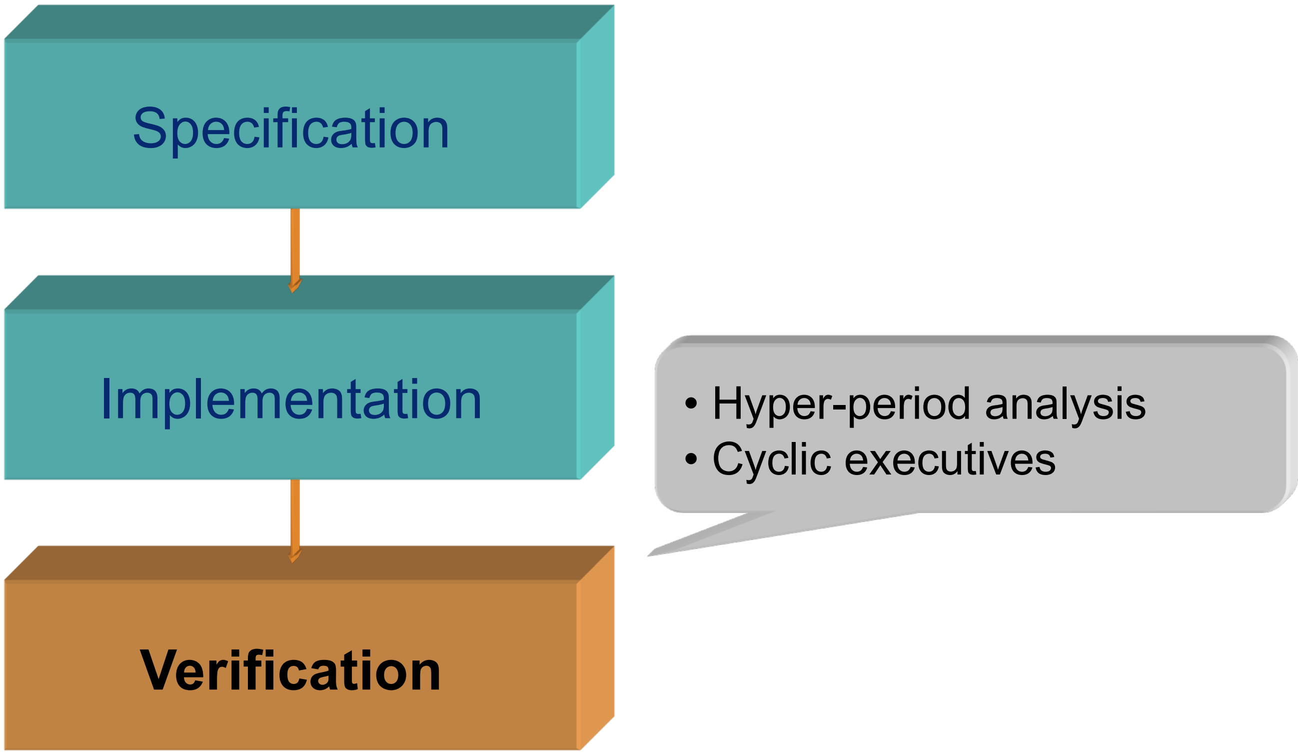
# Real-Time Systems

Lecture #10

Professor Jan Jonsson

Department of Computer Science and Engineering
Chalmers University of Technology

# Real-Time Systems



# Feasibility tests

## What types of feasibility tests exist?

- Hyper period analysis (for any type of scheduler)
  - In an existing schedule no task execution may miss its deadline
- Processor utilization analysis (static/dynamic priority scheduling)
  - The fraction of processor time that is used for executing the task set must not exceed a given bound
- Response time analysis (static priority scheduling)
  - The worst-case response time for each task must not exceed the deadline of the task
- Processor demand analysis (dynamic priority scheduling)
  - The accumulated computation demand for the task set under a given time interval must not exceed the length of the interval

# Hyper period analysis

Motivation:

- When it is not obvious which feasibility analysis should be used for a given task set and a given scheduler it is always possible to generate a schedule by simulating the execution of the tasks, and then check feasibility for individual tasks.
- The schedule interval that is sufficient to investigate is related to the hyper period of the task set, that is, the least common multiple (LCM) of the task periods.

NOTE: Unless the periods of all tasks are harmonically related (multiples of each other) hyper-period analysis will in general have an exponential time complexity.

# Hyper period analysis

Schedule interval to investigate:

- For synchronous task sets: $\forall i, j : O_i = O_j$

  It is sufficient to investigate the interval $[0, P]$ where $P$ is the hyper period of the task set.

