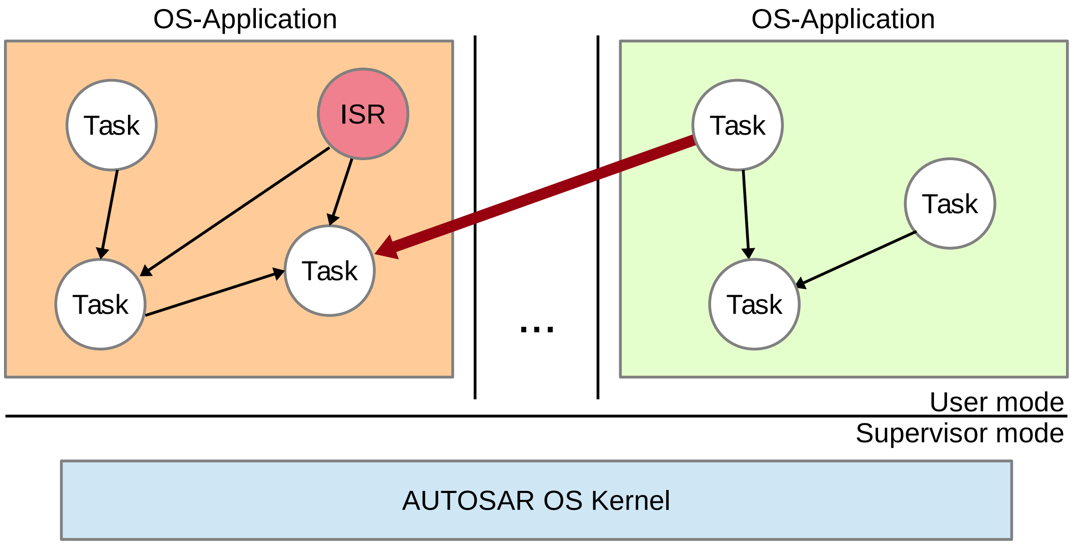
- 4 task states
- Preemptive scheduling
- Waiting:
  - per-task event bitmask
- A task terminates when its job is complete

ARINC 653

- Additional transitions
- Waiting:
  - Single-bit events
  - Semaphores
  - Buffers and blackboards
  - Queuing and sampling ports

Separation & Isolation

- AUTOSAR
  - *OS-Applications*
  - Optional concept
  - Memory protection
  - Configurable access to objects in other Applications



