Implementing AUTOSAR Scheduling and Resource Management on an Embedded SMT Processor

Florian Kluge, Chenglong Yu, Jörg Mische, Sascha Uhrig, Theo Ungerer

Chair of Systems and Networking
University of Augsburg

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Outline

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Motivation (I)

Automotive Software Standards

- AUTOSAR: AUTOmotive Open System ARchitecture
- Provides common platform for automotive applications
- Increases interoperability and interchangeability

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Upcoming Processor Architectures

- Simultaneous MultiThreading (SMT) Cores
- Multi-Core Processors

→ real parallelism!

Motivation (II)

- Is AUTOSAR fit for SMT?

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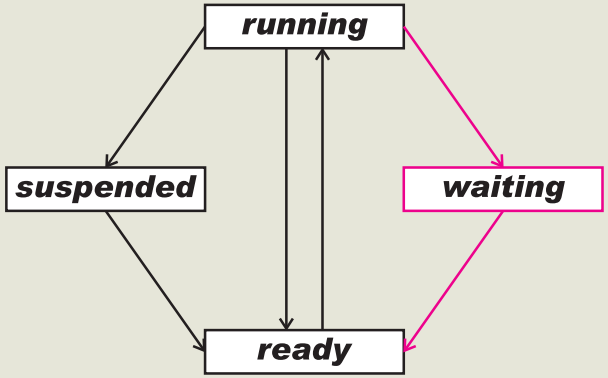
- Is AUTOSAR fit for SMT? NO!
- What can we do?
- How can AUTOSAR benefit from SMT?

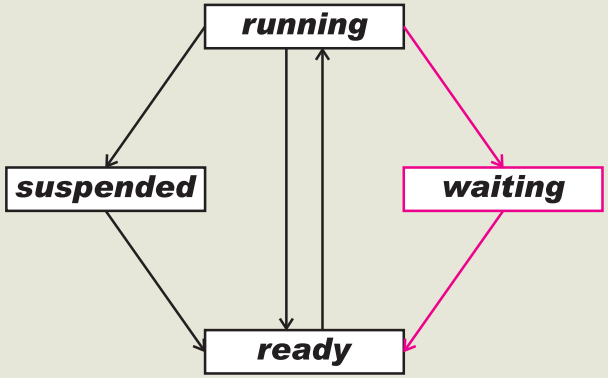
AUTOSAR Scheduling

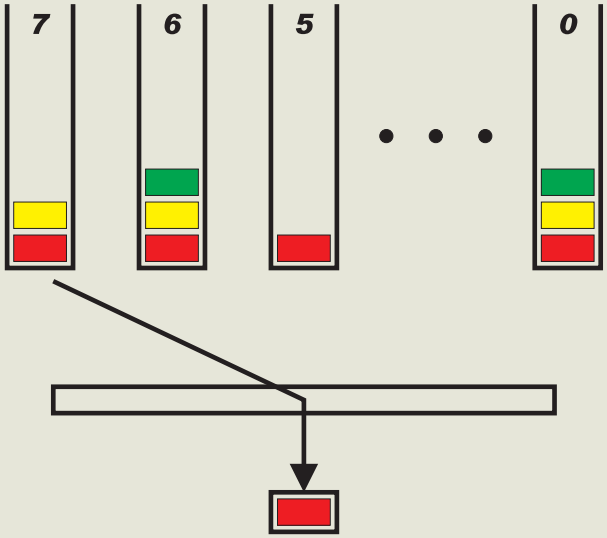
- *Basic* and *Extended* tasks
- Task states: *suspended*, *ready*, *running*, *waiting* (only extended tasks)



AUTOSAR Scheduling

- *Basic* and *Extended* tasks
- Task states: *suspended*, *ready*, *running*, *waiting* (only extended tasks)
- Priority based scheduling: highest priority task is executed
- Designed for singlethreaded processors

