



Real-Time Systems

7.5 credit points

Professor Jan Jonsson

Department of Computer Science and Engineering
Chalmers University of Technology

Course teachers

Jan Jonsson:

- Examiner and course responsible
- Lectures (+ a few exercise sessions)
- Laboratory sessions

Victor Wallsten:

- Course assistant
- Exercise sessions (+ a few lectures)
- Laboratory sessions

Course organization

Lectures (16 of them)

Lectures are offered in full class, with the goal of introducing the real-time programming paradigm and basic scheduling theory as well as demonstrating how the paradigm and theory are applied in practice.

Special sessions (3 of them)

Special sessions are offered in full class on certain weeks, and should be seen as a complement to the lectures. Examples of topics for the special sessions:

- introduction to sound generation and music theory
- discuss solutions to exercise problems or old exam problems

Course organization

Exercise sessions (7 of them)

Exercise sessions are offered in full class, with the goal of further exploring aspects of the laboratory assignment and the scheduling theory.

Laboratory assignment (one big assignment)

The assignment is done in groups and gives the student practical experience with programming of a time-critical embedded system, using the C programming language and the TinyTimber kernel.

The assignment runs for a restricted time period, during which loan equipment is used for solving programming problems.

Laboratory sessions are used for guidance and debugging, as well as examination of the groups' software solutions.

Course aim

After the course, the student should be able to:

- Formulate requirements for embedded systems with strict constraints on computational delay and periodicity.
- Construct concurrently-executing tasks (software units) for real-time applications that interface to sensors and actuators.
- Describe the principles and mechanisms used for designing run-time systems and communication networks for real-time applications.
- Demonstrate knowledge about the terminology used within the theory of scheduling and computational complexity.
- Apply the basic analysis methods used for verifying the temporal correctness of a set of executing tasks.

Course examination

Written exam

The course contents are examined by means of a written exam.
Date and time of ordinary exam: March 17, 2025 @ 08:30-12:30.

Laboratory assignment

The assignment is examined by means of parts 0, 1 and 2 of the Lab-PM.

Final grade

The written exam and the laboratory assignment are both given a score with grade (U, 3, 4, 5). To pass the course the score of each must be equivalent to a grade of 3 or higher. The final grade is based on the scores from the exam and the assignment.

Changes in the course

Since 2018:

- The final course grade is based on the scores for the laboratory assignment and the written exam
- The number of course participants is restricted; pass grades in prerequisite courses guarantee a seat for laboratory assignment

Since 2021/22:

- The work with the laboratory assignment can partly be done at home using loan equipment
- Written exam has a new grading procedure

Since 2025:

- The examination of the laboratory assignment no longer encompasses a written project report

Course material

To download: (via Canvas system)

- Lecture notes and exercise notes. [Powerpoint hand-outs]
- Research articles and book excerpts. [recommended reading only]
- Exercise compendium.
- Lab-PM – Part 0, 1 and 2.
- “Programming with the TinyTimber kernel” compendium.
- Template code. [for target computer software]
- Handbooks and data sheets. [for target computer hardware]
- Development tools. [available for Windows, macOS, Linux]

Course information and support

Examiner/lecturer:

- Questions related to the course are primarily answered in conjunction with lectures, exercises or laboratory sessions.
- Otherwise ask questions via email or Canvas messaging.

Canvas system:

- Get complete information about the course
- Download course material
- Form project groups and submit reports
- View examination progress and awarded grades

<https://chalmers.instructure.com/courses/33127>



Course contents

What this course is all about:

1. Construction methods for real-time systems
 - Specification, implementation, verification
 - Application constraints: origin and implications
2. Programming of concurrent real-time applications
 - Task and communication models (C with TinyTimber kernel)
 - I/O and interrupt programming (C with TinyTimber kernel)
3. Verification of system's temporal correctness
 - Derivation of worst-case task execution times
 - Fundamental scheduling theory

What is a real-time system?

“A real-time system is one in which the correctness of the system depends not only on the logical result of computation, but also on the time at which the results are generated”

J. Stankovic, “Misconceptions of Real-Time Computing”, 1988



What is a real-time system?

It is not only about high-performance computing!

Real-time systems must meet timing constraints



High-performance computing maximizes average throughput

Average performance says nothing about correctness!

“A statistician drowned while crossing a stream
that was, on average, 6 inches deep”

Real-time systems are instead usually optimized with respect
to perceived “robustness” (control systems) or
“comfort” (multimedia)



What is a real-time system?