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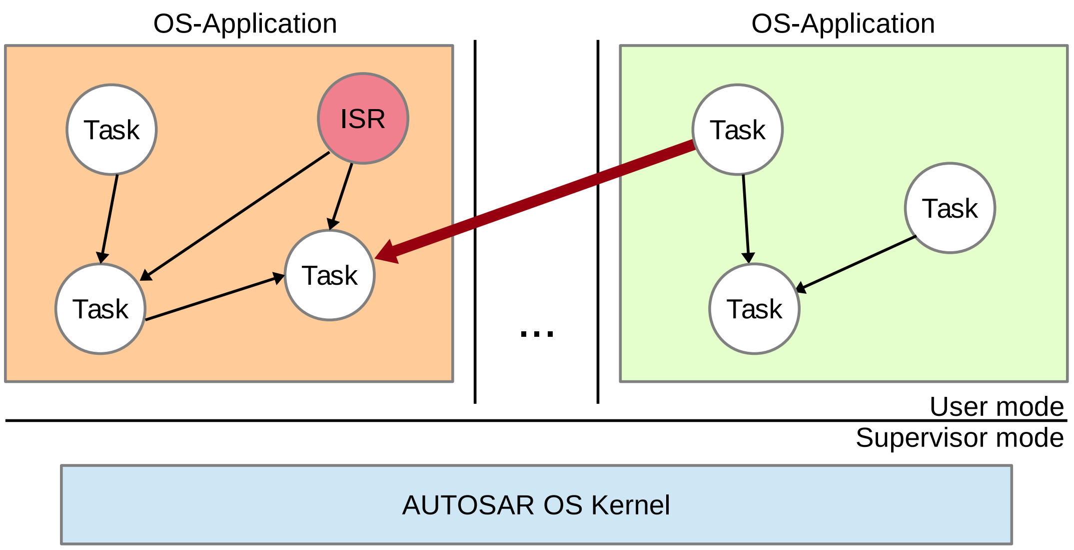
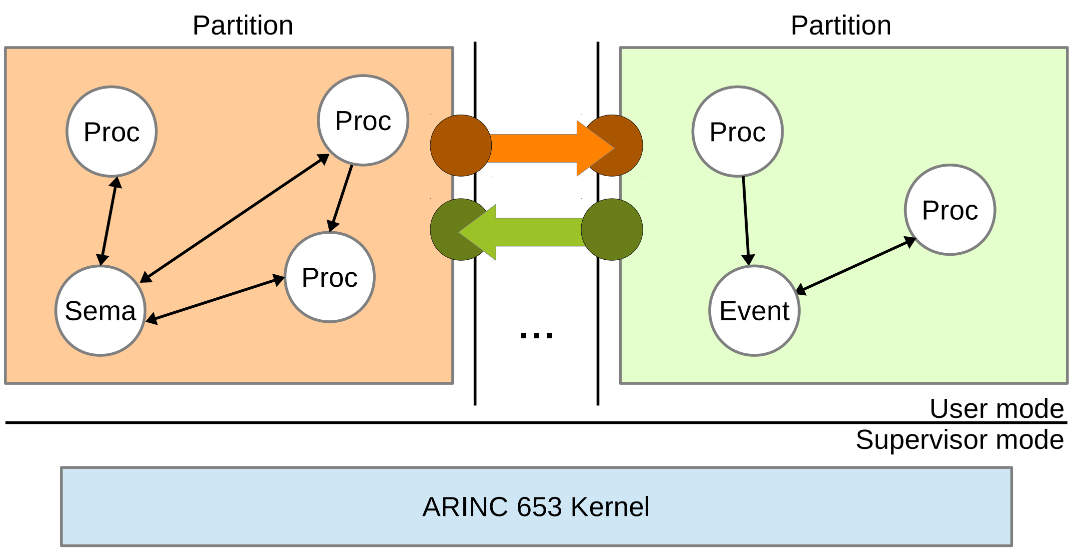
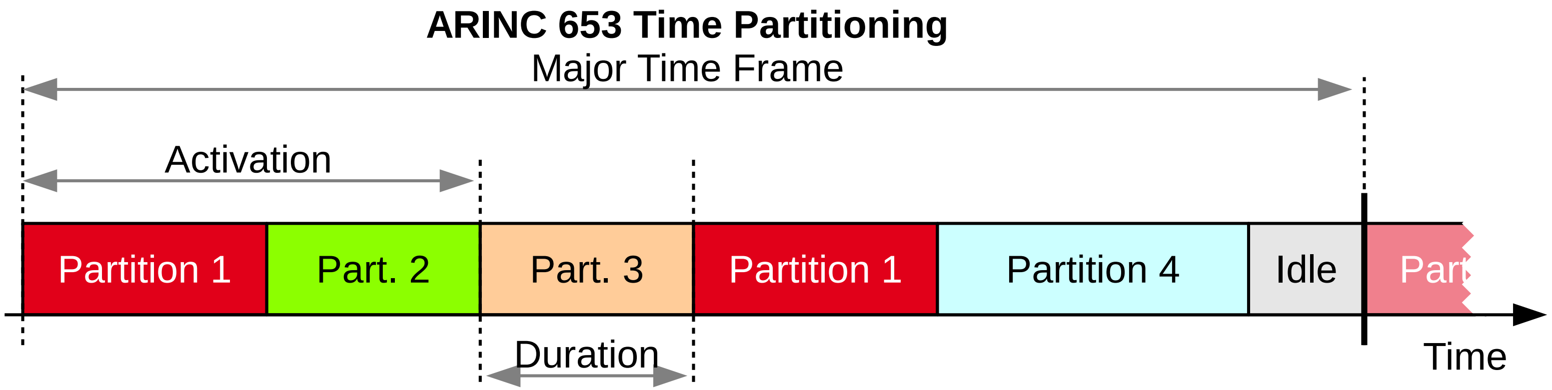


- ARINC 653
  - *Partitions*
  - Mandatory concept
  - Complete isolation
  - Explicit inter-partition communication means

