AADL : about scheduling analysis

Scheduling analysis, what is it ?

- **Embedded real-time critical systems** have temporal constraints to meet (e.g. deadline).

- Many systems are built with operating systems providing multitasking facilities … Tasks may have deadline.

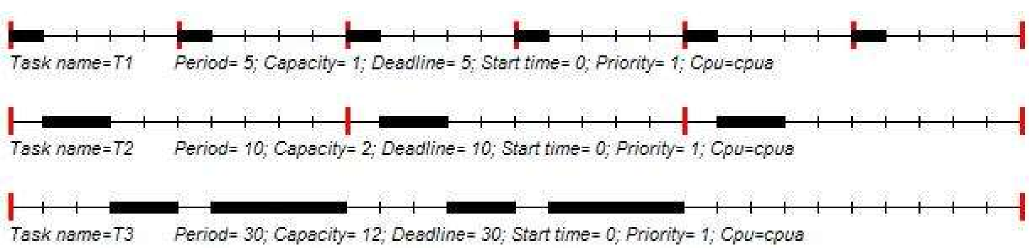
- **But, tasks make temporal constraints analysis difficult to do :**
  - We must take the task scheduling into account in order to check task temporal constraints.
  - Scheduling (or schedulability) analysis.

Real-Time scheduling theory

1. **A set of simplified tasks models** (to model functions of the system)
2. **A set of analytical methods** (called feasibility tests)
   - **Example:**

$$R_i \leq Deadline \qquad\qquad R_i = C_i + \sum_{j \in hp(i)} \left\lceil \frac{R_i}{P_j} \right\rceil \cdot C_j$$

3. **A set of scheduling algorithms**: build the full scheduling/GANTT diagram



Real-Time scheduling theory is hard to apply

- Real-Time scheduling theory
  - Theoretical results defined from 1974 to 1994: feasibility tests exist for uniprocessor architectures
- Now supported at a decent level by POSIX 1003 real-time operating systems, ARINC653, …

- Industry demanding
  - Yet, hard to use

Real-Time scheduling theory is hard to apply

- Requires strong theoretical knowledge/skills
  - Numerous theoretical results: how to choose the right one ?
  - Numerous assumptions for each result.
  - How to abstract/model a system to verify deadlines?
- How to integrate scheduling analysis in the engineering process ?
  - When to apply it ? What about tools ?

It is the role of an ADL to hide those details

Uniprocessor fixed priority scheduling

- **Fixed priority scheduling :**
  - Scheduling based on fixed priority => priorities do not change during execution time.
  - Priorities are assigned at design time (off-line).
  - Efficient and simple feasibility tests.
  - Scheduler easy to implement into real-time operating systems.
- **Rate Monotonic priority assignment :**
  - Optimal assignment in the case of fixed priority scheduling and uniprocessor.
  - Periodic tasks only.

