Real-Time Systems

7.5 credit points

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Course organization

Lectures (15 of them)

Lectures are offered in full class at least once a week, and with the goal of introducing the programming paradigm and basic scheduling theory as well as demonstrating how the paradigm and theory are applied in practice.

Special sessions (5 of them)

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

- help with software design and development tools
- 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 once a week (except on week 8), and with the goal of further exploring aspects of the laboratory assignment and the scheduling theory.

Laboratory assignment (one big assignment)

The compulsory assignment is done in smaller groups and will give the student practical experience with programming of a time-critical embedded system, using the C programming language and the TinyTimber kernel. The application to be considered is a distributed synthetic chorus with real-time tone generators.

The laboratory sessions run continuously from week 2 to week 7.

Course aim

After the course, the student should be able to:

- Formulate requirements for embedded systems with strict constraints on computational delay and periodicity.
- Categorize and describe the different layers in a system architecture for embedded real-time systems.
- Construct concurrently-executing tasks for real-time applications that interface to hardware devices (sensors/actuators)
- Describe the principles and mechanisms used for designing run-time systems and networks for real-time applications.
- 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 18, 2019 @ 08:30-12:30.

Laboratory assignment

The assignment is examined by means of: (i) parts 0, 1 and 2 of the Lab-PM, and (ii) a written project report.

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 much 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

Compared to 2016:

- No mandatory book for course literature
- New laboratory hardware and software development system

Compared to 2017:

- The score of the laboratory assignment is now more fine grain, using the scale Fail (U) and Pass with grade 3, 4, or 5
- The final grade is based on the scores for the laboratory assignment and the written exam

Compared to 2018:

- Laboratory sessions will take place at Lindholmen campus
- Course web pages will be hosted by the Canvas system

Course material

To download: (via Canvas system)

- Lecture notes and exercise notes. [Powerpoint hand-outs]
- *Programming with the TinyTimber kernel.* [also used at written exam]
- Research articles and book excerpts. [recommended reading only]
- Exercise compendium.

- Lab-PM − Part 0, 1 and 2. [paper copies also handed out]
- Template code. [for target computer software]
- Handbooks and data sheets. [for target computer hardware]
- Development tools. [available for Windows, Mac, Linux]

Course information and support

Teachers and assistants:

- Questions related to the course are primarily answered in conjunction with lectures and exercise/laboratory sessions.
- Otherwise send an email or book time for a personal meeting.

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/3802`

Course contents

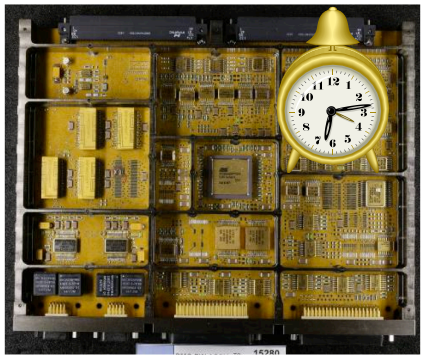
What this course is all about:

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 system 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?

