EINDHOVEN UNIVERSITY OF TECHNOLOGY

Department of Mathematics and Computer Science

Examination Real-time Architectures (2IN60)
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 11 points. Good luck!

1. The hyperbolic bound $HB(n) : \prod_{1 \leq i \leq n}(U_i^{\mathcal{T}} + 1) \leq 2$, where $U_i^{\mathcal{T}}$ 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) (0.5) What can be concluded concerning schedulability of a set $\mathcal{T}$ of n tasks when the hyperbolic bound does not hold for $\mathcal{T}$?
   (c) (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.
   (d) (0.5) Is the task set that you constructed schedulable according to the Liu & Layland bound? Motivate your answer.
   Reminder: $LL(n) : U^{\mathcal{T}} \leq n(2^{1/n} - 1)$, where $U^{\mathcal{T}}$ denotes the processor utilization of the set $\mathcal{T}$.

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

2. (a) (0.5) *Atomicity*: Let the initial state of variables x and y be described by $x = 2$ and $y = 1$. Assume the following parallel program: $x := y \mid\mid y := x$. What are the possible final values for x and y? Motivate your answer.
   Answer: See slides of OS-02-Atomicity addressing pre-knowledge.
   (b) (0.5) A car, such as a member of the BMW 7 Series, may have a network infrastructure consisting of multiple networks, such as K-CAN, MOST, SI-BUS and PT-CAN, which are connected via a gateway. Why are multiple, different networks used?
   Answer: See slides of 2IN60.prior-knowledge-I.
   (c) (0.5) What does "interrupt handlers must be transparent" mean?
   Answer: See slides of 2IN60.prior-knowledge-II.

3. Consider two periodic tasks τ_1 and τ_2 and a polling server S_{P} with characteristics as given in Table 3. Assume scheduling based on FPPS and a rate monotonic priority assignment.

	$T = D$	C	φ
S_{P}	6	1	0
τ_1	5	2	0
τ_2	9	4	0

Table 1: Characteristics of tasks and polling server.

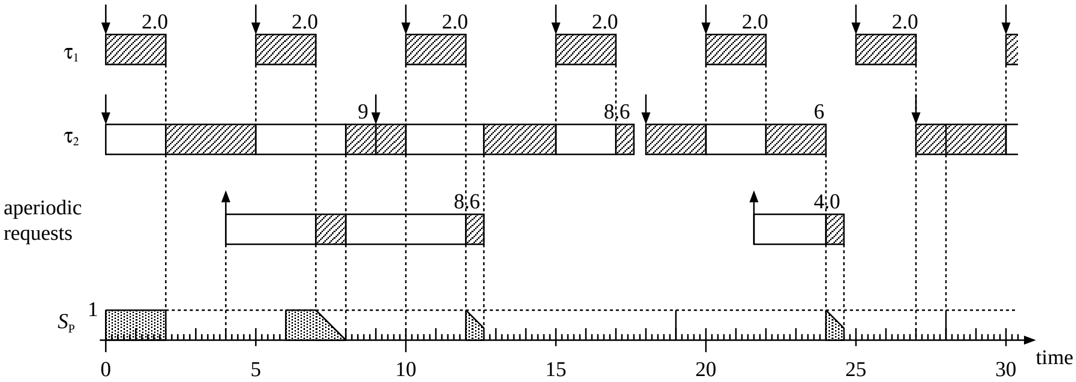

Figure 1: Example of medium-priority Polling Server.

(a) (1.0) Assuming arrivals of aperiodic requests at time $t = 4$ for an amount of 1.6 and at time $t = 20.6$ for an amount of 0.6, draw time-lines illustrating the execution of the tasks and the remaining capacity of the polling server in an interval of length 30. **Answer**: See Figure 1.

(b) (0.5) Are the tasks and the polling server schedulable under arbitrary phasing? Motivate your answer by means of *calculations*. *Hint*: Determine the worst-case response times of the tasks by means of 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: Note that $AJ_P = 0$. Based on (1), we find $WR_1 = 2 < D_1 = 5$ and $WR_2 = 10 > D_2 = 9$. Hence, task τ_2 misses its deadline and task τ_2 is therefore not schedulable.

4. 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

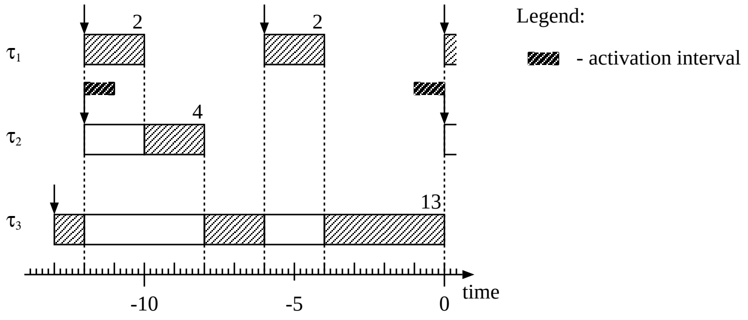

Figure 2: Time line with an optimal instant for task τ_3.

best-case and worst-case situations.
Answer: A *necessary*, but *not exact*, worst-case condition is given during the course, e.g.

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

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 $\underset{1\leq i\leq 3}{\forall} BR_i \geq BD_i$. For $BD_i > 0$, BC_i must be larger than zero. Hence, a necessary best-case condition is

$$\underset{1\leq i\leq 3}{\forall} \left(BD_i > 0 \Rightarrow BC_i > 0\right).$$

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) Draw a time line with an optimal instant for task τ_3.
  Answer: See Figure 2. Note that $BR_3 = 13 > BD_3 = 11$.

  ii. (1.0) Determine the best-case response time 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: Using (1) we first determine the worst-case response time $WR_3 = 28$ as initial value for the iterative procedure to determine the best-case response time BR_3. Using (2), we subsequently find $BR_3 = 13 > BD_3 = 11$.

5. (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) (1.0) Describe the notion of *Offline scheduling* and describe its properties compared to online scheduling.
   Answer: See slide 9 of Offline scheduling.pdf.

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.