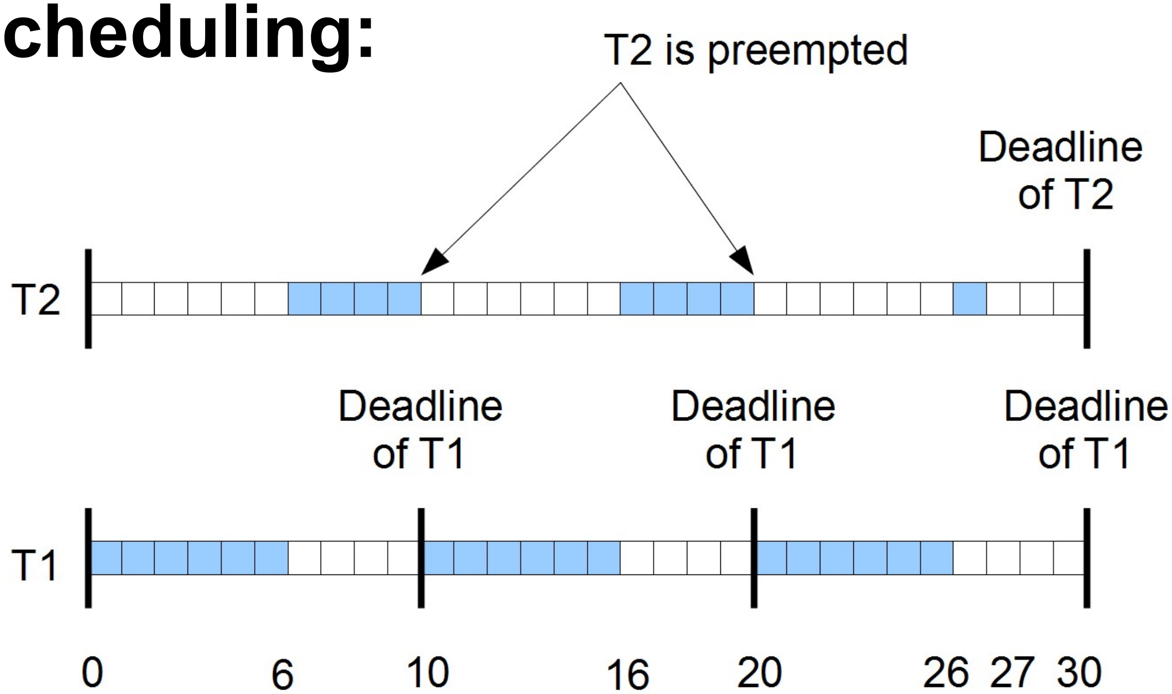
Uniprocessor fixed priority scheduling

- **Two steps:**
  1. **Rate monotonic priority assignment:** the highest priority tasks have the smallest periods. Priorities are assigned off-line (e.g. at design time, before execution).

  2. **Fixed priority scheduling**: at any time, run the ready task which has the highest priority level.

Uniprocessor fixed priority scheduling

- **Rate Monotonic assignment and preemptive fixed priority scheduling:**



- Assuming VxWorks priority levels (high=0 ; low=255)
- T1 : C1=6, P1=10, Prio1=0
- T2 : C2=9, P2=30, Prio2=1

Uniprocessor fixed priority scheduling

- **Feasibility/Schedulability tests <u>to predict at design-time if deadline will be met</u>:**

1. **Run simulations on hyperperiod** = [0,LCM(Pi)]. Sufficient and necessary condition.

2. **Processor utilization factor test:**

   $U = \sum_{i=1}^{n} Ci/Pi \leq n.(2^{\frac{1}{n}}-1)$ (about 69%)
   Rate Monotonic assignment and preemptive scheduling.
   Sufficient but not necessary condition.

3. **Task worst case response time, noted Ri** : delay between task release time and task completion time. Any priority assignment but preemptive scheduling.

Uniprocessor fixed priority scheduling

- **Compute Ri, task i worst case response time:**
  - Task i response time = task i capacity + delay the task i has to wait for higher priority task j. Or:

$$R_i = C_i + \sum_{j \in hp(i)} waiting\ time\ due\ to\ j \qquad or\ R_i = C_i + \sum_{j \in hp(i)} \left\lceil \frac{R_i}{P_j} \right\rceil \cdot C_j$$

  - hp(i) is the set of tasks which have a higher priority than task i.
  - $\lceil x \rceil$ returns the smallest integer not smaller than x.