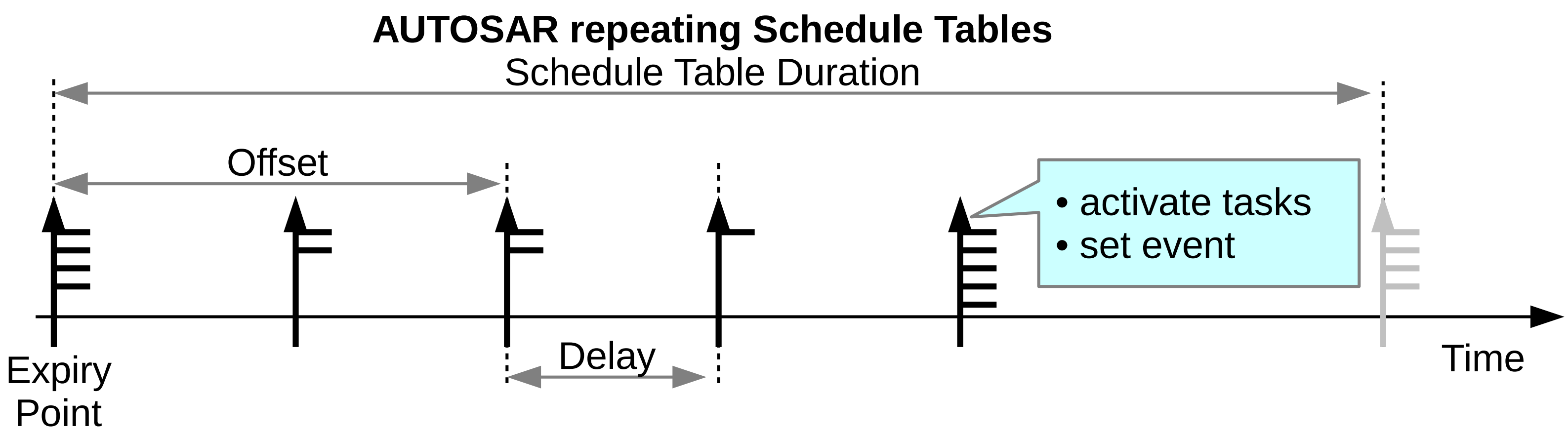


Time Partitioning



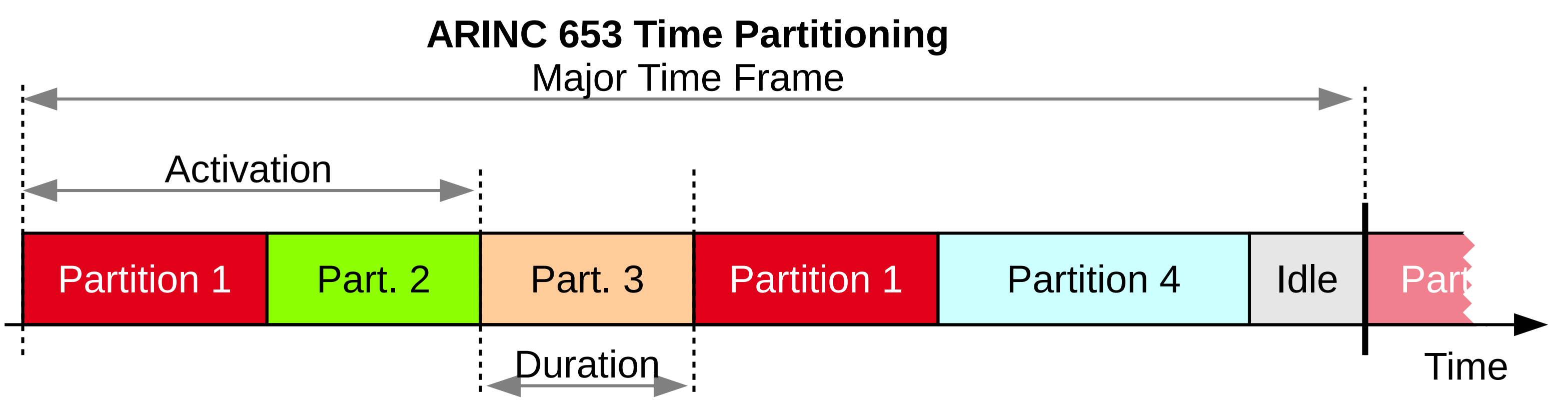
Time partitioning separates partitions and drives time-triggered tasks

