Laboratory 1

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3.3.1 Periodic tasks in Ada

Format:

$$\tau(\phi, T, C, D)$$

Tasks:

$$\tau_1(T_1 = 900, , 300)$$

Task 2,3 and 5 are released at $t = 1.000$, task 2 finishes first, then task 6 so:

$$P_2 > P_6 > P_5$$

Task 3 is released at $t = 1.200$, pre-empting task 5.

$$P_3 > P_5$$

Task 2,6,3 and 5 seem to have a higher priority than task 4 since it finishes at $t = 1.396$ despite being scheduled to start at $t = 0.900$.

$$P_2 > P_6 > P_5 > P_4$$

Tasks 3 and 2 are scheduled to start at the same time at $t = 2.000$. Obviously task 3 has a higher priority than task 2.

$$P_3 > P_2 > P_6 > P_5 > P_4$$

Tasks 2 and 1 are scheduled to be released at the same time at $t = 3.500$. Task 2 seems to have higher priority since task 1 has to wait. Also task 1 has to wait for task 3 which starts at $t = 3.600$.

$$P_2 > P_1$$

$$P_3 > P_1$$

Task 1 and 6 are both scheduled to start at $t = 6.200$. In this case, task 1 starts first due to higher priority.

$$P_1 > P_6$$

Which leads to:

$$P_3 > P_2 > P_1 > P_6 > P_5 > P_4$$

3.3.2 The rate monotonic schedule.

1) **Calculating utilization**

The utilization of a periodic task $\tau_i(T_i, C_i)$ is defined as:

$$u_i = \frac{C_i}{T_i}$$

The total utilization for a set of tasks is defined as:

$$U = \sum_{i=1}^{n} u_i$$

The 3 tasks given are:

$$\tau_i(\phi_i, T_i, C_i, D_i)$$

$$\tau_1(100, 300, 100, 300)$$

$$\tau_2(100, 400, 100, 400)$$

$$\tau_3(100, 600, 100, 600)$$

Their respective utilizations are:

$$u_1 = \frac{C_1}{D_1} = \frac{100}{300} = \frac{1}{3}$$

$$u_2 = \frac{C_2}{D_2} = \frac{100}{400} = \frac{1}{4}$$

$$u_3 = \frac{C_3}{D_3} = \frac{100}{600} = \frac{1}{6}$$

The total utilization U can thus be calculated:

$$U = \frac{1}{3} + \frac{1}{4} + \frac{1}{6} = \frac{9}{12} = \frac{3}{4} = 0.75$$

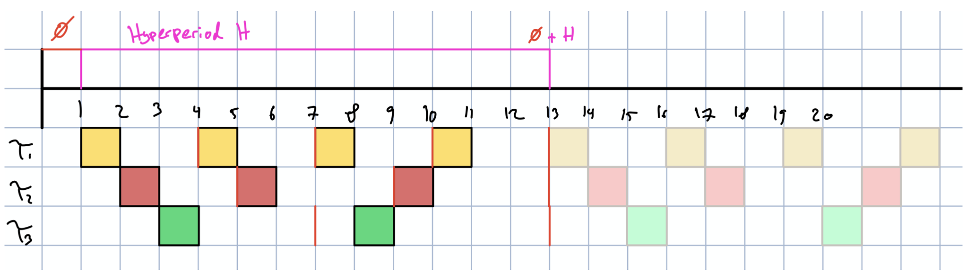
The hyperperiod H is defined as the least common multiplier from the set of task periods:

$$H = lcm(T_1, T_2, T_3) = lcm(300, 400, 600) = 1200$$

According to RMS the priorities should therefore be:

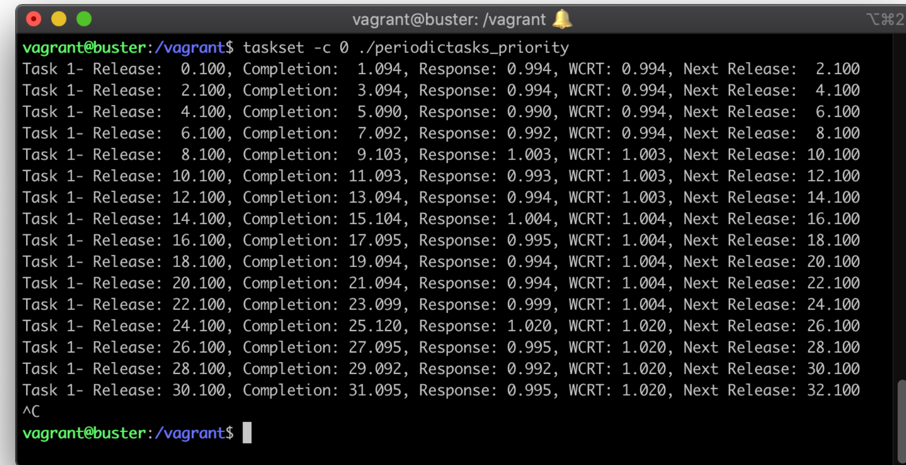
$$P_1 > P_2 > P_3$$

For one hyperperiod of 1200ms the ideal schedule looks like this:



2) Calibrating execution time

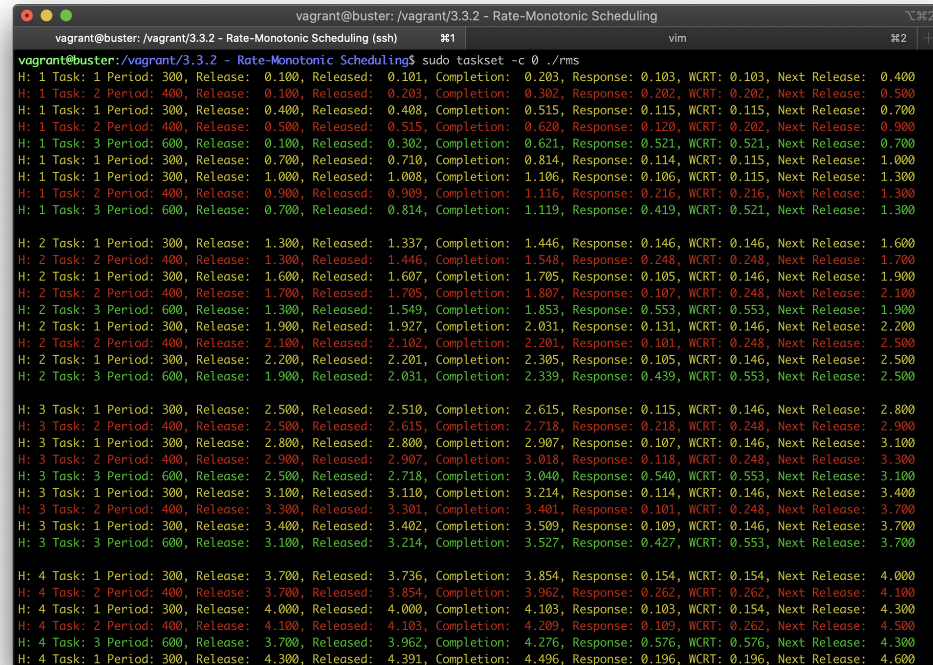
Constraining the execution of the program to use only a single CPU core using taskset was made possible on a macOS system by using a virtual machine. The calibration parameter was set to **1208** which produced the following output:



```
vagrant@buster: /vagrant
vagrant@buster:/vagrant$ taskset -c 0 ./periodictasks_priority
Task 1- Release:  0.100, Completion:  1.094, Response: 0.994, WCRT: 0.994, Next Release:  2.100
Task 1- Release:  2.100, Completion:  3.094, Response: 0.994, WCRT: 0.994, Next Release:  4.100
Task 1- Release:  4.100, Completion:  5.090, Response: 0.990, WCRT: 0.994, Next Release:  6.100
Task 1- Release:  6.100, Completion:  7.092, Response: 0.992, WCRT: 0.994, Next Release:  8.100
Task 1- Release:  8.100, Completion:  9.103, Response: 1.003, WCRT: 1.003, Next Release: 10.100
Task 1- Release: 10.100, Completion: 11.093, Response: 0.993, WCRT: 1.003, Next Release: 12.100
Task 1- Release: 12.100, Completion: 13.094, Response: 0.994, WCRT: 1.003, Next Release: 14.100
Task 1- Release: 14.100, Completion: 15.104, Response: 1.004, WCRT: 1.004, Next Release: 16.100
Task 1- Release: 16.100, Completion: 17.095, Response: 0.995, WCRT: 1.004, Next Release: 18.100
Task 1- Release: 18.100, Completion: 19.094, Response: 0.994, WCRT: 1.004, Next Release: 20.100
Task 1- Release: 20.100, Completion: 21.094, Response: 0.994, WCRT: 1.004, Next Release: 22.100
Task 1- Release: 22.100, Completion: 23.099, Response: 0.999, WCRT: 1.004, Next Release: 24.100
Task 1- Release: 24.100, Completion: 25.120, Response: 1.020, WCRT: 1.020, Next Release: 26.100
Task 1- Release: 26.100, Completion: 27.095, Response: 0.995, WCRT: 1.020, Next Release: 28.100
Task 1- Release: 28.100, Completion: 29.092, Response: 0.992, WCRT: 1.020, Next Release: 30.100
Task 1- Release: 30.100, Completion: 31.095, Response: 0.995, WCRT: 1.020, Next Release: 32.100
^C
vagrant@buster:/vagrant$
```

