This is a closed book exam.

You may use a simple calculator only (i.e. graphical calculators are not permitted).

Write your answers with a black or blue pen, not with a pencil.

Always justify your answers, unless stated otherwise.

The last question is optional (bonus).

EDF and FP refer to the preemptive Earliest-Deadline-First and preemptive Fixed-Priority scheduling algorithms unless it is explicitly mentioned that they are non-preemptive.

Assume that there is no preemption overhead unless it is stated explicitly in the question.

Assume that a smaller priority value indicates a higher priority for the FP scheduling algorithm.

The exam covers the following material:

(b) the paper “The Worst-Case Execution-Time Problem” by Wilhelm et al. (except Section 6)
(c) the paper “Non-Work-Conserving Non-preemptive Scheduling: Motivations, Challenges, and Potential Solutions” by Mitra Nasri and Gerhard Fohler
(d) the paper “An Exact and Sustainable Analysis of Non-Preemptive Scheduling” by Mitra Nasri and Björn B. Brandenburg
(e) the paper “Best-case response times and jitter analysis of real-time tasks” by R.J. Bril, E.F.M. Steffens, and W.F.J. Verhaegh
<table>
<thead>
<tr>
<th>Clause</th>
<th>Expression</th>
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<tbody>
<tr>
<td>Liu and Layland (LL) test</td>
<td>$U \leq n(2^{1/n} - 1)$</td>
</tr>
<tr>
<td>Hyperbolic bound (HB) test</td>
<td>$\prod_{i=1}^{n} (U_i + 1) \leq 2$</td>
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| Response-Time Analysis (FP) No jitter | $R_i = C_i + \sum_{k=1}^{i-1} \left\lceil \frac{R_i}{T_k} \right\rceil C_k$  
$R_i^{(0)} = C_i$ |
| With jitter | $WR_i = C_i + \sum_{k=1}^{i-1} \left\lceil \frac{WR_i + AJ_k}{T_k} \right\rceil C_k$  
$BR_i = C_i + \sum_{k=1}^{i-1} \left( \left\lfloor \frac{BR_i - AJ_k}{T_k} \right\rfloor - 1 \right) + C_k$  
$w^+ = \max(w, 0)$ |
| Demand Bound Analysis | $g(t_1, t_2) = \sum_{r_i \geq t_1} C_i$  
$g(0, L) = \sum_{i=1}^{n} \left\lceil \frac{L + T_i - D_i}{T_i} \right\rceil C_i$ |
| Schedulability | $\forall L \in D, \quad g(0, L) \leq L$  
$D = \{d_k | d_k \leq \min(H, \max(D_{max}, L^*))\}$  
$H = \text{lcm}(T_1, \ldots, T_n)$  
$D_{max} = \max\{D_i | \tau_i \in \tau\}$  
$L^* = \sum_{i=1}^{n} (T_i - D_i) \cdot U_i$  
$L = \frac{1 - U}{1 - U}$ |
| CBS Server: Arrival of a job $J_k$ | if (exists a pending aperiodic job) then enqueue $J_k$;  
else if $(q_s \geq (d_s - a_k) \cdot U_s)$ then  
\{ $q_s \leftarrow Q_s$;  
$d_s \leftarrow \max\{d_s, a_k\} + T_s$;  
\} |
| Budget exhaustion | $q_s \leftarrow Q_s$  
$d_s \leftarrow d_s + T_s$ |
| Response-time NP-FP | pre-requisites: $D \leq T$ and preemptive-schedulable  
$WO_i^{(n)} = B_i + \sum_{k=1}^{i-1} \left\lceil \frac{WO_i^{(n-1)}}{T_k} \right\rceil + 1 \right\rceil \cdot C_k$  
$B_i = \max\{C_j | \forall \tau_j, P_i < P_j\}$  
$R_i = C_i + WO_i$  
$WO_i^{(0)} = B_i + \sum_{k=1}^{i-1} C_k$ |
| Response-time NP-EDF | $\forall \tau_i, 1 < i \leq n, \forall L, T_1 < L < T_i$:  
$L \geq C_i + \sum_{k=1}^{i-1} \left\lceil \frac{L - 1}{T_k} \right\rceil \cdot C_k$ |