First read the entire examination. There are 6 exercises in total. Grades are included between parentheses at all parts and sum up to 9 points. Good luck!

1. A recursive equation to determine the worst-case response time of a periodic task \( \tau_i \) is given by
   \[
   x = C_i + \sum_{j<i} \left\lceil \frac{x}{T_j} \right\rceil C_j.
   \]
   (a) (0.5) For which class of scheduling algorithms is this equation applicable?
   (b) (0.5) Give at least four assumptions that need to hold to use this equation.
   
   **Answer**: See RTA examination of August 30th 2006.

2. Consider two periodic tasks \( \tau_1 \) and \( \tau_2 \), with characteristics as given in the following table, which are scheduled by means of fixed-priority scheduling with deferred pre-emption (FPDS), where \( \tau_1 \) has a higher priority than \( \tau_2 \).

<table>
<thead>
<tr>
<th></th>
<th>( T = D )</th>
<th>( C )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \tau_1 )</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>( \tau_2 )</td>
<td>4</td>
<td>( \frac{1}{2} )</td>
</tr>
</tbody>
</table>

   (a) (1.0) Determine the worst-case length \( WL_2 \) of the level-2 active period.
   
   **Answer**: Draw a timeline with a simultaneous release of both tasks at time \( t = 0 \). Because the pending load becomes zero at time \( t = 2\frac{1}{2} \), the worst-case length \( WL_2 = 2\frac{1}{2} \).

   (b) (1.0) Determine the worst-case response times \( WR^D_1 \) of \( \tau_1 \) and \( WR^D_2 \) of \( \tau_2 \) using
   
   \[
   WR^D_{ik} = \begin{cases} 
   WR^P_i(B^D_i + kC_i - F_i) + F_i - (k-1)T_i & \text{for } i < n \\
   WO^P_i(kC_n - F_n) + F_n - (k-1)T_n & \text{for } i = n 
   \end{cases},
   \]
   
   and the following recursive equations for \( WR^P_i(C) \) and \( WO^P_i(C) \), respectively.

   \[
   x = C + \sum_{j<i} \left\lceil \frac{x}{T_j} \right\rceil C_j,
   \]
   \[
   x = C + \sum_{j<i} \left( \left\lceil \frac{x}{T_j} \right\rceil + 1 \right) C_j.
   \]

   **Answer**: For task \( \tau_1 \), it is only necessary to consider the first job: \( WR^D_1 = 2\frac{1}{2} \). Because the worst-case length \( WL_2 \) of the level-2 active period contains \( \left\lceil \frac{W_2}{T_2} \right\rceil = 1 \) job, we need to consider one job for task \( \tau_2 \). Hence \( WR^D_2 = WR^D_{2,1} = 2\frac{1}{2} \).
3. (1.0) 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.

4. (2.0) Let tasks $\tau_1$ and $\tau_2$ both use resources $r_1$ and $r_2$. Task $\tau_1$ first locks $r_1$ and subsequently $r_2$, and $\tau_2$ first locks $r_2$ and subsequently $r_1$, which may give rise to a deadlock without a resource access protocol; see Figure 1. Discuss what happens when a resource access protocol is used and illustrate the behaviour by means of appropriate drawings for PIP, HLP, PCP, and SRP.

**Answer:** See RTA examination of June 13th 2008 or RTA.Exercises-8+solutions.

5. The following questions concern presentations of assignments.

(a) **Hierarchical scheduling of dependent applications:** Two approaches were presented for global resource access, one approach termed H-SRP and the other termed SIRAP. The approaches differed with respect to their behavior when the amount of remaining capacity of a reservation was less than the amount of time needed for accessing the global resource.

i. (0.5) Explain the difference between both approaches.

**Answer:** H-SRP assumes budget overrun (optionally with pay-back) and SIRAP assumes (self-) blocking.

ii. (0.5) What are the consequence of SIRAP for a supporting mechanism?

**Answer:** Upon entering a critical section, a check is needed whether or not there is still enough remaining capacity to use the global resource, i.e. to execute the critical section.

(b) **Fixed Priority Scheduling in Multiprocessor Systems:** Is the following sporadic task system schedulable on two identical processors? Motivate your answer. Assume fixed-priority pre-emptive scheduling and that task $\tau_1$ has highest and $\tau_3$ has lowest priority.

<table>
<thead>
<tr>
<th></th>
<th>$T$</th>
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<tbody>
<tr>
<td>$\tau_1$</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>$\tau_2$</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>$\tau_3$</td>
<td>6</td>
<td>6</td>
<td>5</td>
</tr>
</tbody>
</table>

**Answer:** No; see slides.
6. The following questions concern guest-lectures.

(a) (0.5) Mike Holenderski gave a guest lecture entitled *Swift mode changes*. He con- sidered two scheduling approaches for mode changes, fixed-priority pre-emptive scheduling (FPPS) and fixed-priority scheduling with deferred pre-emption (FPDS). Which approach is better and why?

**Answer**: Assuming that processing a mode corresponds with a single sub-job, the worst-case lead-time of a mode-change is larger for FPPS than for FPDS, because for FPDS we need to wait for at most 1 sub-job to complete.

(b) (0.5) Alina Weffers-Albu gave a guest-lecture entitled *Behavioural Analysis of Real-Time Systems with Interdependent Tasks*. She explained that the behaviour of a chain of components scheduled by means of fixed-priority pre-emptive scheduling (FPPS) assumes a repetitive pattern after an finite amount of time. How can that amount of time for the so-called initial phase be minimized?

**Answer**: By giving the first task in the chain the lowest priority and/or by minimizing the size of the buffers prior to the lowest priority component in the chain.