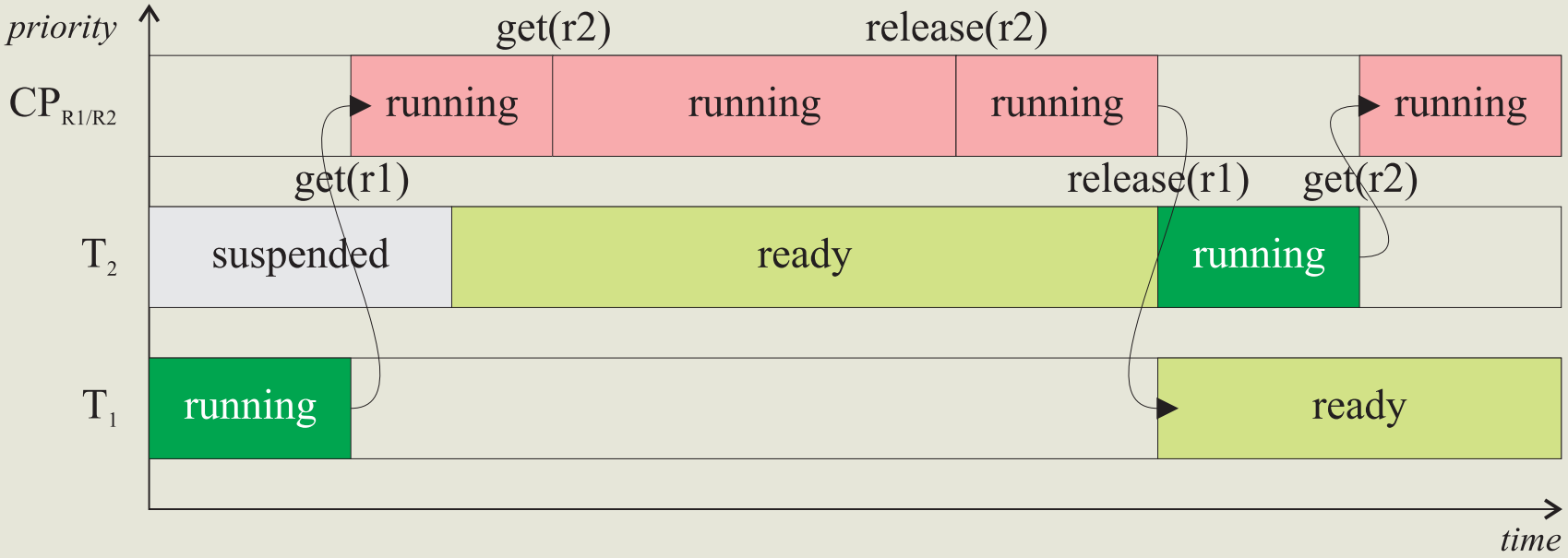




AUTOSAR Resource Management

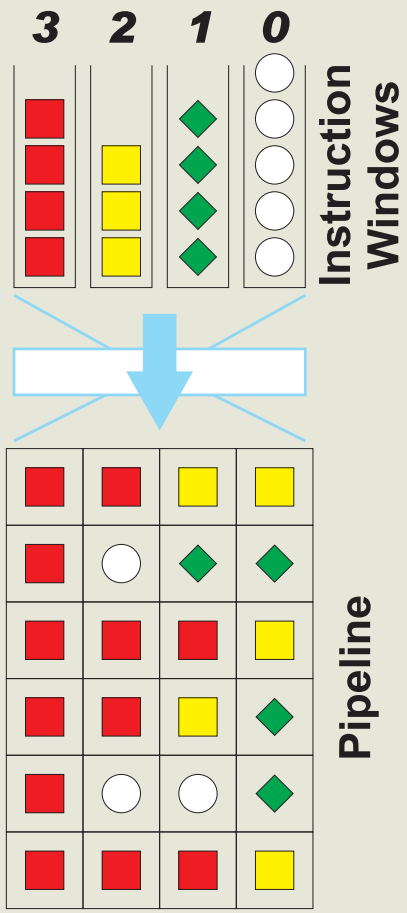
- Mutual exclusion on resource access
- Prevent priority inversion and deadlocks
- Resource access never results in *waiting* state

→ Priority Ceiling Protocol (PCP)