Time-Triggered



AUTOSAR Schedule Tables allow similar time-triggered task activation

For temporal separation, optional timing protection facilities are available



Time partitioning separates partitions and drives time-triggered tasks

Differences

AUTOSAR

- Construction kit
- Task classes
- Scalability classes
- Isolation is an add-on
- Goals:
  - reduce resource usage
  - *keep it simple*

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- Construction kit
- Task classes
- Scalability classes
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ARINC 653

- General purpose API
- No configuration options
- Certification
- Decoupling of partitions
- Goals:
  - fault mitigation
  - *safety first*

Challenges

- Support both AUTOSAR and ARINC 653 APIs
- Full ARINC 653 partitioning at minimal resource costs
- Performance comparable to other AUTOSAR implementations
- Keep system easy to (re-)certify

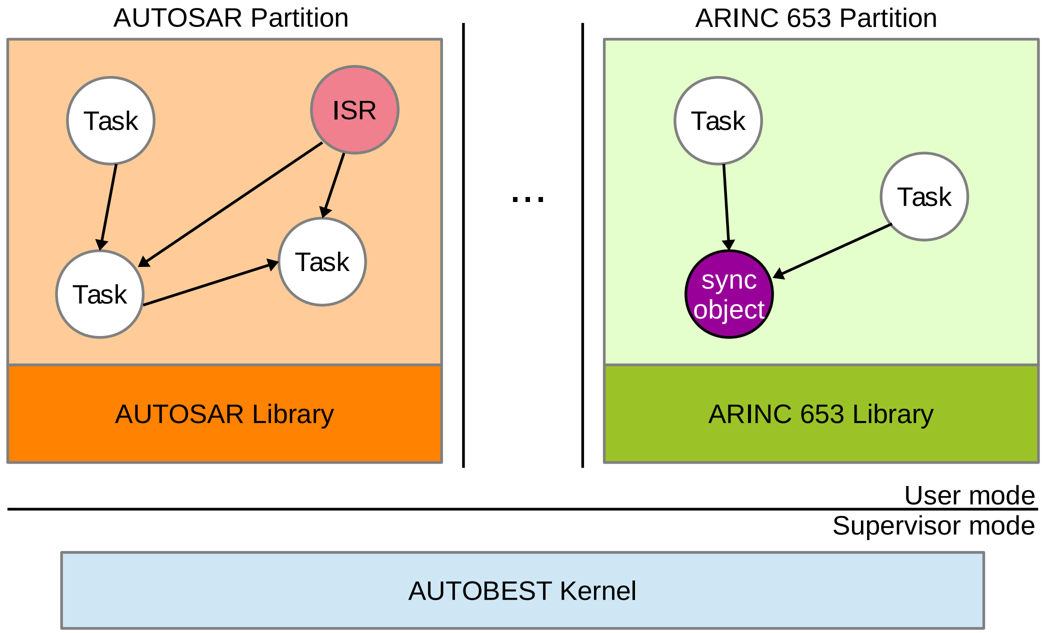
AUTOBEST

AUTOBEST Architecture

Statically configured microkernel

Partitions

- Space partitioning
- Time partitioning
- Driven by ARINC 653



Tasks

- Superset of AUTOSAR & ARINC 653 task API
- Keep OS specific differences out of the kernel
- User space libraries provide full AUTOSAR or ARINC 653 API

AUTOBEST Architecture

Scheduling

- Two-level scheduler
- Time-Partition Scheduling
  - One ready queue per time partition
  - Multiple space partitions can share one time partition
- Task Scheduling
  - Priority Scheduling with FIFO order on tie
- Fast critical sections using priority ceiling protocols
- Futex wait queues

