EINDHOVEN UNIVERSITY OF TECHNOLOGY

Department of Mathematics and Computer Science

Examination Real-time Architectures (2XN26)
on Monday, January 23^{rd} *2012, 9.00h-10.30h.*

First read the entire examination. There are 5 exercises in total. Grades are included between parentheses at all parts and sum up to 9.5 points. Good luck!

1. This exercise concerns general aspects of real-time systems.

   (a) (0.5) Describe the essentials of a real-time system in at most two sentences.

   (b) (0.5) Timing requirements can be classified as either *functional* requirements or as *quality* requirements. When should which classification be used?

   (c) (0.5) Describe the differences between *dependable* and *high-performance* real-time systems. *Hint*: address requirements with respect to *failure*.

   Answer: See RTS.A1-Introduction.

2. (1.0) Timeliness constraints on a *controlling system* are typically *derived* from the functional requirements and *determined* by (the environment and) design choices in the *system*. Give an example, explicitly describing the *functional requirements*, the (environment and) *design choices*, and the derived *timeliness constraint*.
   Hint: think of water-vessel.
   Answer: See RTS.B3-Specification-concepts (and optionally RTS.D0-Water-Vessel).

3. Consider three tasks that are scheduled by means of fixed-priority pre-emptive scheduling (FPPS), where τ_1 has highest and τ_3 has lowest priority, with arbitrary phasing and characteristics as given in the following table.

	T	WD	BD	AJ	$WC = BC$
τ_1	3	1	1	1	1
τ_2	6	6	4	2	3
τ_3	23	25	7	3	5

   (a) (0.5) Determine the smallest positive solution of (1) for task τ_3 using

$$x = B_i + WC_i + \sum_{1 \leq j < i} \left\lceil \frac{x + AJ_j}{WT_j} \right\rceil WC_j. \qquad (1)$$

   Answer: Note that the *lowest* priority task is *never* blocked. Hence, $B_3 = 0$ irrespective of potential resource sharing. Using an iterative procedure, we find $WR_3 = 40$, which is larger than $WD_3 = 25$.

   (b) (0.5) The period $T_3 = 23$ of τ_3 is *smaller* than the deadline $D_3 = 25$. Is the value determined above therefore indeed the worst-case response time WR_3 of τ_3? Motivate your answer.
   Answer: The utilization U of the set of tasks is equal to $\frac{1}{3} + \frac{3}{6} + \frac{5}{23} > \frac{1}{3} + \frac{3}{6} + \frac{5}{25} > 1$. The task set is therefore not schedulable and the worst-case response of the lowest

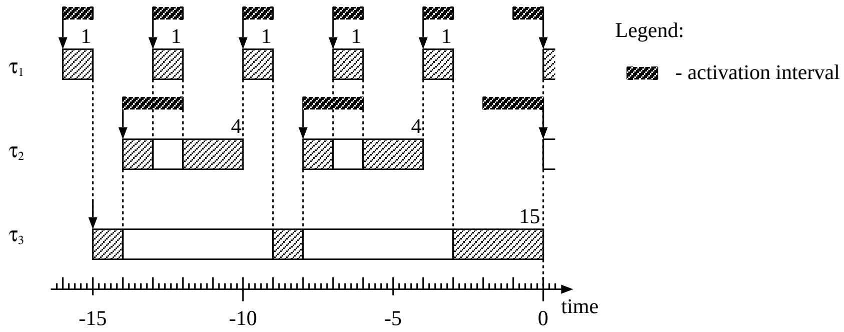

Figure 1: Timeline with an optimal instant for task τ_3.

priority task τ_3 can become arbitrary large. Assuming all three tasks start at the same time, the smallest solution of (1) presents the response time of the first job of τ_3.

(c) Determine the best-case response time of task τ_3

i. (0.5) by drawing a time line with an optimal instant for τ_3.
Answer: See Figure 1. Note that $BR_3 = 15$. Further note that because $U > 1$, we would get additional interference of a previous job when the time line would be extended towards the left.

ii. (0.5) by means of the following recursive equation.

$$x = BC_i + \sum_{1 \le j < i} \left(\left\lceil \frac{x - AJ_j}{BT_j} \right\rceil - 1 \right)^+ BC_j \tag{2}$$

Answer: Using $WR_3 = 40$ as initial value for the iterative procedure to determine the best-case response time BR_3, we find $BR_3 = 15$. Note that because $U > 1$, the result of the calculation will only hold for the specific instantiation shown in Figure 1.

(d) (0.5) Is task τ_3 schedulable? Motivate your answer.
Answer: No, because $U > 1$.

4. This exercise concerns servers.

(a) *Periodic servers*

i. (0.5) Two types of periodic servers have been presented, *idling* and *gain-time consumption*. Explain the difference between both types in your own words.
Answer: See RTS.B4-Policies-2-FP-servers.

ii. (0.5) Is the choice of the type of periodic server of influence on worst-case response time calculations? Motivate your answer.
Answer: No, because the worst-case characteristics of both servers are identical; see RTS.Exercises-5.

(b) *Schedulability of a system with servers*
Let a system S consist of a set $\mathcal{T}$ of n hard real-time tasks τ_i with $1 \le i \le n$ and a server at highest priority. Assume $D_i \le T_i$ and scheduling based on FPPS.

i. (1.0) Describe a worst-case schedulability condition of system S with a *deferrable server DS* based on worst-case response-time analysis. *Hint*: use (1).

Answer: $\forall_{1 \leq i \leq n} WR_i \leq WD_i \;\wedge\; C_{DS} \leq T_{DS}$, where $J_{DS} = T_{DS} - C_{DS}$, T_{DS} is the period of DS and C_{DS} is the capacity of DS. We can now simply add a term $\lceil \frac{x+J_{DS}}{T_{DS}} \rceil C_{DS}$ to the RHS of (1) to determine WR_i for all i.

ii. (0.5) Describe a best-case schedulability condition of a system with a *polling server PS* based on best-case response-time analysis. *Hint*: use (2).

Answer: $\forall_{1 \leq i \leq n} BR_i \geq BD_i$. We can now simply reuse (2) to determine BR_i for all i, because $BC_{PS} = 0$.

5. This exercise concerns resource access protocols (RAPs).

(a) (0.5) The Priority Ceiling Protocol (PCP) and the Stack Resource Policy (SRP) are both based on resource ceilings. They differ with respect to the *moment* blocking occurs. Describe the difference in your own words.

Answer: Blocking occurs upon an attempt to

- *lock* a resource under PCP, i.e. on *resource access*;
- *start* execution (of a job) under SRP, i.e. on *preemption*.

See RTS.B4-Policies-3-RAP.

(b) (0.5) Describe how to compute the maximum blocking B_i of a task τ_i under the highest locker protocol. *Hint*: use the notion of *ceiling* cr_R of a resource R and the (worst-case) execution time C_j^R of a task τ_j when accessing R.

Answer: See RTS.exercises-8-RAP.

(c) This exercise concerns deadlocks.

i. (0.5) Describe the characteristics of a deadlock and give an example.

ii. (0.5) Describe two approaches to avoid deadlocks.

Answer: See RTS.B4-Policies-3-RAP.