SMT Processor

- Simultaneous MultiThreading
  - issue instructions of different threads in one cycle
- Use latencies of one thread to execute another
- Prioritised slots
- Real parallelism



Challenges

Goal: Earlier execution of low-priority tasks

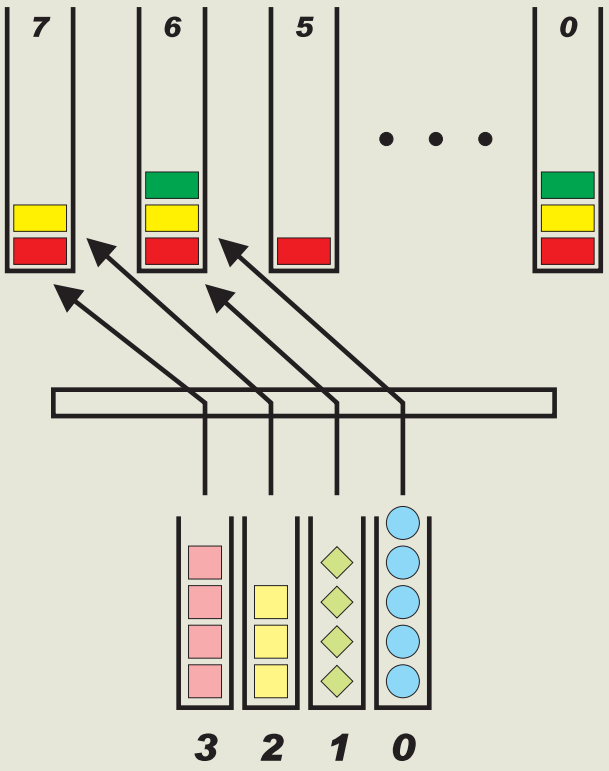
Challenges

- Preserve WCET analysability
- Preserve externally observable behaviour of highest-priority task
  - Lower-priority tasks can be interrupted by higher-priority tasks!
- As few changes as possible to standard definition