Typical properties of a real-time system:

- Application-specific design
 - Part of a bigger system (“embedded system”)
 - Carefully specified system properties
 - Well-known operating environment
- Strict timing constraints
 - Responsiveness (= deadline)
 - Periodicity (= sampling rate)
 - Important design parameters in the context of system safety
 - Should be verified at design time to be met at run-time

What is a real-time system?

Typical properties of a real-time system (cont'd):

- Strict safety requirements
 - “Safety must be considered early in the design process”
 - Safety standards and certification
 - IEC 61508 (industrial systems)
 - IEC 62304 (medical systems)
 - ISO 26262 (automotive systems)
 - DO-178C (airborne systems)
 - Programming language restrictions (e.g. MISRA C)
 - Run-time system restrictions (e.g. cyclic executive)
 - Thorough testing of software and hardware components
 - Reliability in presence of component faults (“fault tolerance”)

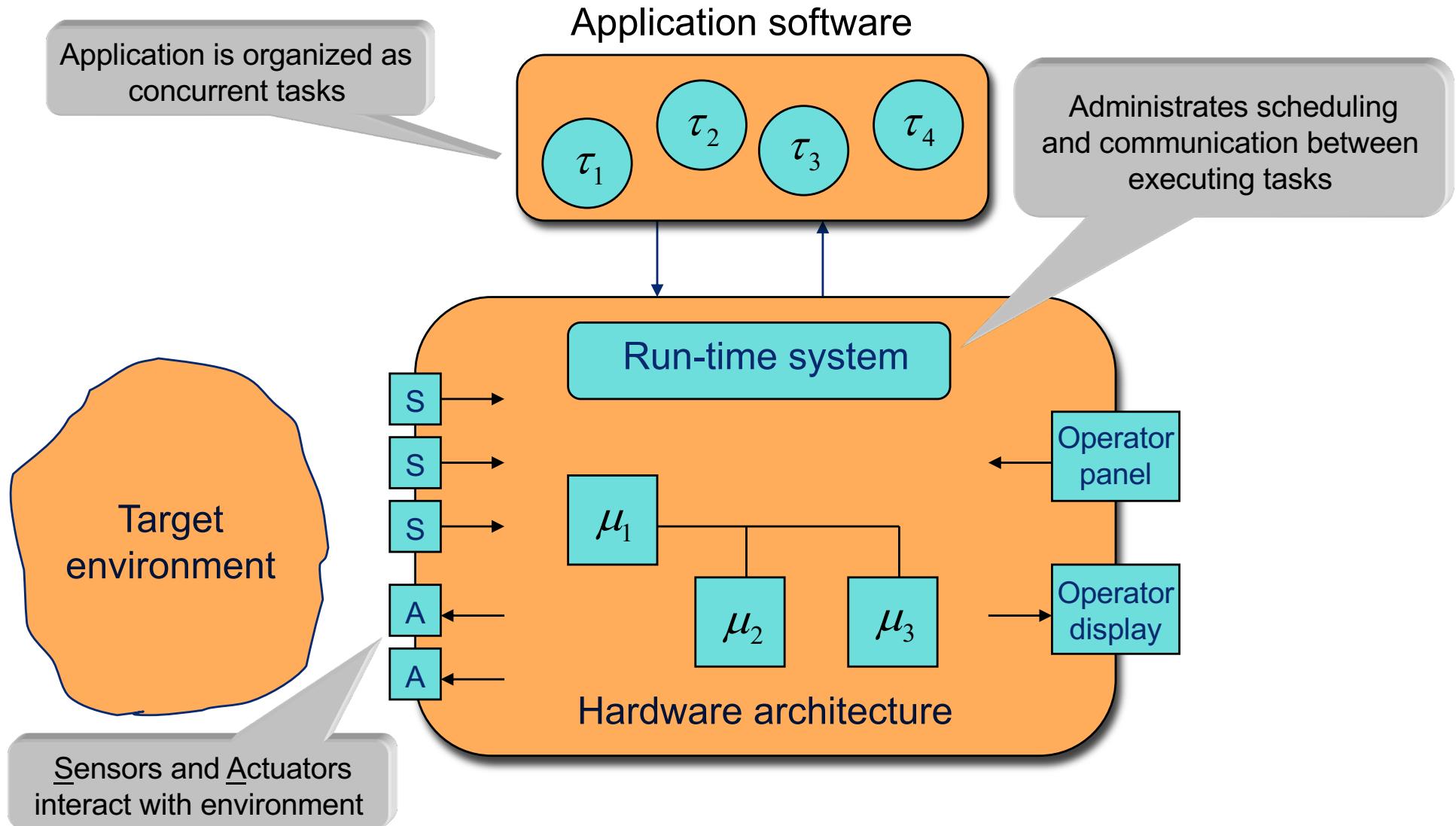
What is a real-time system?