3) Implementing the periodic task set Γ_1

Running the rms on a single core produces the following output:



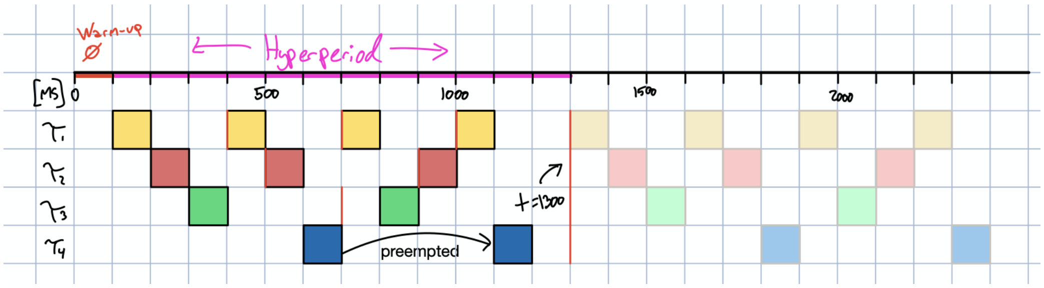
```
vagrant@buster: /vagrant/3.3.2 - Rate-Monotonic Scheduling
vagrant@buster: /vagrant/3.3.2 - Rate-Monotonic Scheduling (ssh)  ⌘1    vim  ⌘2
vagrant@buster:/vagrant/3.3.2 - Rate-Monotonic Scheduling$ sudo taskset -c 0 ./rms
H: 1 Task: 1 Period: 300, Release:  0.100, Released:  0.101, Completion:  0.203, Response: 0.103, WCRT: 0.103, Next Release:  0.400
H: 1 Task: 2 Period: 400, Release:  0.100, Released:  0.203, Completion:  0.302, Response: 0.202, WCRT: 0.202, Next Release:  0.500
H: 1 Task: 1 Period: 300, Release:  0.400, Released:  0.408, Completion:  0.515, Response: 0.115, WCRT: 0.115, Next Release:  0.700
H: 1 Task: 2 Period: 400, Release:  0.500, Released:  0.515, Completion:  0.620, Response: 0.120, WCRT: 0.202, Next Release:  0.900
H: 1 Task: 3 Period: 600, Release:  0.100, Released:  0.302, Completion:  0.621, Response: 0.521, WCRT: 0.521, Next Release:  0.700
H: 1 Task: 1 Period: 300, Release:  0.700, Released:  0.710, Completion:  0.814, Response: 0.114, WCRT: 0.115, Next Release:  1.000
H: 1 Task: 1 Period: 300, Release:  1.000, Released:  1.008, Completion:  1.106, Response: 0.106, WCRT: 0.115, Next Release:  1.300
H: 1 Task: 2 Period: 400, Release:  0.900, Released:  0.909, Completion:  1.116, Response: 0.216, WCRT: 0.216, Next Release:  1.300
H: 1 Task: 3 Period: 600, Release:  0.700, Released:  0.814, Completion:  1.119, Response: 0.419, WCRT: 0.521, Next Release:  1.300

H: 2 Task: 1 Period: 300, Release:  1.300, Released:  1.337, Completion:  1.446, Response: 0.146, WCRT: 0.146, Next Release:  1.600
H: 2 Task: 2 Period: 400, Release:  1.300, Released:  1.446, Completion:  1.548, Response: 0.248, WCRT: 0.248, Next Release:  1.700
H: 2 Task: 1 Period: 300, Release:  1.600, Released:  1.607, Completion:  1.705, Response: 0.105, WCRT: 0.146, Next Release:  1.900
H: 2 Task: 2 Period: 400, Release:  1.700, Released:  1.705, Completion:  1.807, Response: 0.107, WCRT: 0.248, Next Release:  2.100
H: 2 Task: 3 Period: 600, Release:  1.300, Released:  1.549, Completion:  1.853, Response: 0.553, WCRT: 0.553, Next Release:  1.900
H: 2 Task: 1 Period: 300, Release:  1.900, Released:  1.927, Completion:  2.031, Response: 0.131, WCRT: 0.146, Next Release:  2.200
H: 2 Task: 2 Period: 400, Release:  2.100, Released:  2.102, Completion:  2.201, Response: 0.101, WCRT: 0.248, Next Release:  2.500