Outline

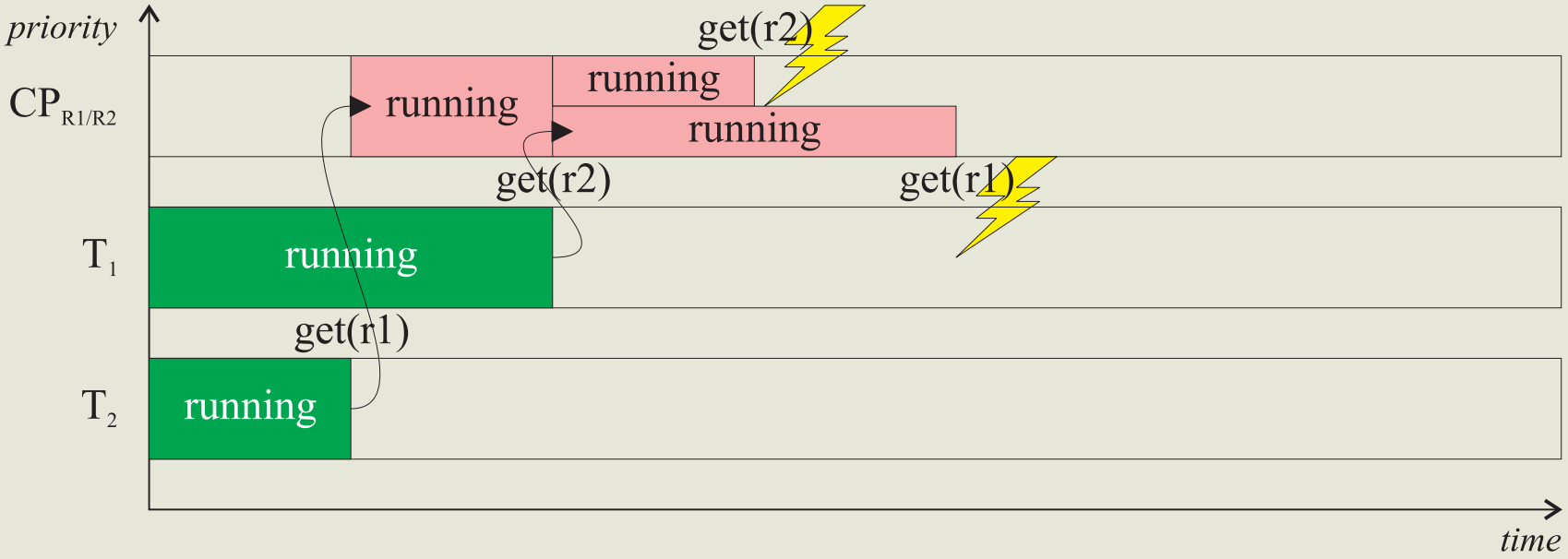
Forward Implementation

- SMT processor with n thread slots
- Issue n highest priority tasks
  - $\longrightarrow$ Keep execution order
- Map AUTOSAR task priorities to thread priorities



Resource Management and Parallel Execution

- PCP relies on singlethreaded program execution
- No prevention from priority inversion and deadlocks in multithreaded program execution



Related Work: Resource Management

Resource Management for Multiprocessor Systems

- Multiprocessor Priority Ceiling Protocol
- Multiprocessor Stack Resource Policy
- LP-Time Inheritance and Returning

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- Multiprocessor Priority Ceiling Protocol
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- ⛔ No transfer of processing time possible on SMT
- ⛔ No nested resource accesses possible

Data Synchronisation

Scheduler

- Shared data structures (FIFO queues)
- NO lock variables available!
- Further synchronisation necessary

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Related Work

- Lamport (*Bakery Algorithm*), Peterson's Algorithm:
  - Spinning or sleeping/suspending
  - ⛔ Spinning wastes processing time
  - ⛔ Suspending can violate task state model

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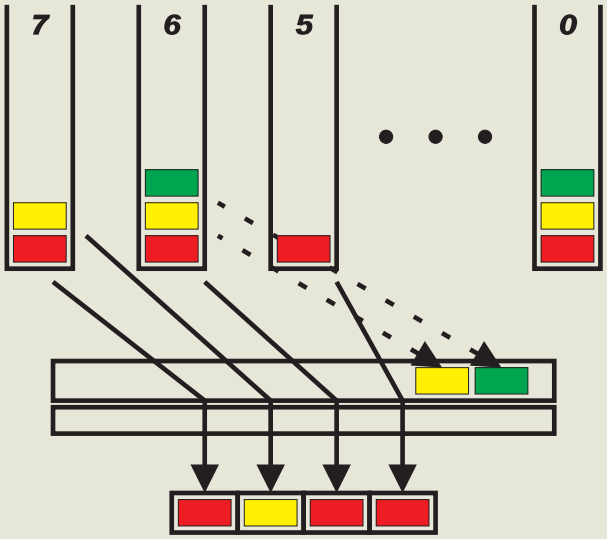
Related Work

- Lamport (*Bakery Algorithm*), Peterson's Algorithm:
  - Spinning or sleeping/suspending
  - ⛔ Spinning wastes processing time
  - ⛔ Suspending can violate task state model
- Lock-free algorithms
  - Special instructions necessary
  - Compare&Swap or Load Link/Store Conditional

Outline

Task Filtering

- Execute only tasks that do not use the same resources
- Deferred tasks are buffered in *task filter*
- Internal task state *resource ready*
  - Task has highest priority of all tasks accessing the same resources