- For asynchronous task sets: $\exists i, j : i \neq j, O_i \neq O_j$

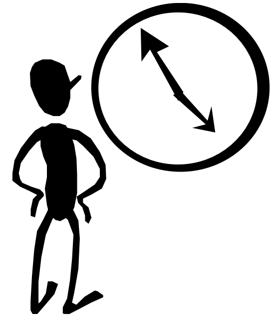
  It is sufficient to investigate the interval $[0, P]$ if no task instance that arrives within the interval executes beyond time $P$.

  In all other cases it is necessary to investigate more than one hyper period.

# Cyclic executives

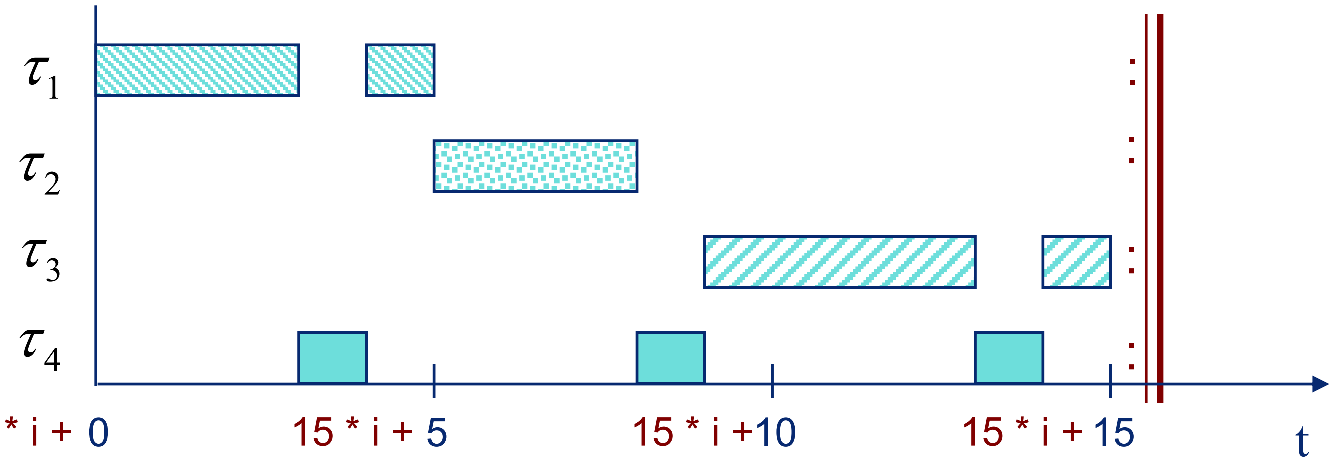

Because of its deterministic properties the cyclic executive is often the choice of scheduler in safety-critical real-time systems, such as automotive and aircraft applications.

# Cyclic executives



## General properties:

- Table-based schedule
- Feasibility test performed when generating table
- Schedule repeats itself (= "cyclic executive")



# Cyclic executives

## General properties:

- Off-line schedule generation
  - Explicit start and finish times for each task are derived off-line, and chosen so that at most one task at a time requests access to the processor during run time.
- Mutual exclusion is handled explicitly
  - The schedule must be generated in such a way that a task switch is not made within a critical region (= no need for mutual exclusion support at run-time, e.g. mutex objects)
- Precedence constraints are handled explicitly
  - The schedule must be generated in such a way that specified task execution orderings are respected (= no need for task synchronization at run-time, e.g. semaphores)

# Cyclic executives

## Advantages:

- Communication between tasks is facilitated
  - The time instant when data becomes available is known
  - Task execution can easily be adapted to any existing time-slot network protocol (e.g., TTCAN, FlexRay).
- Low overhead for scheduling decisions
  - Everything is pre-planned: time table guides the run-time system
  - Feasibility test is done off-line during time table generation
- Task execution becomes very deterministic
  - Simplifies feasibility tests (compare finish time against deadline)
  - Simplifies software debugging (increased observability)
  - Simplifies fault tolerance (natural points in time for self control)

# Cyclic executives

## Disadvantages:

- Low flexibility (a.k.a. the ”Skalman” factor)
  - The run-time system cannot adapt its schedule to changes in the task set or in the system environment
- External events are not handled efficiently
  - Data from I/O-based events (interrupts) may not be consumed directly by a periodic task due to the pre-planned schedule, which could lead to long response times.
  - An external event with a short deadline must be handled by a task with short period, which may lead to resource waste
- Not so efficient for tasks with ”bad” periods
  - Tasks with mutually inappropriate periods give rise to large time tables, which may require more program code and/or data

# Cyclic executives

## How is the schedule generated?

- Simulation of pseudo-parallel execution:
  - Simulate a run-time system with a (myopic) priority-based scheduler and then ”execute” the tasks on that simulator.
  - Example: find a schedule by simulating a run-time system with the (dynamic priority) earliest-deadline-first scheduler.
- Exhaustive search:
  - Use an algorithm that searches for a feasible schedule by considering all possible execution orders for the tasks.
  - Example: use the well-known A* search algorithm to find a feasible (optimal or non-optimal) schedule.