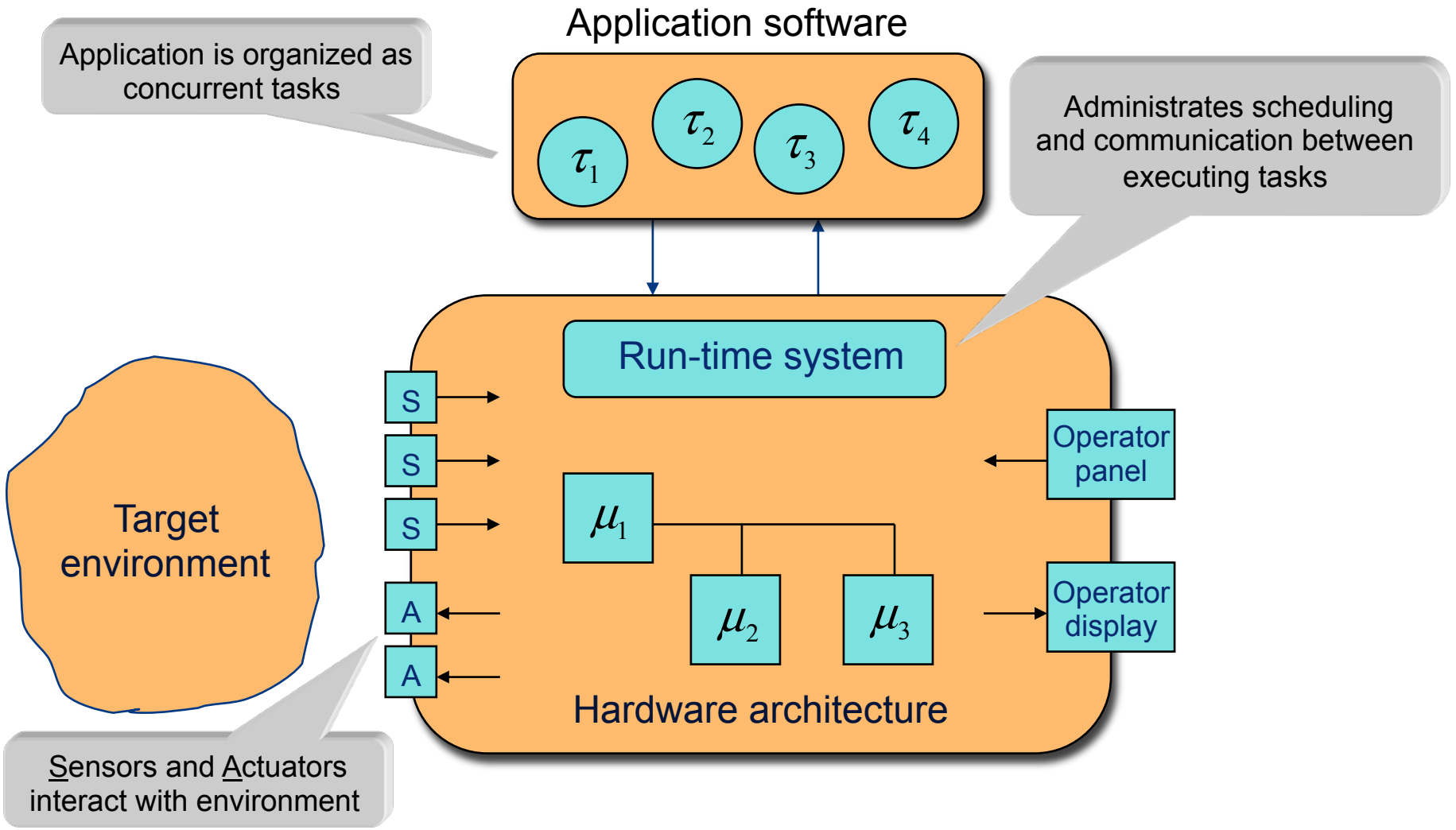
Examples of real-time systems:

- Control systems
  - Manufacturing systems; process industry
  - Cars, aircrafts, submarines, satellites

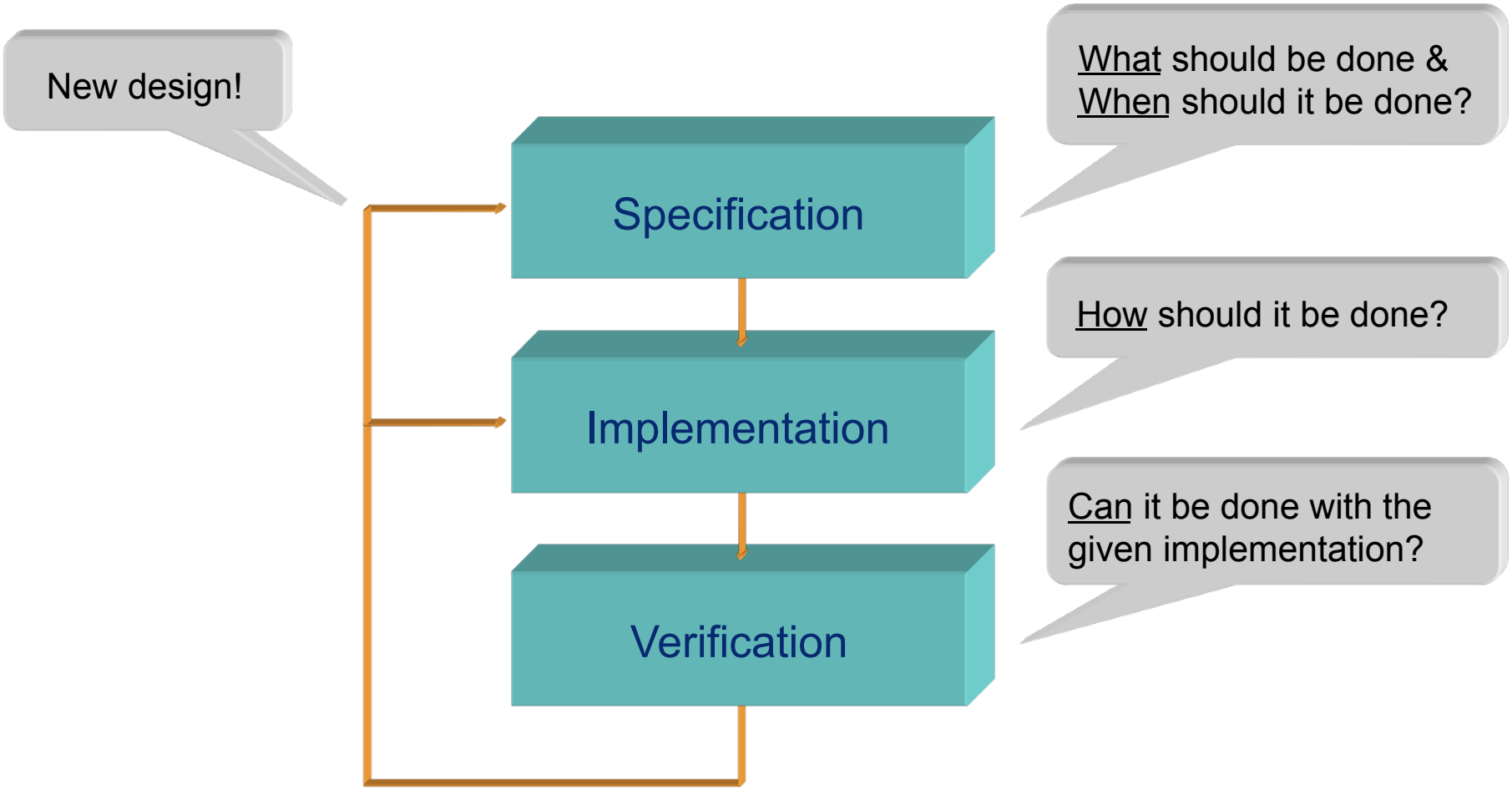
- Transaction systems
  - E-commerce; ticket booking; teller machines; stock exchange
  - Wireless phones; telephone switches

