EINDHOVEN UNIVERSITY OF TECHNOLOGY
Department of Mathematics and Computer Science

Examination Real-time Architectures (2IN25)
on Friday, January 22^{nd} 2010, 9.00h-12.00h.

First read the entire examination. There are 7 exercises in total. Grades are included between parentheses at all parts and sum up to 9 points. Good luck!

1. The hyperbolic bound $HB(n) : \prod_{1 \le i \le n}(U_i^\tau + 1) \le 2$, where U_i^τ denotes the processor utilization of the task τ_i, is an example of a *sufficient* schedulability test.

   (a) (0.5) Give at least four conditions that need to hold to use this bound.

   (b) (1.0) Construct an example set of four tasks for which the left-hand side of $HB(4)$ is equal to 2, where all tasks have *different* periods.

   Answer: See exercise 1 of the examination for 2IN25 of January 6^{th}, 2009 for (b).

2. Consider three tasks with arbitrary phasing and the following characteristics:

   - an *elastic* task τ_1 with a minimum inter-arrival time of 5 and a maximum inter-arrival time of 6, a worst-case deadline equal to 6 and a best-case deadline equal to 2, and a fixed computation time of 2;
   - a *periodic* task τ_2 *with jitter* with a period of 11, activation jitter of 1, a worst-case deadline equal to 9 and a best-case deadline equal to 2, a best-case computation time of 2 and worst-case computation time of 3;
   - a *sporadic* task τ_3 with a minimum inter-arrival time of 31, a worst-case deadline equal to 29 and a best-case deadline equal to 11, and a fixed computation time of 7.

   Preparation towards an answer: The characteristics of the tasks are given below.

	WT	WD	BT	BD	AJ	WC	BC
τ_1	5	6	6	2	0	2	2
τ_2	11	9	11	2	1	3	2
τ_3	31	29	∞	11	0	7	7

   (a) (0.5) Give a *necessary* condition for schedulability of the three tasks that is *not sufficient*, i.e. *not exact*. The necessary condition must have separate clauses for best-case and worst-case situations.
   Answer: A *necessary*, but *not exact*, worst-case condition is given during the course, e.g.

$$\sum_{1 \le i \le 3} \frac{WC_i}{WT_i} \le 1.$$

   During the course, we did not address a best-case condition. We know that *if* the best-case schedulability condition is *not* met *then* the necessary best-case condition will not hold. The best-case schedulability condition is given by $\underset{1 \le i \le 3}{\forall} BR_i \ge BD_i$.

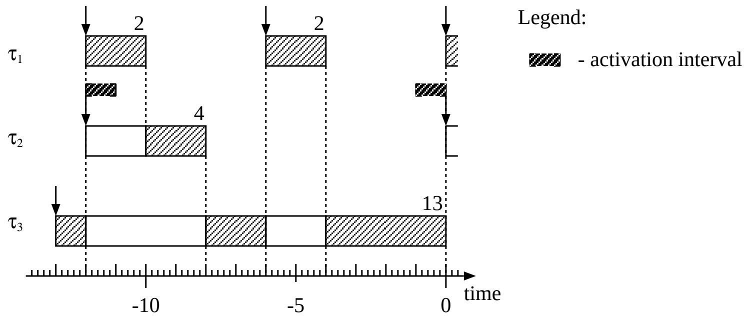

Figure 1: Time line with an optimal instant for task τ_3.

For $BD_i > 0$, BC_i must be larger than zero. Hence, a necessary best-case condition is

$$\forall_{1 \leq i \leq 3} (BD_i > 0 \Rightarrow BC_i > 0).$$

When $\forall_{1 \leq i \leq n} BC_i > 0$ is basic assumption of our real-time scheduling model, the necessary best-case condition becomes `true`.

(b) Assume fixed-priority pre-emptive scheduling, where τ_1 has highest and τ_3 has lowest priority.

i. (0.5) Determine the worst-case response time WR_3 of task τ_3 using the following recursive equation.

$$x = WC_i + \sum_{j<i} \left\lceil \frac{x + AJ_j}{WT_j} \right\rceil WC_j \tag{1}$$

Answer: $WR_3 = 28$.

ii. (0.5) Draw a time line with an optimal instant for task τ_3.
Answer: See Figure 1. Note that $BR_3 = 13 > BD_3 = 11$.

iii. (0.5) Determine the best-case response time BR_3 of task τ_3 using the following recursive equation.

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

Answer: We use $WR_3 = 28$ as initial value for the iterative procedure to determine the best-case response time BR_3. Using (2), we subsequently find $BR_3 = 13$, which is larger than $BD_3 = 11$.

3. The following questions concern fixed-priority servers.

(a) (0.5) Consider a system consisting of a periodic server, which is used to service aperiodic requests, and a set of hard real-time tasks. Describe the consequence of selecting either an *idling* or a *gain-time providing* periodic server for determining the best-case and worst-case response times of hard-real-time tasks.
Answers: The choice only potentially influences the best-case response time of hard real-time tasks with a priority lower than the periodic server; see RTA.Exercises-5 slide 8. In particular, those best-case response times can be *smaller* when selecting a gain-time providing periodic server.
This question has been taken from the 2IN25 Exam. of 090312.

(b) (0.5) Under which conditions does a deferrable server behave as a periodic task *without* self-suspension?
Answer When there is always work pending for the deferrable server if its capacity is larger than zero.
This question has been taken from the 2IN20 Exam. of 080613.

4. The following questions concern “Expected reading”.

   (a) (0.5) In ”Risk Forum: *What really happened on Mars Rover Pathfinder*, December 1997.”, both the problem and solution to the problem with the Mars Rover pathfinder are described. Describe the problem and its solution in your own words.

   (b) (0.5) In “I. Shin and I. Lee, *Periodic resource model for compositional real-time guarantees*, In: Proc. 24^{th} IEEE Real-Time Systems Symposium (RTSS), pp. 2-13, December 2003.” a resource supply bound function $\mathtt{sbf}_\Gamma(t)$ of a time interval of length t is defined that calculates the minimum resource supply of Γ during t units. Given a periodic resource $\Gamma(\Pi, \Theta)$, draw $\mathtt{sbf}_\Gamma(t)$ as a function of t for $0 \leq t \leq 5\Pi$, where $\Pi/4 \leq \Theta \leq \Pi/3$.

5. The following questions concern specific lectures.

   (a) (0.5) Describe the notion of *Offline scheduling* and describe its properties compared to online scheduling.
   Answer: See slide 9 of Offline scheduling.pdf.

   (b) One of the lectures concerned *A QoS approach for multimedia consumer terminals with media processing in software*. The aim of the QoS approach was *cost-effective high-quality video processing in software for multimedia consumer terminals*, motivated by the requirements for *openness* and *flexibility* of these systems, and having as boundary condition that *the existing system qualities should be preserved*.

      i. (0.5) Explain which real-time problems were addressed.
      ii. (0.5) Explain how these problems have been solved.

   Answer See slides of the lecture.

6. Explain the following concepts in your own words.

   (a) (0.5) Priority inversion.
   Answer: See slide 6 of RTA.B4-Policies-3 and book.

   (b) (0.5) Chained blocking.
   Answer: See slide 8 of RTA.B4-Policies-3 and book.

7. (1.0) Give an example illustrating transitive adjustment of priorities for the Priority Inheritance Protocol (PIP).
   Answer: See slides RTA.B4-Policies-3 and book Fig. 7.8.