# In-Class Activity #1

## CPEN 432: Real-time System Design

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A single on-board computer controls several features on a new car. The on-board computer plays music from a local hard-disk, and this task (Task $T_1$) requires 20ms of time every 100ms. The GPS system (Task $T_2$) that provides directions requires 30ms of execution time every 250ms. The one other task that runs on this computer manages the temperature and humidity in the car; this task (Task $T_3$) is performed every 400ms and requires 100ms of execution each period. Tasks are scheduled using the **rate monotone** priority assignment.

1. You are a new engineer on this project and you have been assigned the task of integrating an additional feature on this on-board computer. This feature, a traffic monitor, scans a special communications channel and identifies routes that are congested or under repair. The traffic monitor (Task $T_4$), as it is currently implemented, runs for 100ms every 280ms. You need to determine if this task can be introduced without causing any deadline violations. If not, you need to instruct the feature engineers to redesign the traffic monitor and reduce its execution time (you cannot alter the frequency because it has been determined to provide drivers with sufficient time to change routes). What would your recommendation be?

   **Solution.** The worst-case response time for $T_1$ is, of course, 20ms. The worst-case response time for $T_2$ is 50ms. The worst-case response time for $T_4$ can be computed as follows: (Note that $T_4$ is the task with the next highest priority because we are using rate monotonic scheduling; some of you had assumed $T_4$ was the lowest priority task.)

$$
\begin{aligned}
R_4^0 &= 100 \\
I_4^1 &= \lceil 100/100 \rceil 20 + \lceil 100/250 \rceil 30 \\
&= 50 \\
R_4^1 &= I_4^1 + e_4 \\
&= 150 \\
I_4^2 &= \lceil 150/100 \rceil 20 + \lceil 150/250 \rceil 30 \\
&= 70 \\
R_4^2 &= I_4^2 + e_4 \\
&= 170 \\
I_4^3 &= \lceil 170/100 \rceil 20 + \lceil 170/250 \rceil 30 \\
&= 70 \\
R_4^3 &= I_4^2 + e_4 \\
&= 170
\end{aligned}
$$

   The response time for $T_4$ is 170ms and it will meet all its deadlines.

For Task $T_3$:

$$\begin{aligned}
R_3^0 &= 100 \\
I_3^1 &= \lceil 100/100 \rceil 20 + \lceil 100/250 \rceil 30 + \lceil 100/280 \rceil 100 \\
&= 150 \\
R_3^1 &= I_4^1 + e_4 \\
&= 250 \\
I_3^2 &= \lceil 250/100 \rceil 20 + \lceil 250/250 \rceil 30 + \lceil 250/280 \rceil 100 \\
&= 190 \\
R_3^2 &= I_4^2 + e_4 \\
&= 290 \\
I_3^3 &= \lceil 290/100 \rceil 20 + \lceil 290/250 \rceil 30 + \lceil 290/280 \rceil 100 \\
&= 320 \\
R_3^3 &= I_4^2 + e_4 \\
&= 420
\end{aligned}$$

$T_3$ will miss deadlines if we introduce task $T_4$. Without $T_4$ note that the response time for $T_3$ is 150ms.

If $T_3$ is to meet its deadlines its response time must be at most $400$ms. Using this information, we must have the following relationship hold if the execution time of $T_4$ is the maximum possible:

$$\lceil 400/100 \rceil 20 + \lceil 400/250 \rceil 30 + \lceil 400/280 \rceil e_4 + 100 = 400.$$

$e_4$, therefore, is at most $80$ms.

If we did use the hyperbolic bound, then we must have

$$\prod_{i=1}^{n} (1 + U_i) = 2$$

and therefore

$$(1.2)(1.12)(1.25)(1 + U_4) = 2,$$

which gives us $U_4 = 2/1.68 - 1 = 0.19$ and hence $e_4 = 53.33$. This is an acceptable answer but one should bear in mind that it may be possible to cut the execution time for $T_4$ from 100ms to 80ms (a 20 percent reduction) with some effort but to achieve nearly 50 percent reduction in execution times would be an extremely challenging target for the team engineering the component.

2. Assume that only the original three tasks $(T_1, T_2, T_3)$ are running on the on-board computer. In a redesign stage, it is determined that these tasks need to update a display by sending some information over a data bus. This communication takes time but the display needs to be updated within the task's period. As a result, the relative deadlines for the three tasks need to be shortened and the tasks scheduled using the **deadline monotone** priority assignment. For simplicity, all tasks will have their deadlines reduced by a factor $f$. In other words, the relative deadline $D_i$ for task $T_i$ will become $D_i = f \cdot P_i$ where $P_i$ is the period of the task. What is the smallest value of $f$ such that the tasks will continue to meet their deadlines.

**Solution.** We always want the response times to be less than or equal to the relative deadlines for schedulability. The response time for $T_1$ is 20ms therefore $f \geq R_1/P_1 = 20/100 = 0.2$. The response time for $T_2$ is 50ms therefore $f \geq R_2/P_2 = 50/250 = 0.2$. The response time for $T_3$ is 170ms therefore $f \geq R_3/P_3 = 170/400 = 0.425$. $f = 0.425$ satisfies all the conditions and is the smallest possible value for $f$ such that no task misses its deadline.