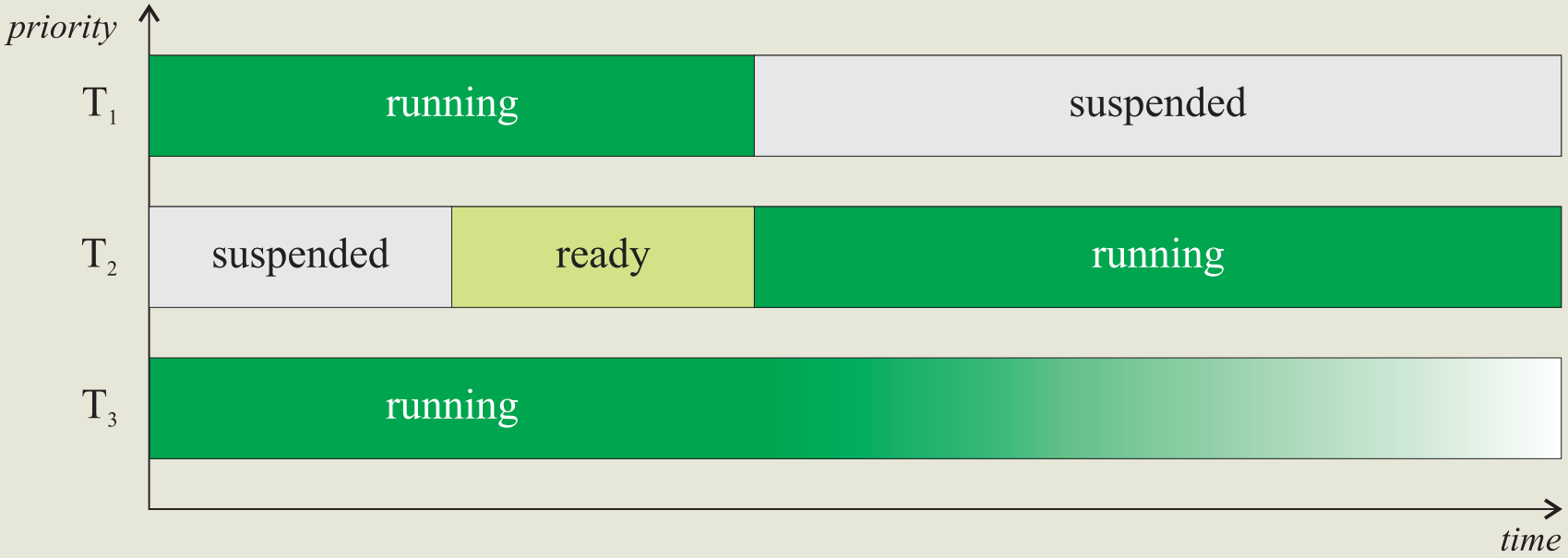


Task Filtering: Example

	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8
R_1	X							
R_2			X			X		
R_3	X							
R_4				X				
R_5	X		X					
R_6					X		X	
R_7			X				X	X
R_8					X			
SC	**o**	**o**		**o**	**o**	**o**		**o**