AUTOBEST Architecture

Special Requirements of AUTOSAR

- Counters, Alarms, and Schedule Tables

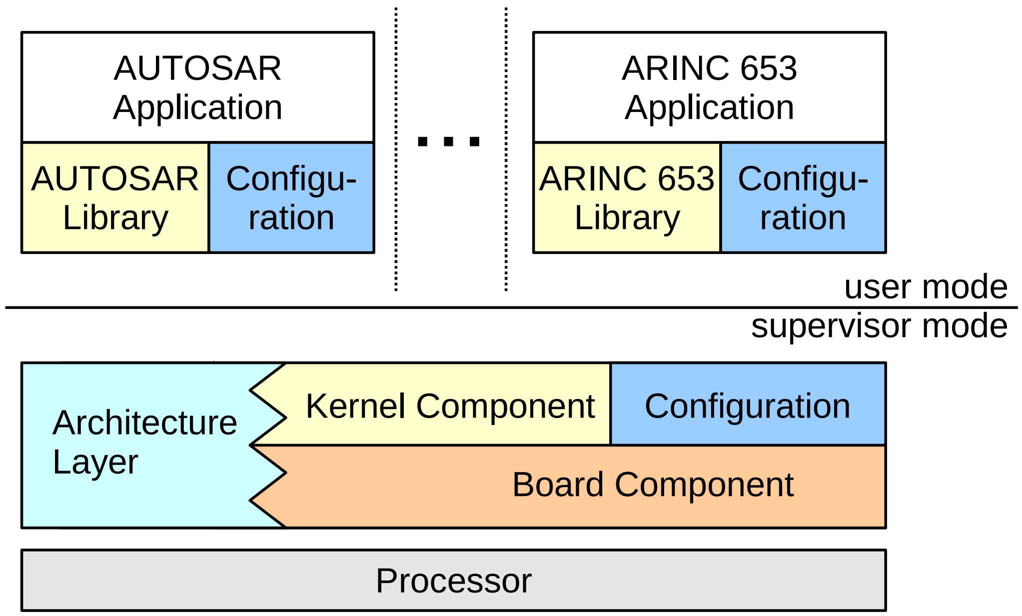
  → difficult to implement in user space
- Interrupt Handling
  - Allow ISRs in both kernel and user space
    - ISR cat 1 → kernel domain (no interaction with OS)
    - ISR cat 2a → kernel domain
    - ISR cat 2b → partition domain
  - Partitioned ISRs are mapped to high priority tasks
  - DisableInterrupts() → raise priority to partition maximum
- "*hooks*" (high priority pseudo tasks) for error handling

AUTOBEST Architecture

Special Requirements of ARINC 653

- Futex wait queues for ARINC sync objects
- 64-bit Nanosecond Timeout API
- Health Monitoring
  - Strict error handling using HM tables
  - Error process is mapped to a hook (like for AUTOSAR)
- Partitioning API
  - Start & Shutdown of other partitions
  - Privileged system calls
- Task deadline monitoring

AUTOBEST Architecture



Component Architecture

- Generic code
- Architecture code
- Board code
  - Boot, Interrupt Handling, ...
  - Kernel device drivers
- Configuration data
- OS specific libraries
- Kernel and partition code kept in dedicated binary images

System Configuration

- XML config → C language data structs (no C code, no #ifdefs)
- Binary reuse possible + reduces testing efforts

AUTOBEST Architecture

Resource Efficiency: RAM is precious!

- Split data model:
  - keep config in flash
  - keep data in RAM
- Most expensive:
  - task data (64 bytes)
  - register contexts
  - kernel stacks
  - ready queue per time partition (2 KiB / 256 priority levels)

Task Data

Queues use doubly-linked lists: → 24 bytes
- either ready queue or timeout queue
- sync object's wait queue
- deadline monitoring queue

Time tracking in 64-bit nanoseconds: → 24 bytes
- timeout expiry time
- phase shift of task activation
- deadline timeout

House keeping: → 16 bytes
- task state, priorities,
- pending events and task activations
- etc

AUTOBEST Architecture

Resource Efficiency: And flash as well!