H: 2 Task: 1 Period: 300, Release:  2.200, Released:  2.201, Completion:  2.305, Response: 0.105, WCRT: 0.146, Next Release:  2.500
H: 2 Task: 3 Period: 600, Release:  1.900, Released:  2.031, Completion:  2.339, Response: 0.439, WCRT: 0.553, Next Release:  2.500

H: 3 Task: 1 Period: 300, Release:  2.500, Released:  2.510, Completion:  2.615, Response: 0.115, WCRT: 0.146, Next Release:  2.800
H: 3 Task: 2 Period: 400, Release:  2.500, Released:  2.615, Completion:  2.718, Response: 0.218, WCRT: 0.248, Next Release:  2.900
H: 3 Task: 1 Period: 300, Release:  2.800, Released:  2.800, Completion:  2.907, Response: 0.107, WCRT: 0.146, Next Release:  3.100
H: 3 Task: 2 Period: 400, Release:  2.900, Released:  2.907, Completion:  3.018, Response: 0.118, WCRT: 0.248, Next Release:  3.300
H: 3 Task: 3 Period: 600, Release:  2.500, Released:  2.718, Completion:  3.040, Response: 0.540, WCRT: 0.553, Next Release:  3.100
H: 3 Task: 1 Period: 300, Release:  3.100, Released:  3.110, Completion:  3.214, Response: 0.114, WCRT: 0.146, Next Release:  3.400
H: 3 Task: 2 Period: 400, Release:  3.300, Released:  3.301, Completion:  3.401, Response: 0.101, WCRT: 0.248, Next Release:  3.700
H: 3 Task: 1 Period: 300, Release:  3.400, Released:  3.402, Completion:  3.509, Response: 0.109, WCRT: 0.146, Next Release:  3.700
H: 3 Task: 3 Period: 600, Release:  3.100, Released:  3.214, Completion:  3.527, Response: 0.427, WCRT: 0.553, Next Release:  3.700

H: 4 Task: 1 Period: 300, Release:  3.700, Released:  3.736, Completion:  3.854, Response: 0.154, WCRT: 0.154, Next Release:  4.000
H: 4 Task: 2 Period: 400, Release:  3.700, Released:  3.854, Completion:  3.962, Response: 0.262, WCRT: 0.262, Next Release:  4.100
H: 4 Task: 1 Period: 300, Release:  4.000, Released:  4.000, Completion:  4.103, Response: 0.103, WCRT: 0.154, Next Release:  4.300
H: 4 Task: 2 Period: 400, Release:  4.100, Released:  4.103, Completion:  4.209, Response: 0.109, WCRT: 0.262, Next Release:  4.500
H: 4 Task: 3 Period: 600, Release:  3.700, Released:  3.962, Completion:  4.276, Response: 0.576, WCRT: 0.576, Next Release:  4.300
H: 4 Task: 1 Period: 300, Release:  4.300, Released:  4.391, Completion:  4.496, Response: 0.196, WCRT: 0.196, Next Release:  4.600
```

Comparing the command output to the theoretical schedule, one can easily verify that indeed the jobs run according to the schematic. While there are minor differences in the order of completion, the **Released** field reveals when each job was started, which matches the theory.

