Robotics
Real-Time Systems: scheduling of aperiodic tasks

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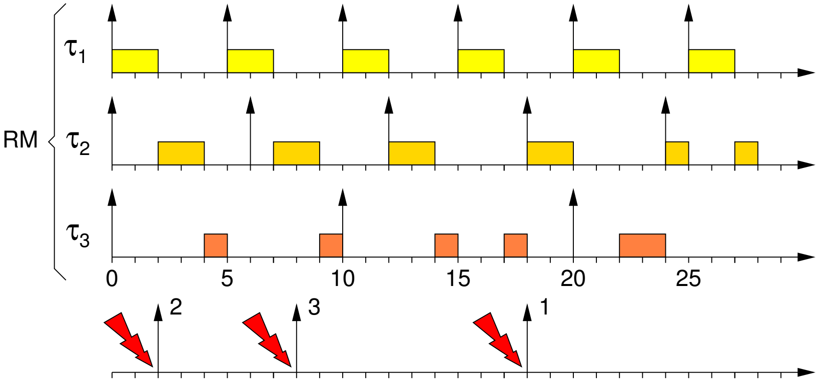
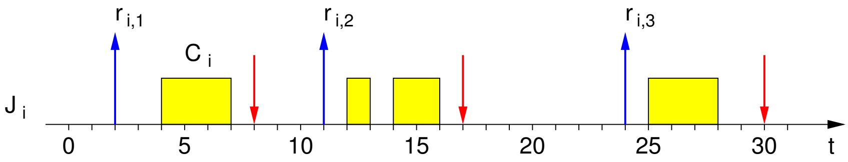
http://robot.unipv.it/toolleeo

Aperiodic tasks: task model



- when aperiodic requests need to be scheduled
- guarantees on periodic tasks

Aperiodic tasks



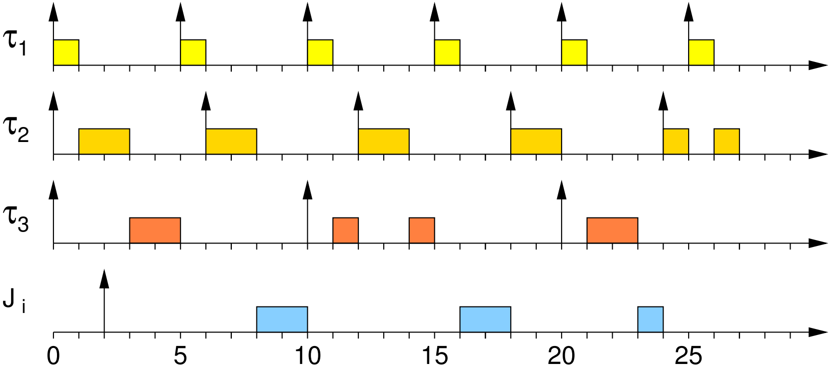
aperiodic tasks

$$r_{i,k+1} > r_{i,k}$$

sporadic tasks

$$r_{i,k+1} \geq r_{i,k} + T_i$$

Background scheduling



- aperiodic tasks are scheduled when the processor is idle
- simple and easy-to-implement technique

Dedicated methods

different methods have been proposed, distinguishing between **static** and **dynamic** priority assignment

considered algorithms:

Static priorities

- Polling Server
- Sporadic Server

Dynamic priorities

- Total Bandwidth Server
- Constant Bandwidth Server

Polling Server

scheduling of soft aperiodic tasks concurrently with hard periodic tasks

assumptions:

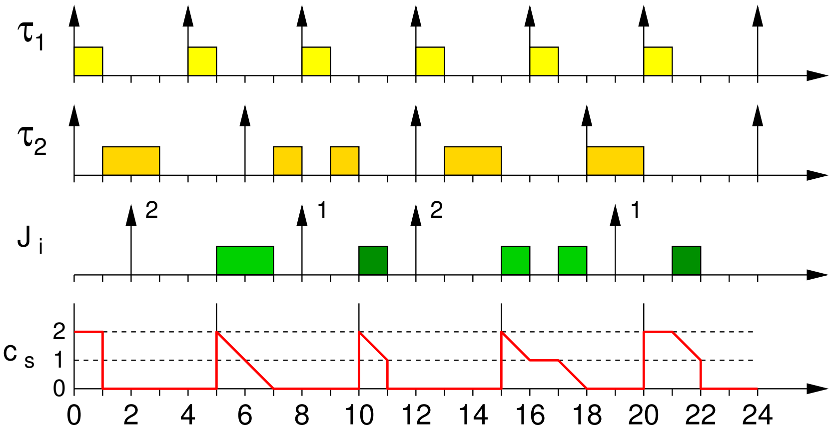
- full-preemption
- periodic tasks are scheduled by RM
- implicit deadlines
- aperiodic tasks have
  - unknown arrival time
  - known worst-case computation time

Polling Server

1. **period** T_s, **nominal capacity** C_s and **current capacity** c_s
2. every T_s time units the current capacity is recharged up to the nominal value C_s (i.e., $c_s = C_s$)
3. one unit of c_s is consumed for each slot served to an aperiodic task
4. if there are no aperiodic tasks ready for execution, the server self-suspends and flushes its current capacity (i.e., $c_s = 0$)

> the flushing of the capacity may cause the presence of idle times that is not exploitable by aperiodic tasks ready for execution

Polling Server



$\tau_1 = (1,4)$ $\tau_2 = (2,6)$ $C_s = 2$ e $T_s = 5$

Schedulability analysis

from the schedulability viewpoint, a Pollig Server behaves like a periodic task having period T_s and WCET C_s

$$U_p + U_s \leq U_{lub}(n+1)$$

$$\sum_{i=1}^{n} \frac{C_i}{T_i} + \frac{C_s}{T_s} \leq (n+1)\left[2^{1/(n+1)} - 1\right]$$

in case there are m Polling Servers:

$$U_p + \sum_{j=1}^{m} U_{s_j} \leq U_{lub}(n+m)$$

Sporadic Server

parameters for its definition:

- period T_s
- maximum budget C_s
- static priority P_s (e.g., set according to RM)

parameters used for its functioning:

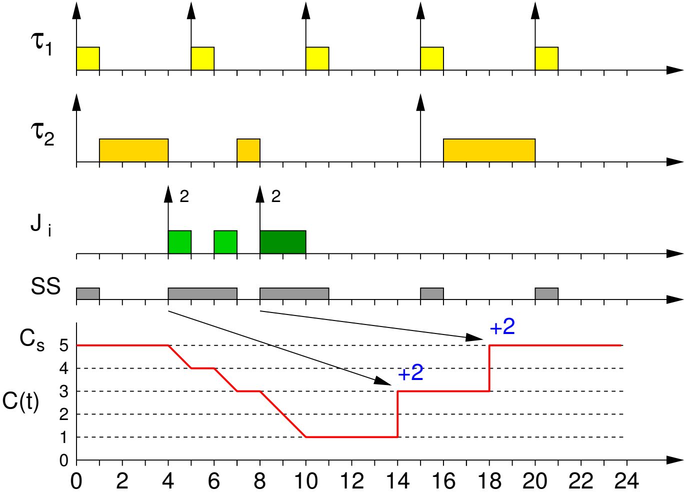
- $C(t)$: current server capacity
- P_{exe} : priority of the running task

Sporadic Server: operating rules

the Sporadic Server works according to the following rules:

1. the server is said active at time t if $P_{exe} \geq P_s$ and $C(t) > 0$
2. the server is said idle at time t if $P_{exe} < P_s$ or $C(t) = 0$
3. at time $t = 0$ the server is idle and $C(0) = C_s$
4. when the server becomes active at time t_1 a corresponding recharging time is set at time $t_r = (t_1 + T_s)$
5. when the server becomes idle at time $t_2 > t_1$ a recharge budget is set equal to the budget C_r consumed during the interval $[t_1, t_2)$
6. at time t_r the capacity C_r is added to the current budget