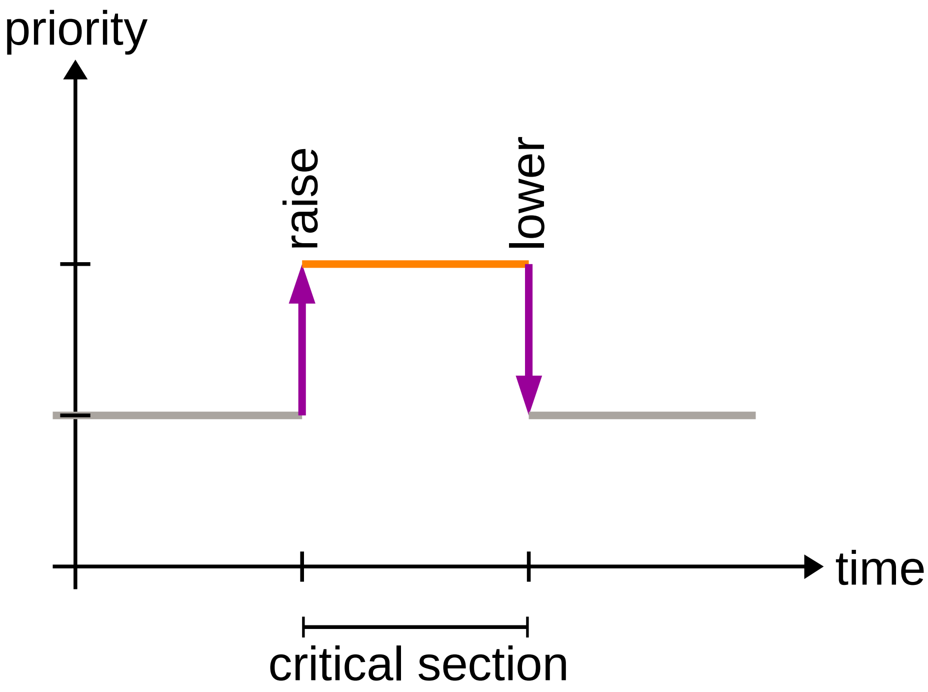
- Example Configuration:
  - 5 resource partitions, 1 time partition
  - 29 tasks, 10 hooks, 1 ISR
  - 4 schedule tables, 2 alarms
- Kernel memory usage on TMS570:
  - 13.5 KiB code (ARM thumb code, gcc -O2)
  - 7.5 KiB config
  - 17 KiB data (8 KiB stacks, 3.5 KiB registers, 2 KiB ready queues)

Lazy Priority Switching

Lazy Priority Switching

Typical critical section

(using the AUTOSAR priority ceiling protocol)



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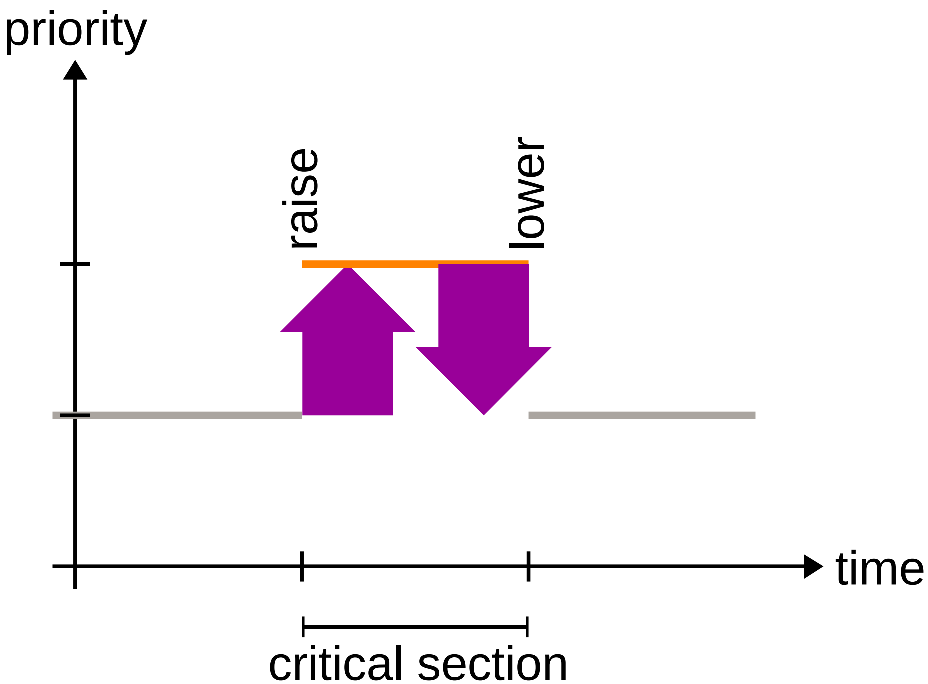


If critical sections are
short and frequent,
the
overhead
to change the caller's
scheduling priority
dominates
runtime costs!