- Multimedia
  - Portable music players, streaming music
  - Computer games; video-on-demand, virtual reality

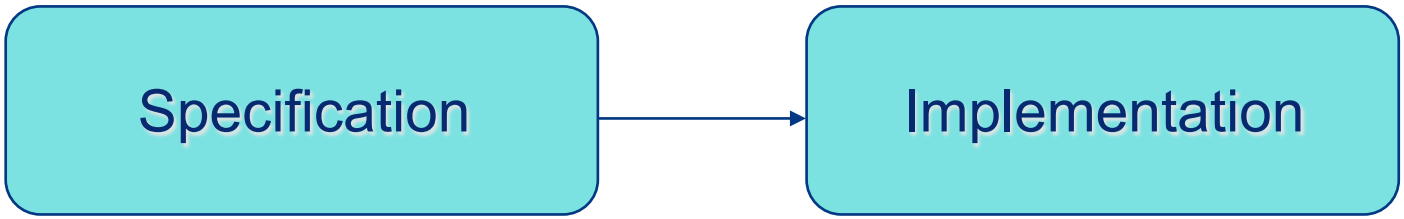
Real-time system components



Designing a real-time system



Specification



Requirements:		Constraints:
Sampling rate	→	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

Critical choices to be made at design time:

- 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

Critical choices to be made at design time:

- 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

How do we verify the system?

Ad hoc testing:

Run the system for ”a while” and let the absence of failures ”prove” the correctness

- fast method that indicates that ”everything seems to work”
- pathological cases can be overlooked during testing
- too frequently used as the only method in industrial design

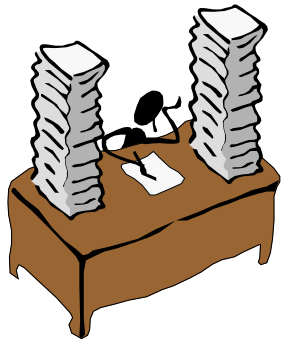
Exhaustive testing:

Verify all combinations of input data, time and faults

- considers all possible cases
- requires an unreasonable amount of time for testing

Verification

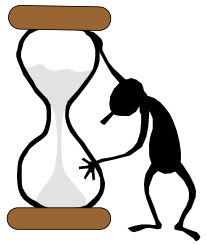
How do we verify the system?



Formal analysis of the implementation:

Verify logical correctness using proof machine

- requires dedicated description language
- abstraction level very high (often implementation independent)



Verify temporal correctness using schedulability analysis

- necessary for verifying hard-real-time systems
- requires WCET for each task
- requires support in programming language and run-time system

Note: results from the verification phase are only valid if all assumptions actually apply at run-time!

Verification

What sources of uncertainty exist in formal verification?

- Non-determinism in tasks' WCET (undisturbed execution)
  - Input data and internal state controls execution paths
  - Memory access patterns control delays in processor architecture (pipelines and cache memories)
- Non-determinism in tasks' execution interference
  - Run-time system's scheduling policy controls interference pattern of tasks with pseudo-parallel execution
- Conflicts in tasks' demands for shared resources
  - Pseudo-parallel task execution may give rise to uncontrolled blocking of shared hardware and software resources