4) **Adding the additional task** τ_4 A new task τ_4 is added:

$$\tau_4 = (\phi = 100, T = 1200, C = 200, D = 1200)$$

Since it has twice the computing time of the other tasks, it can be broken down into two time units and added to the schedule. Starting at $t = 600$ it gets pre-empted by τ_1 due to its higher priority and will have to wait until $t = 1100$ when there are no other tasks pending in order to resume and finish its work.



The output produced by rms2 (the value of Calibration was increased to 1280):

```
vagrant@buster: /vagrant/3.3.2 - Rate-Monotonic Scheduling
vagrant@buster: /vagrant/3.3.2 - Rate-Monotonic Scheduling (ssh)    ⌘1    vim    ⌘2
vagrant@buster:/vagrant/3.3.2 - Rate-Monotonic Scheduling$ sudo taskset -c 0 ./rms2
H: 1 Task: 1 Period: 300, Release:  0.100, Released:  0.136, Completion:  0.242, Response: 0.142, WCRT: 0.142, Next Release:  0.400
H: 1 Task: 2 Period: 400, Release:  0.100, Released:  0.242, Completion:  0.346, Response: 0.246, WCRT: 0.246, Next Release:  0.500
H: 1 Task: 1 Period: 300, Release:  0.400, Released:  0.407, Completion:  0.509, Response: 0.109, WCRT: 0.142, Next Release:  0.700
H: 1 Task: 2 Period: 400, Release:  0.500, Released:  0.509, Completion:  0.615, Response: 0.115, WCRT: 0.246, Next Release:  0.900
H: 1 Task: 3 Period: 600, Release:  0.100, Released:  0.346, Completion:  0.660, Response: 0.560, WCRT: 0.560, Next Release:  0.700
H: 1 Task: 1 Period: 300, Release:  0.700, Released:  0.705, Completion:  0.807, Response: 0.107, WCRT: 0.142, Next Release:  1.000
H: 1 Task: 1 Period: 300, Release:  1.000, Released:  1.007, Completion:  1.110, Response: 0.110, WCRT: 0.142, Next Release:  1.300
H: 1 Task: 2 Period: 400, Release:  0.900, Released:  0.908, Completion:  1.118, Response: 0.218, WCRT: 0.246, Next Release:  1.300
H: 1 Task: 3 Period: 600, Release:  0.700, Released:  0.808, Completion:  1.121, Response: 0.421, WCRT: 0.560, Next Release:  1.300
H: 1 Task: 4 Period: 1200, Release:  0.100, Released:  0.660, Completion:  1.284, Response: 1.184, WCRT: 1.184, Next Release:  1.300

H: 2 Task: 1 Period: 300, Release:  1.300, Released:  1.448, Completion:  1.561, Response: 0.261, WCRT: 0.261, Next Release:  1.600
H: 2 Task: 1 Period: 300, Release:  1.600, Released:  1.600, Completion:  1.707, Response: 0.107, WCRT: 0.261, Next Release:  1.900
H: 2 Task: 2 Period: 400, Release:  1.300, Released:  1.561, Completion:  1.776, Response: 0.476, WCRT: 0.476, Next Release:  1.700 ==> Task 2 violates Deadline!
H: 2 Task: 2 Period: 400, Release:  1.700, Released:  1.776, Completion:  1.885, Response: 0.185, WCRT: 0.476, Next Release:  2.100
H: 2 Task: 1 Period: 300, Release:  1.900, Released:  1.901, Completion:  2.009, Response: 0.109, WCRT: 0.261, Next Release:  2.200
H: 2 Task: 1 Period: 300, Release:  2.200, Released:  2.201, Completion:  2.305, Response: 0.105, WCRT: 0.261, Next Release:  2.500
H: 2 Task: 2 Period: 400, Release:  2.100, Released:  2.100, Completion:  2.306, Response: 0.206, WCRT: 0.476, Next Release:  2.500
H: 2 Task: 3 Period: 600, Release:  1.300, Released:  1.885, Completion:  2.312, Response: 1.012, WCRT: 1.012, Next Release:  1.900 ==> Task 3 violates Deadline!