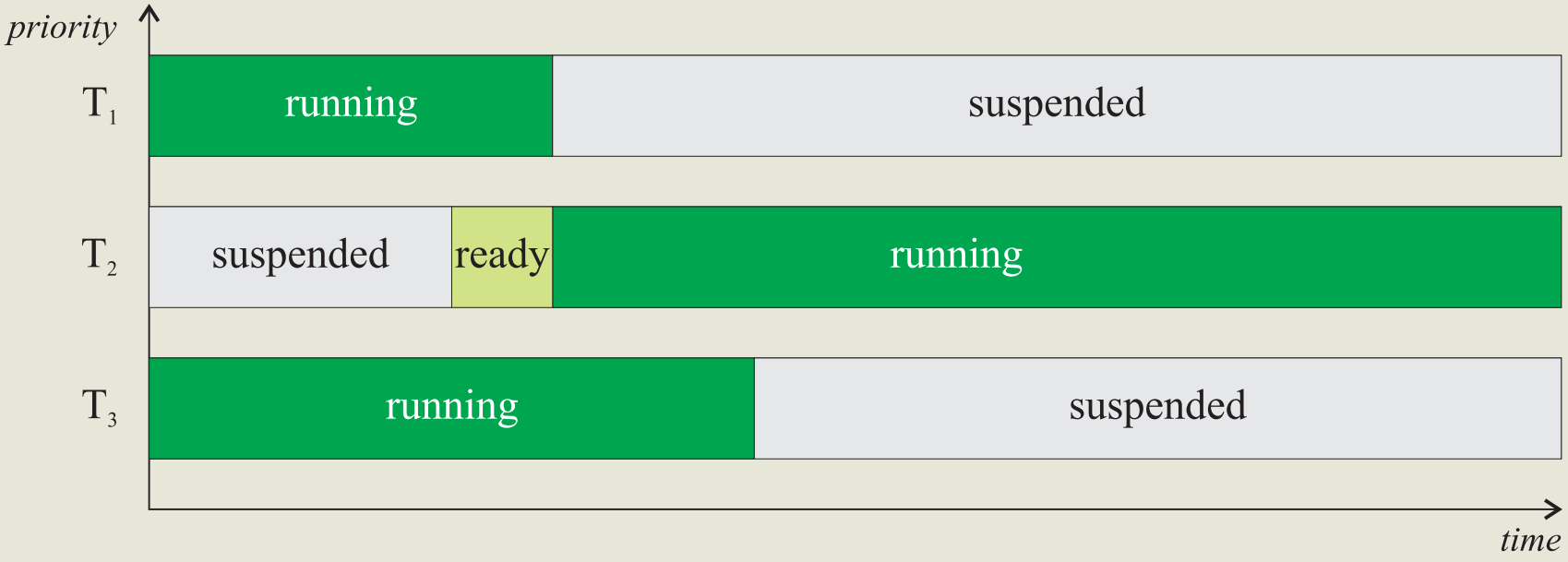
Discussion

- Tasks T_1, T_2, T_3
- Priorities $P_1 > P_2 > P_3$
- 2 thread slots
- T_1, T_3 running
- T_1 and T_2 have resource conflict



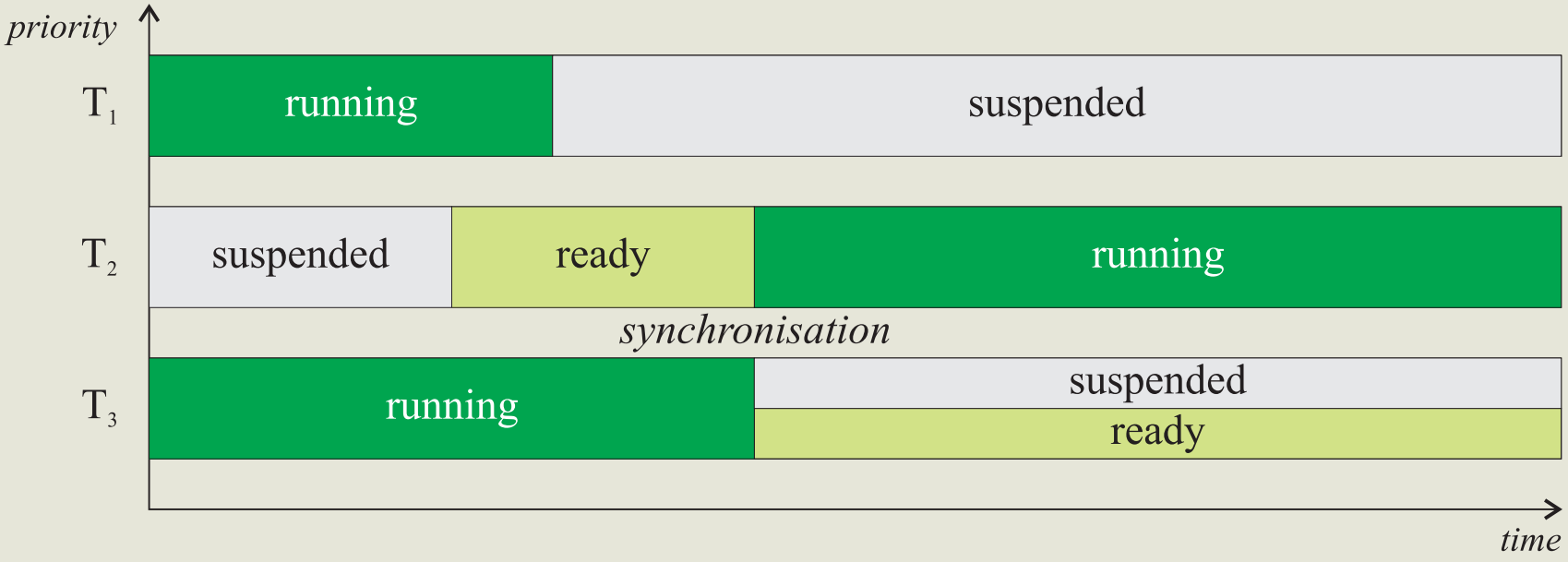
Discussion (I)