Examples of real-time systems:

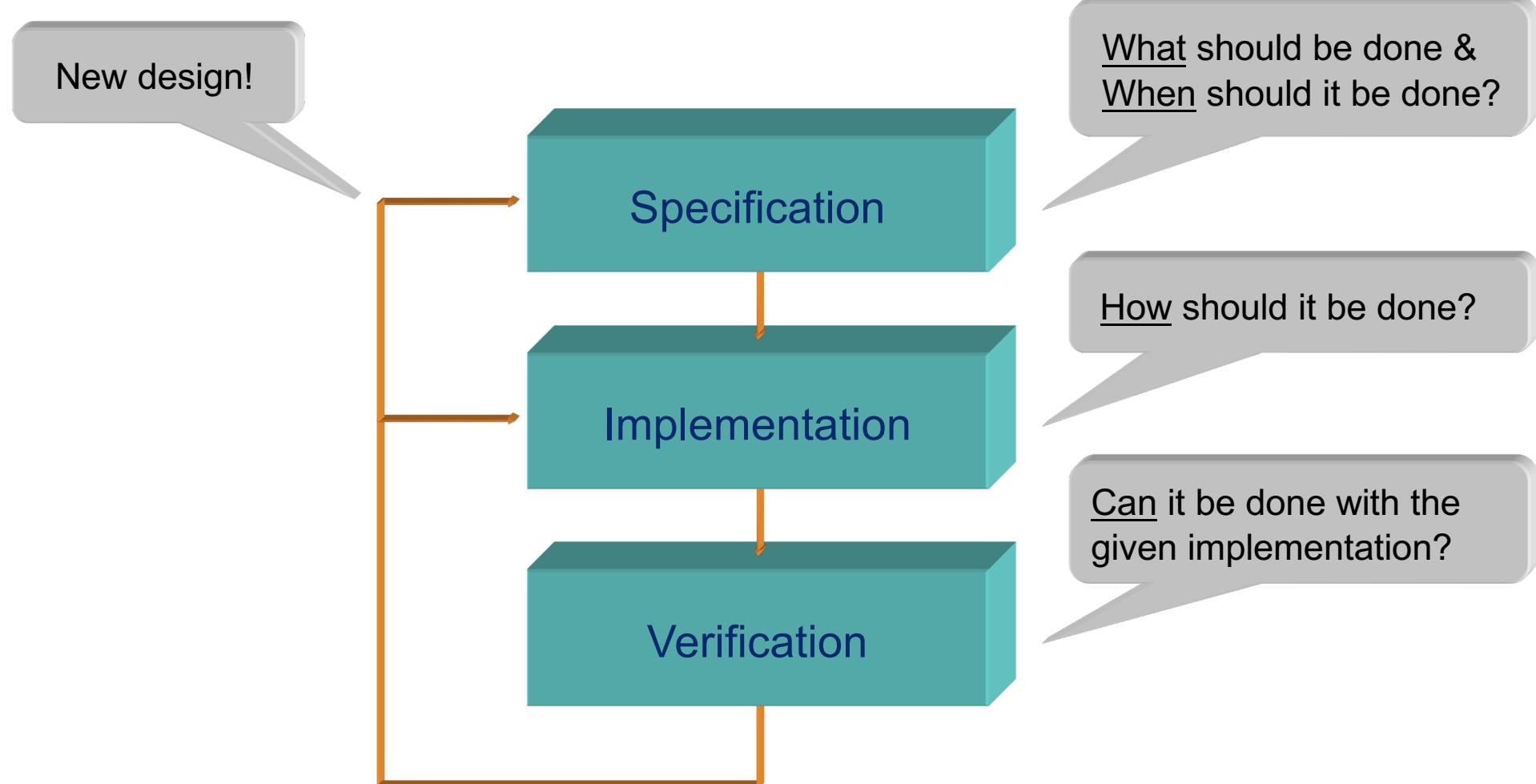
- Control systems
 - Manufacturing systems; process industry
 - Cars, aircrafts, submarines, satellites
- Transaction systems
 - E-commerce; ticket booking; teller machines; stock exchange
 - Wireless phones; telephone switches
- Multimedia
 - Portable music players, streaming music
 - Computer games; video-on-demand, virtual reality