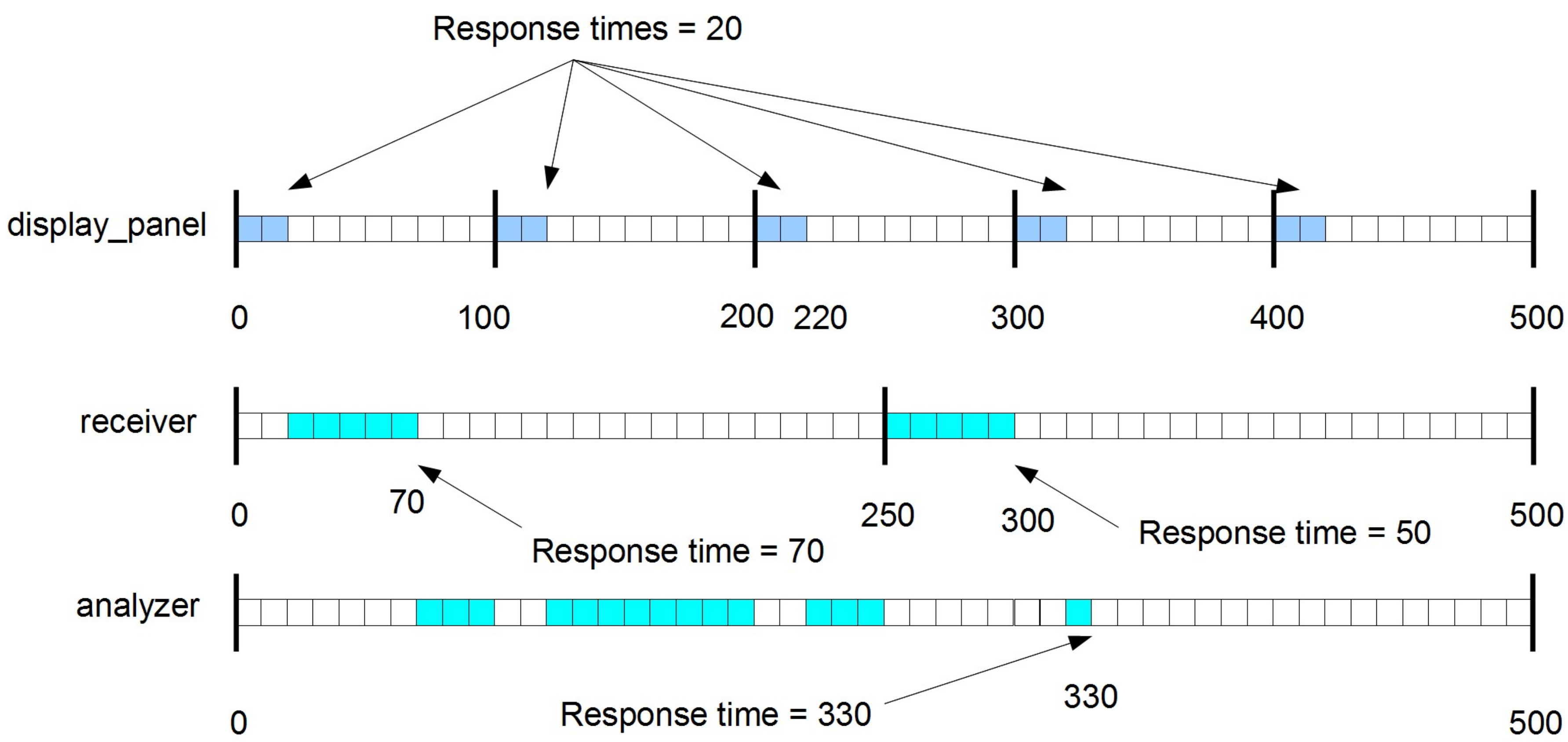
Uniprocessor fixed priority scheduling

- To compute task response time: compute wi^k with:

$$wi^n = Ci + \sum_{j \in hp(i)} \lceil wi^{n-1}/Pj \rceil . Cj$$

- Start with wi^0=Ci.
- Compute wi^1, wi^2, wi^3, ... wi^k upto:
  - If wi^k >Pi. No task response time can be computed for task i. Deadlines will be missed !
  - If wi^k = wi^{k-1}. wi^k is the task i response time. Deadlines will be met.

Uniprocessor fixed priority scheduling



Fixed priority and shared resources

- Previous tasks were independent … does not really exist in true life.

- **Task dependencies :**
  - Shared resources.
    - E.g. with AADL: threads may wait for AADL protected data component access.
  - Precedencies between tasks.
    - E.g with AADL: threads exchange data by data port connections.