If the simulated scheduler or search algorithm is optimal for the given system model a feasible schedule will be found whenever one exists.

# Cyclic executives

## How is the size of the time table restricted?

- Only cyclic schedules are considered:
  - Schedule is repeated with a cycle time (“hyper period”) that is equal to the LCM (”least common multiple”) of the task periods.
  - Tasks that are not periodic, or that have very long periods, can be handled by reserving time slots in the schedule for a “server” that can handle such special tasks when they arrive.
- Suitable task periods are chosen:
  - To obtain reasonably large time tables, the task periods should (if application allows) be adjusted to be multiples of each other.
  - Example:

    7, 13, 23 ms ⇒ cycle time 2093 ms (551 task instances), but
    5, 10, 20 ms ⇒ cycle time 20 ms (only 7 task instances)

# Cyclic executives

## How is the scheduler implemented?

- Use a circular queue that corresponds to the time table
  - Each element in the queue contains start and finish times for a certain task (or task segment in case of preemptive scheduling)
  - The elements in the queue are sorted by the start time
- Use clock interrupts
  - When a task starts executing, a real-time clock is programmed to generate an interrupt at the start time of the next (the one whose start time is closest in time) element in the queue.
  - When the interrupt occurs, the next element in the circular queue is fetched and the procedure is repeated.

# Cyclic executives

## How is a generated schedule visualized?

- Timing diagram
  - A timing diagram illustrates how each task executes at run-time, by explicitly denoting on a time line the start and finish times for each execution of a task (or a task segment).
- Execution semantics
  - In a timing diagram all task executions must run to completion, regardless of whether the task misses its deadline or not. This also applies when simulating the pseudo-parallel execution of tasks in a priority-based run-time system.

A run-time system normally does not terminate the execution of a task that has missed a deadline, because it is assumed that the system designer has made sure that a task will never miss a deadline at run-time by means of schedulability analysis.

# Cyclic executives

## Programming with the TinyTimber kernel (p. 17):

```
int main() {
   INSTALL( &sonar, echo, IRQ_ECHO_DETECT );
   return TINYTIMBER( &sonar, tick, 0 );
}
```

TinyTimber uses both deadlines and baselines as input to its scheduling algorithm, although it is actually only the deadlines that pose any real challenge to the scheduler. However, missed deadlines are not trapped at run-time; if such behavior is desired it must be programmed by means of a separate watchdog task.

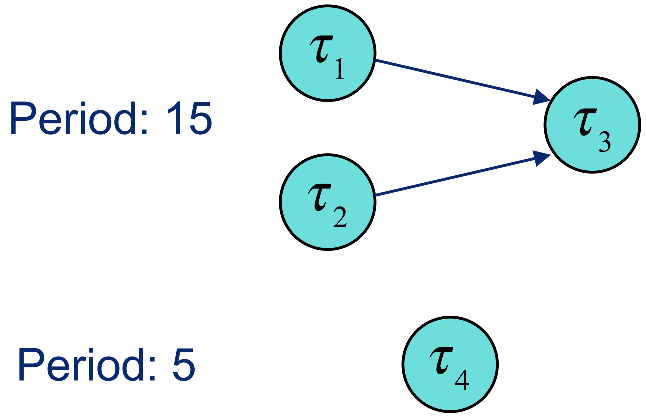
Judging whether a TinyTimber program will meet all its deadlines at run-time is an interesting problem, that can only be solved using a separate schedulability analysis and known worst-case execution times for all methods. That topic, however, is beyond the scope of the present text.

### 7 Summary of the TinyTimber interface

- `#include "TinyTimber.h"`

# Example: simulating EDF

Problem: Assume a system with tasks and precedence constraints according to the figure below. Timing constraints for the tasks are given in the table. Generate a cyclic schedule for these tasks by simulating preemptive earliest-deadline-first (EDF) scheduling.




| Task | $C_i$ | $O_i$ | $D_i$ | $T_i$ |
|---|---|---|---|---|
| $\tau_1$ | 4 | 0 | 7 | 15 |
| $\tau_2$ | 3 | 0 | 12 | 15 |
| $\tau_3$ | 5 | 0 | 15 | 15 |
| $\tau_4$ | 1 | 3 | 1 | 5 |