Sporadic Server: example



$\tau_1 = (1, 5)$ $\quad\tau_2 = (4, 15)$ $\quad C_s = 5$ e $T_s = 10$

SS: schedulability analysis

a Sporadic Server does not behave like a periodic task

$$\sum_{i=1}^{n} \frac{C_i}{T_i} \leq n \left[\left(\frac{2}{U_s + 1} \right)^{1/n} - 1 \right]$$

- let U_p be the utilization of all periodic tasks
- the highest utilization of the sporadic server that guarantees the schedulability of periodic tasks is U_{SS}^*

$$U_{SS}^* = 2 \left(\frac{U_p}{n} + 1 \right)^{-n} - 1$$

Scheduling algorithms for dynamic priorities

many algorithms are adaptations of static priority scheduling algorithms

example:

- Dynamic Sporadic Server

some algorithms were born for dynamic priorities:

- Total Bandwidth Server
- Total Bandwidth Server*
- Constant Bandwidth Server

Assumptions

concurrent scheduling of soft aperiodic tasks and hard periodic tasks

assuming that

- periodic tasks are scheduled by EDF
- implicit deadlines (deadlines are equal to periods)
- full preemption
- for aperiodic tasks:
  - unknown arrival times
  - known computation times

Total Bandwidth Server

server design parameter:

- bandwidth (utilization) U_s

operating rules:

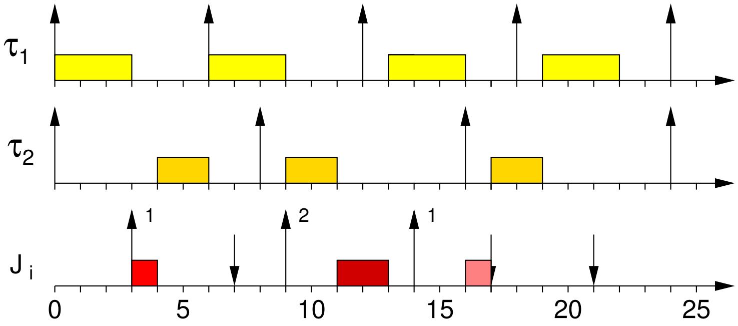
- an aperiodic task J arrives at time r_k
- the J task requires C_k time units to execute
- an absolute deadline d_k is calculated for J

$$d_k = \max(r_k, d_{k-1}) + \frac{C_k}{U_s}$$

- being $d_0 = 0$ by definition
- J is scheduled by EDF considering the computed deadline d_k

TBS: example

$\tau_1 = (3, 6)$ $\tau_2 = (2, 8)$ $U_s = 1 - U_p = 0.25$



$$d_k = \max(r_k, d_{k-1}) + \frac{C_k}{U_s}$$

$\max(3, 0) + \frac{1}{0.25} = 3 + 4 = 7$

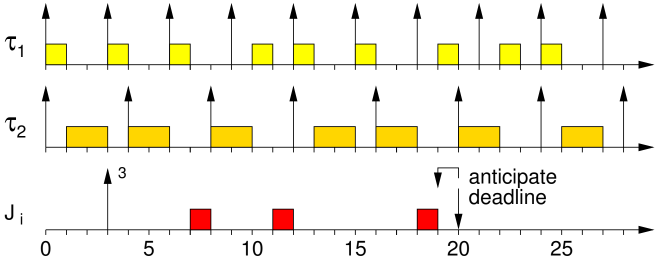
$\max(9, 7) + \frac{2}{0.25} = 9 + 8 = 17$

$\max(14, 17) + \frac{1}{0.25} = 17 + 4 = 21$

Total Bandwidth Server*

TBS* shortens the deadline of the aperiodic task J as much as possible

- the first assignment is done as in TBS
- the deadline can be shortened to the actual finishing time



$\tau_1 = (1, 3)$ $\tau_2 = (2, 4)$ $U_s = 1 - U_p = 0.1667$

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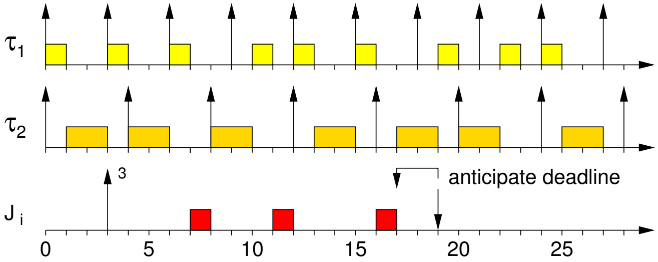