- No resource conflict between T_2 and T_3



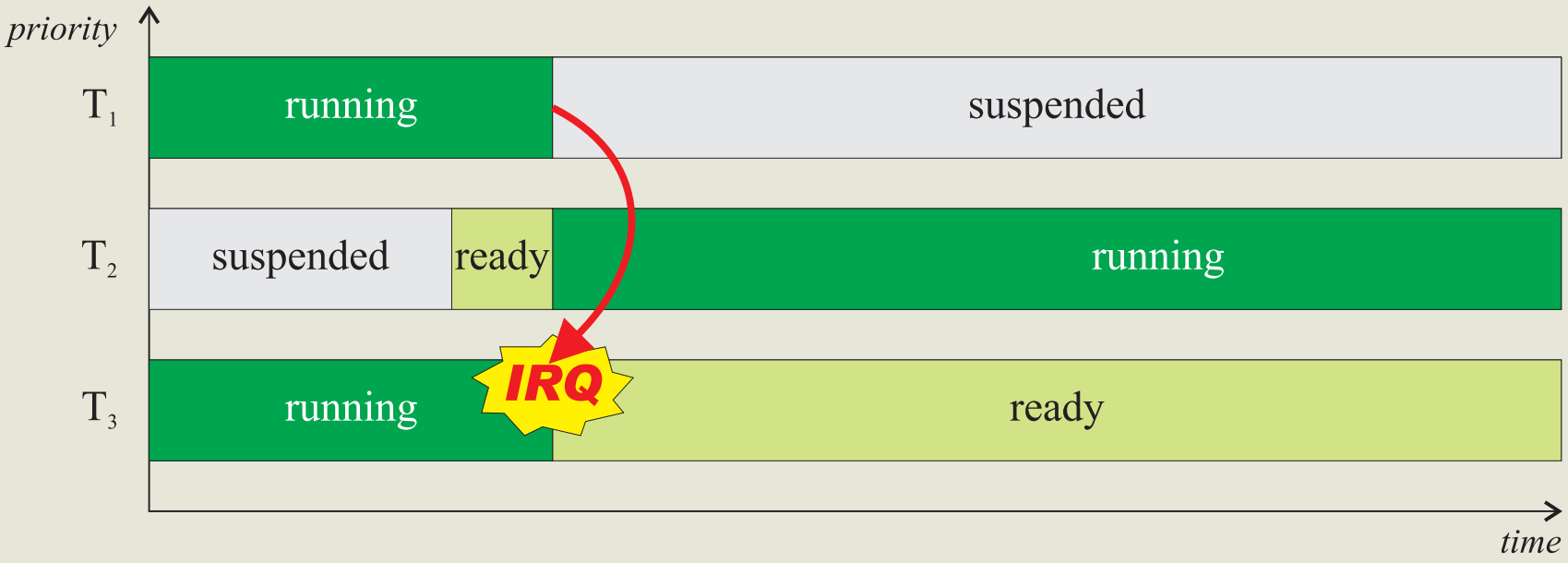
Discussion (II)