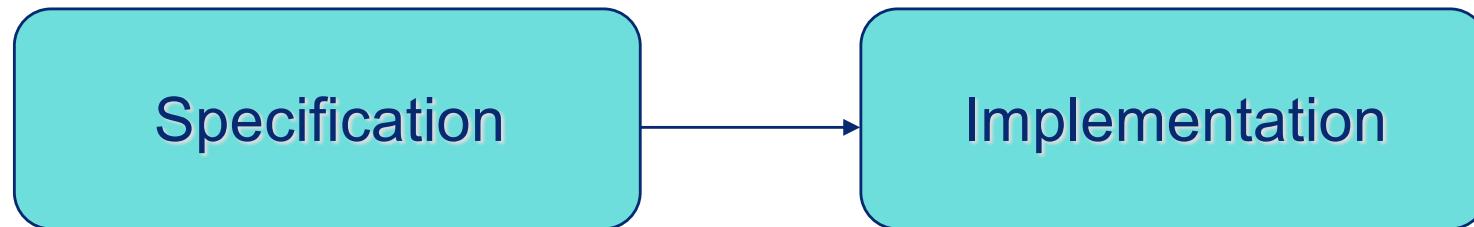
Real-time system components



Designing a real-time system



Specification



Requirements:

Sampling rate



Constraints:

Periodicity

Response time



Deadline

Reliability



Replication

Specification

Examples of application constraints:

- Timing constraints
 - A task must complete its execution within given time frames
(example: task periodicity or deadline)
- Exclusion constraints
 - A task must execute a code region without being interrupted
(example: a task needs exclusive access to a shared resource)
- Precedence constraints
 - A task must complete its execution before another task can start
(example: a data exchange must take place between the tasks)

Specification

Where do the timing constraints come from?

- Laws of nature
 - Bodies in motion: robot arms in manufacturing, vehicles in traffic, missiles in flight
 - Inertia of the eye: minimal frame rate in film
- Mathematical theory
 - Control theory: recommended sampling rate
- Artificial derivation
 - Observable events: overall (global) timing constraints are given for a set of tasks, but individual (local) timing constraints are needed for each task.
For example: data processing in a vehicle braking system

Specification

How critical are the constraints?

Hard constraints:

If the system fails to fulfill a timing constraint, the computational results is useless.



Non-critical: system can still function with reduced performance

- Navigational functions; diagnostics

Critical: system cannot continue to function

- Flight control system; control loop

Safety-critical: can cause serious damage or even loss of life

- Braking systems (ABS); defense system (missiles)

Correctness must be verified before system is put in mission!

Specification

How critical are the constraints?

Soft constraints:



Single failures to fulfill a timing constraint is acceptable, but the usefulness of the computational result is reduced (often to what can be considered useless).

- Reservation systems: seat booking for aircraft; teller machine
- E-commerce: stock trading, eBay
- Multimedia: video-on-demand, computer games, Virtual Reality

Statistical guarantees often suffice for these systems!

Implementation

Design choices during implementation:

- Application software
 - Programming language: determines run-time performance, code size and degree of timing verification that is possible.
 - Concurrency: determines degree of application parallelism that can potentially be exploited by the hardware.
- Run-time system:
 - Task and message scheduling policy: determines potential of meeting timing constraints, and sets limits of maximum processor and network utilization.

Implementation

Design choices during implementation:

- Hardware architecture:
 - **Hardware parallelism**: determines the degree of application parallelism that can actually be exploited
 - uniprocessor system: only pseudo-parallel execution is possible
 - multiprocessor system: truly parallel execution is possible
 - **Microprocessor family**: determines run-time performance, as well as difficulty in analyzing the worst-case execution time (WCET) of a software task.
 - **Communication network technology**: determines run-time performance, as well as difficulty in analyzing worst-case message delays.

Verification

Available approaches for checking correctness:

- Verification
 - Capability: prove the absence of incorrect behavior
 - Requires formal methods based on mathematical models and theories (e.g., schedulability analysis)
- Testing and validation
 - Capability: detect the presence of incorrect behavior
 - **Testing:** checking whether the system works correctly in a simplified environment (e.g. in a laboratory room)
 - **Validation:** checking whether the system works in its real target environment (e.g., in a vehicle or a satellite)

Verification

Existing challenges in checking correctness:

- Verification

Model accurately the “sources of uncertainty” in the system

- A single task’s WCET
- Concurrent tasks’ execution interference on a processor
- Concurrent tasks’ waiting times for shared resources

- Testing and validation

Ensure that at least one case of incorrect behavior is detected

- Considering only a subset of execution scenarios could mean that a pathological (worst) case will be overlooked
- Considering all possible execution scenarios could require an unreasonable amount of time for testing or validation