Lazy Priority Switching

Change scheduling priority:

- System call overhead
- Raising priority: check & update some values
- Lowering priority: same + check for rescheduling

Lazy Priority Switching

Change scheduling priority:

- System call overhead
- Raising priority: check & update some values
- Lowering priority: same + check for rescheduling

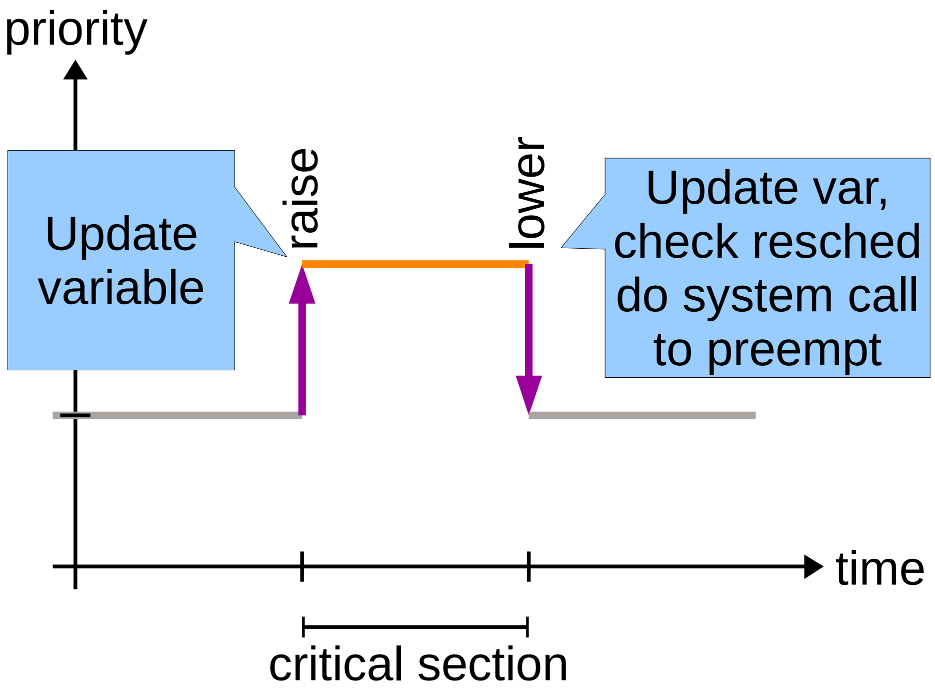
Idea for Optimization:

- Get rid of system call to set some values
- Kernel and user share variables to set priority
- Move rescheduling check into user space (checked when leaving a critical section)

Lazy Priority Switching

Optimized critical section:

One system call in the worst case (preemption)



Frequently used pattern, esp. in OS libraries!

Best case / no preemption:
MPC5646C: 688 → 31
TMS570: 843 → 94
(CPU cycles)

Futex Wait Queues

Futex Wait Queues

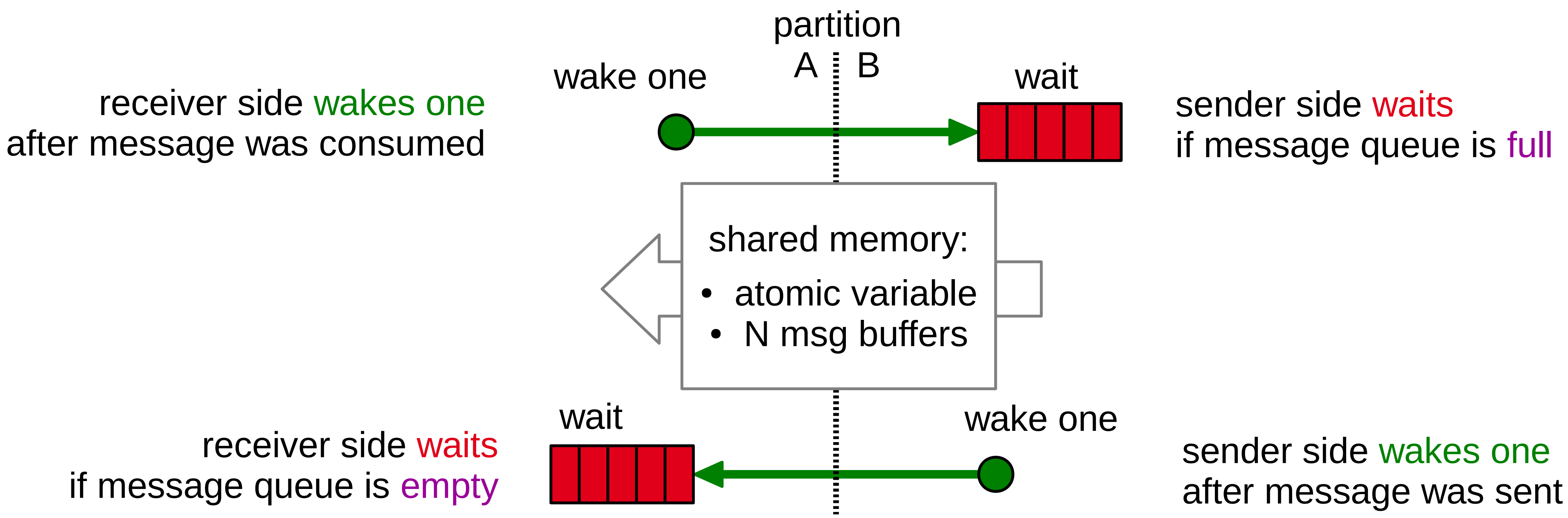
All ARINC 653 synchronization objects behave similar:

- Some tasks wait for something to happen
- Other tasks wake one or all waiters
- Each sync object has a wait queue
- Queue discipline: FIFO or priority-sorted (configured at partition start)
- Optional timeout
- Provide an API for wait queue operations

Futex Wait Queues

Example: Queuing port communication

- Shared memory for message buffers in queuing port channel
- One atomic Futex variable encodes read and write positions
- Two cross-connected wait queues



Futex Wait Queues

The kernel needs to manage wait queues only:

- Abstract wait and wake operations like in Linux Futexes
- Wait and wake sides can reside in different partitions

All ARINC 653 synchronization objects can be built upon Futexes and wait queues

Bonus: all copy operations done in user space (copy messages in user space at highest priority)

Conclusion

Conclusion

Conclusion

- Possible: unified kernel for AUTOSAR and ARINC
- Lazy priority switching improves performance
- Futex wait queues for ARINC 653 synchronization means keep complexity out of the kernel

Lessons learned

- Statically tailored kernels: good choice for safety-critical systems (much simpler than using runtime configuration)
- AUTOSAR nowadays provides similar functionality as ARINC 653

Outlook

Status

- Single core: PPC (e200) and ARM (Cortex R4)
- AUTOSAR OS 4.1 rev 3
- ARINC 653 part 1 suppl 3
- Pthread subset as additional OS environment

Future work

- Multi core: Infineon AURIX
- Real-world benchmarks
- Interrupts do not fit well to a time partitioned world
- Problem: Lock step not available for all cores

Thank you for your attention!

Backup Slides

POSIX

Subset of POSIX PSE5.1

- Pthread API
  - Pthreads
  - Mutexes
  - Condition Variables
- Minimal C-library
- Dynamic memory allocation
- Scheduling
  - SCHED_FIFO supported
  - SCHED_RR not supported
- No Signal Handling
- No Thread Cancellation

No additional efforts in the kernel!

Performance

Performance (Nov 2014)

- Freescale MPC5646C *Bolero* @120 MHz
  - Syscall 87 cycles / 0.73 µs
  - OSEK resource fast 29 cycles / 0.24 µs
  - OSEK resource slow 300 cycles / 2.50 µs
  - Task switch 390 cycles / 3.25 µs
- Texas Instruments TMS570LS3137 @180 MHz
  - Syscall 151 cycles / 0.83 µs
  - OSEK resource fast 70 cycles / 0.38 µs
  - OSEK resource slow 431 cycles / 2.39 µs
  - Partition switch overhead 659 cycles / 3.66 µs

AUTOBEST Architecture

Considered alternative: Hypervisor design

Microkernel	Hypervisor
Kernel knows all OS tasks	HV knows only partitions
Kernel schedules tasks and partitions	HV schedules partitions, delegates task scheduling to partition
API: OSEK + Partitioning API	API: Virtual CPU + virtual interrupt controller programming interface
ISRs: - Cat 2 ISRs → partitioned - Cat 1 ISRs → global	ISRs: similar
Cat 2 ISRs are scheduled like tasks	How to inject interrupts with priority?

The End