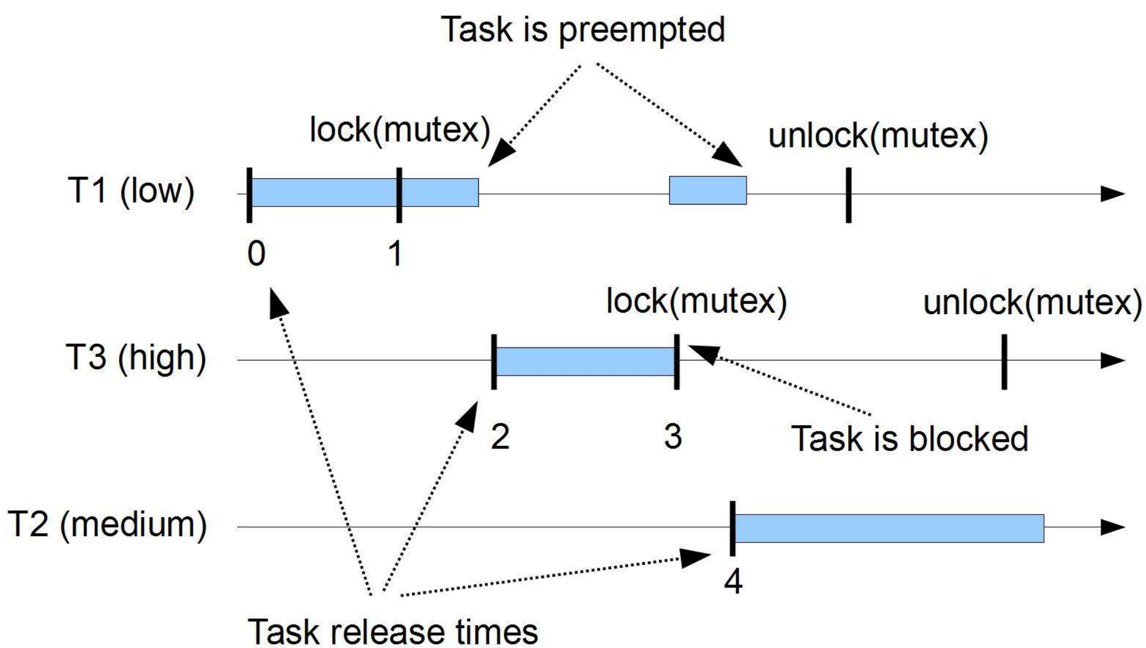
Fixed priority and shared resources

- Shared resources are modeled by semaphores for scheduling analysis.
- **We use specific semaphores implementing inheritance protocols:**
  - To take care of priority inversion.
  - To compute worst case task waiting time for the access to a shared resource. Blocking time Bi.

- **Inheritance protocols:**
  - PIP (Priority inheritance protocol), can not be used with more than one shared resource due to deadlock.
  - PCP (Priority Ceiling Protocol) , implemented in most of real-time operating systems (e.g. VxWorks).
  - Several implementations of PCP exists: OPCP, ICPP, …