- Resource conflict between T_2 and T_3 on R
- T_3 non-preemptable



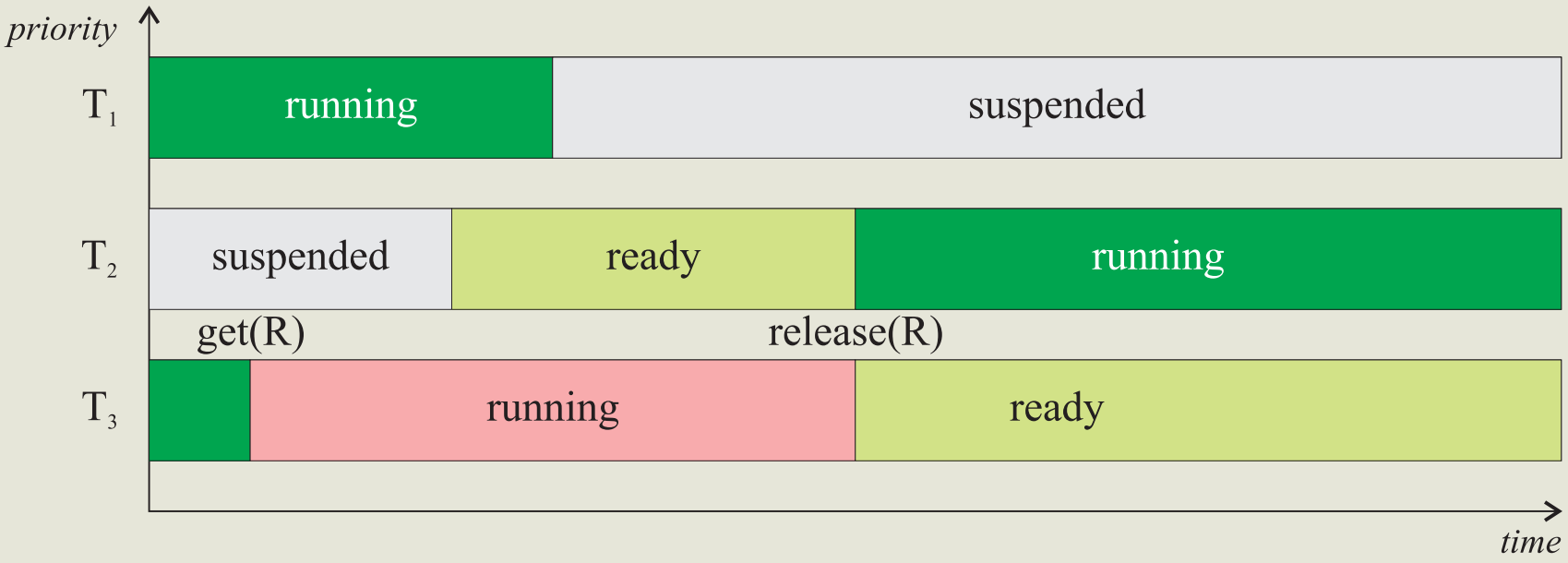
Discussion (III)

- Resource conflict between T_2 and T_3 on R
- T_3 preemptable
- T_3 not holding R or other with $CP > P_2$



Discussion (IV)

- Resource conflict between T_2 and T_3 on R
- T_3 preemptable
- T_3 holding R



Consequences

- Start of high priority tasks may be delayed, but time-predictable
- Once running, behaviour is same as in single-threaded processor for highest priority task
- Lower prioritiy tasks: may start earlier, but with lower performance
- Time for scheduling increases about 100 cycles - total time about 1.600 cycles (on prototype)
- Hardware requirement: slot-to-slot interrupt

Synchronisation of Scheduler Data

- Scheduler's FIFO-Queues accessed from every slot
- Must ensure consistency
- Use lock-free linked lists
- HW Requirement: COMPARE&SWAP or LOAD LINK/STORE CONDITIONAL instructions
- Work in progress

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Summary & Conclusion

Extensions to AUTOSAR

- Task Filtering method prevents resource conflicts
- New state *resource-ready* introduced
- Necessary hardware extensions
  - CAS
  - Slot-to-slot interrupts

⇒ Timing behaviour of highest-priority task is preserved

Summary & Conclusion

Extensions to AUTOSAR

- Task Filtering method prevents resource conflicts
- New state *resource-ready* introduced
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Conclusions

- Current AUTOSAR not ready for multiprocessing
- More changes on specification necessary
- This work is just one step on the road...

Future Work

- Lock-free Algorithms
  - Implementation and evaluation
- Benchmarking
  - Current benchmarks just look at performance
  - Design benchmark to test resource accesses
- Integration with Multi-Core Research
  - MERASA project (Multi-Core Execution of Hard Real-Time Applications Supporting Analysability)

Thank you!

Any Questions?