H: 2 Task: 3 Period: 600, Release:  1.900, Released:  2.312, Completion:  2.414, Response: 0.514, WCRT: 1.012, Next Release:  2.500

H: 3 Task: 1 Period: 300, Release:  2.500, Released:  2.501, Completion:  2.616, Response: 0.116, WCRT: 0.261, Next Release:  2.800
H: 3 Task: 2 Period: 400, Release:  2.500, Released:  2.616, Completion:  2.730, Response: 0.230, WCRT: 0.476, Next Release:  2.900
H: 3 Task: 1 Period: 300, Release:  2.800, Released:  2.803, Completion:  2.914, Response: 0.114, WCRT: 0.261, Next Release:  3.100
H: 3 Task: 2 Period: 400, Release:  2.900, Released:  2.914, Completion:  3.026, Response: 0.126, WCRT: 0.476, Next Release:  3.300
H: 3 Task: 3 Period: 600, Release:  2.500, Released:  2.730, Completion:  3.070, Response: 0.570, WCRT: 1.012, Next Release:  3.100
H: 3 Task: 1 Period: 300, Release:  3.100, Released:  3.102, Completion:  3.207, Response: 0.107, WCRT: 0.261, Next Release:  3.400
H: 3 Task: 1 Period: 300, Release:  3.400, Released:  3.406, Completion:  3.510, Response: 0.110, WCRT: 0.261, Next Release:  3.700
H: 3 Task: 2 Period: 400, Release:  3.300, Released:  3.308, Completion:  3.517, Response: 0.217, WCRT: 0.476, Next Release:  3.700
H: 3 Task: 3 Period: 600, Release:  3.100, Released:  3.207, Completion:  3.525, Response: 0.425, WCRT: 1.012, Next Release:  3.700
H: 3 Task: 4 Period: 1200, Release:  1.300, Released:  2.414, Completion:  3.615, Response: 2.315, WCRT: 2.315, Next Release:  2.500 ==> Task 4 violates Deadline!

H: 4 Task: 1 Period: 300, Release:  3.700, Released:  3.705, Completion:  3.809, Response: 0.109, WCRT: 0.261, Next Release:  4.000
H: 4 Task: 2 Period: 400, Release:  3.700, Released:  3.810, Completion:  3.914, Response: 0.214, WCRT: 0.476, Next Release:  4.100
H: 4 Task: 1 Period: 300, Release:  4.000, Released:  4.004, Completion:  4.109, Response: 0.109, WCRT: 0.261, Next Release:  4.300
H: 4 Task: 2 Period: 400, Release:  4.100, Released:  4.109, Completion:  4.229, Response: 0.129, WCRT: 0.476, Next Release:  4.500
H: 4 Task: 3 Period: 600, Release:  3.700, Released:  3.914, Completion:  4.244, Response: 0.544, WCRT: 1.012, Next Release:  4.300
H: 4 Task: 1 Period: 300, Release:  4.300, Released:  4.300, Completion:  4.403, Response: 0.103, WCRT: 0.261, Next Release:  4.600
H: 4 Task: 1 Period: 300, Release:  4.600, Released:  4.607, Completion:  4.710, Response: 0.110, WCRT: 0.261, Next Release:  4.900
H: 4 Task: 2 Period: 400, Release:  4.500, Released:  4.507, Completion:  4.716, Response: 0.216, WCRT: 0.476, Next Release:  4.900
H: 4 Task: 3 Period: 600, Release:  4.300, Released:  4.403, Completion:  4.717, Response: 0.417, WCRT: 1.012, Next Release:  4.900
H: 4 Task: 4 Period: 1200, Release:  2.500, Released:  3.615, Completion:  4.787, Response: 2.287, WCRT: 2.315, Next Release:  3.700 ==> Task 4 violates Deadline!
```

Here one can clearly see the program struggling to keep the deadlines. While τ_4 manages to complete just in time during hyperperiod 1, it doesn't make it in time during hyperperiod 2 and is thus way over deadline when i finally completes at the end of hyperperiod 3. Other tasks also have problems, which is not unexpected since the system is now being utilized at a much higher rate ($U = 11/12 \approx 0.92$).