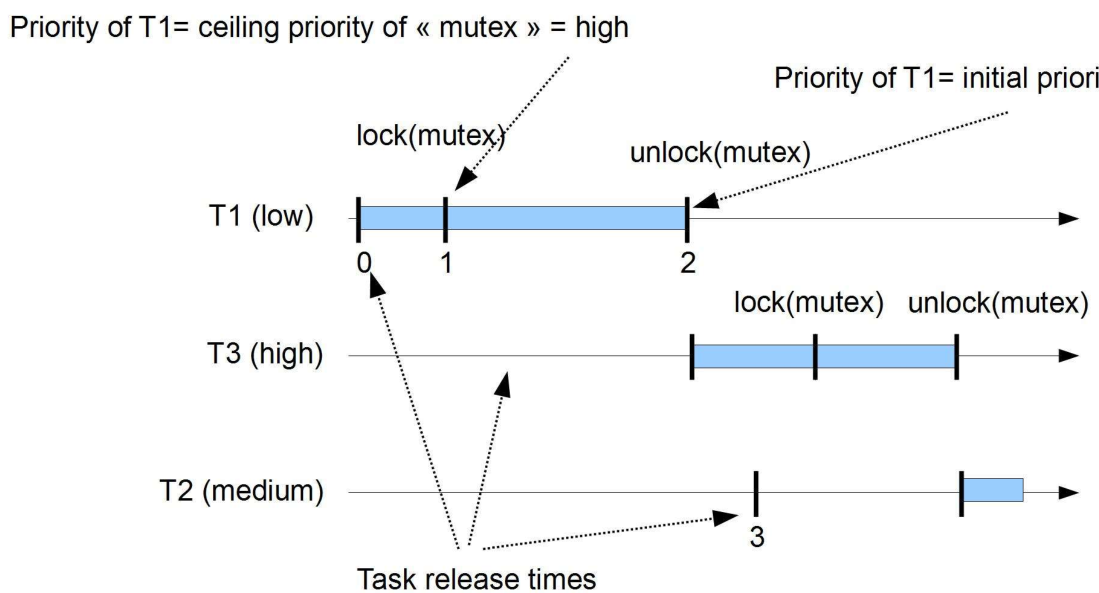
Fixed priority and shared resources

- **What is Priority inversion:** a low priority task blocks a high priority task



- B_i = worst case on the shared resource waiting time.

Fixed priority and shared resources



- **ICPP (Immediate Ceiling Priority Protocol):**
  - Ceiling priority of a resource = maximum fixed priority of the tasks which use it.
  - Dynamic task priority = maximum of its own fixed priority and the ceiling priorities of any resources it has locked.
  - B_i=longest critical section ; prevent deadlocks

Fixed priority and shared resources

- **How to take into account the waiting time Bi:**

  - Processor utilization factor test :

$$\forall\, i, 1 \ \leq i \ \leq n : \sum_{k=1}^{i-1} \frac{Ck}{Pk} + \frac{Ci+Bi}{Pi} \leq \ i.\,(2^{\frac{1}{i}} - 1)$$

  - Worst case response time :

$$R_i = B_i + C_i + \sum_{j \in hp(i)} \left\lceil \frac{R_i}{P_j} \right\rceil \cdot C_j$$

AADL to the rescue ?

- **Issues when we try to apply scheduling analysis:**
  - Many scheduling feasibility tests, many assumptions
  - Ensure model elements are compliant with analysis/feasibility test requirements/assumptions
  - Ensure all required model elements are given for the analysis

- **AADL helps for the first issue:**
  - AADL as a pivot language between tools. International standard.
  - Close to the real-time scheduling theory: real-time scheduling analysis concepts can be found. Ex:
    - Component categories: thread, data, processor
    - Property: `Deadline, Fixed Priority, ICPP, Ceiling Priority, …`

Property sets for scheduling analysis

- **Properties related to processor component:**

```
Preemptive_Scheduler : aadlboolean applies to (processor);

 Scheduling_Protocol:
  inherit list of Supported_Scheduling_Protocols
  applies to (virtual processor, processor);
 -- RATE_MONOTONIC_PROTOCOL,
 -- POSIX_1003_HIGHEST_PRIORITY_FIRST_PROTOCOL, ..
```

Property sets for scheduling analysis

- **Properties related to the threads/data components:**

```
Compute_Execution_Time: Time_Range
 applies to (thread, subprogram, …);

Deadline: inherit Time => Period applies to (thread, …);

Period: inherit Time applies to (thread, …);

Dispatch_Protocol: Supported_Dispatch_Protocols
 applies to (thread);
--  Periodic, Sporadic, Timed, Hybrid, Aperiodic, Background,
...

Priority: inherit aadlinteger applies to (thread, …, data);

Concurrency_Control_Protocol:
 Supported_Concurrency_Control_Protocols applies to (data);
--  None, PCP, ICPP, …
```

Property sets for scheduling analysis

- **Example:**

```
thread implementation receiver.impl
  properties
    Dispatch_Protocol => Periodic;
    Compute_Execution_Time => 31 ms .. 50 ms;
    Deadline => 250 ms;
    Period => 250 ms;
    Priority => 5;
end receiver.impl;

data implementation target_position.impl
  properties
   Concurrency_Control_Protocol
        => PRIORITY_CEILING_PROTOCOL;
end target_position.impl;
```

```
process implementation processing.others
  subcomponents
    receiver : thread receiver.impl;
    analyzer : thread analyzer.impl;
    target : data target_position.impl;
    . . .
processor implementation leon2
  properties
    Scheduling_Protocol =>
          RATE_MONOTONIC_PROTOCOL;
      Preemptive_Scheduler => true;
end leon2;

system implementation radar.simple
subcomponents
  main : process processing.others;
  cpu : processor leon2;
   . . .
```