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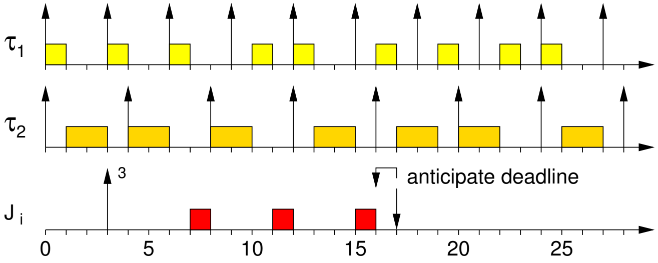

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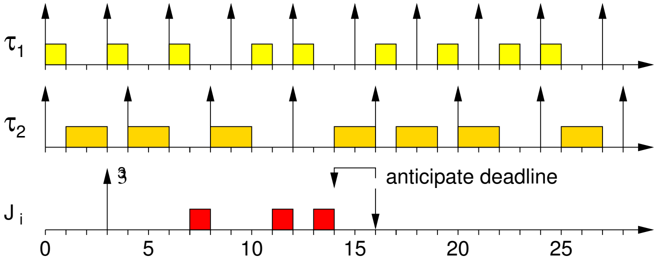

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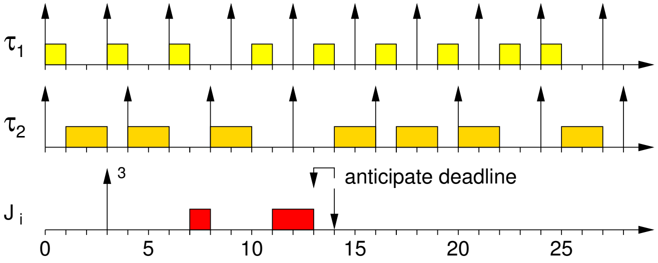

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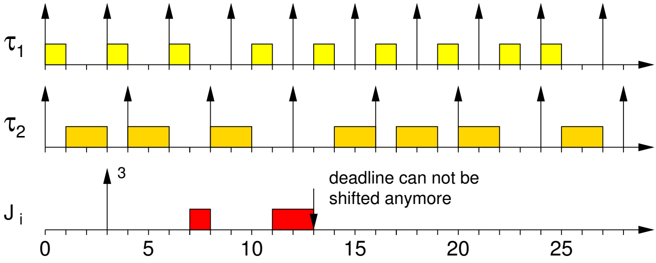

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Total Bandwidth Server*

the deadline is shortened
using an iterative process

being at iteration s:

- d_k^s is the deadline assigned to J_k
- f_k^s is the finishing time of J_k

the iterative shortening process is:

- at step $s+1$ it is set $d_k^{s+1} = f_k^s$
- the process stops when $d_k^{s+1} = d_k^s$

Total Bandwidth Server*

computational issue

- the calculation of the worst-case finishing time may require to perform the schedule until the desired time
- in many cases (e.g., high utilization of periodic tasks), this may lead to impractical computation times

- the finishing time f_k^s can be approximated
- an upper bound is proved to exist
- its calculation is fast enough to be used online

TBS*: optimality

Theorem

TBS* generates the absolute deadline of an aperiodic task such as its response time is minimized

therefore, TBS* is optimal
(in the sense of response time minimization)

Constant Bandwidth Server

- the CBS implements a bandwidth reservation scheme
- let U_s be the bandwidth assigned to the CBS
- the CBS never requires more that U_s to work

the server deadline is based on the server bandwidth

- ... even in case of overload (overrun of aperiodic tasks)

the deadline is postponed to achieve the constraint on the bandwidth assigned to the server

- performance in terms of response time for aperiodic tasks is similar to those of TBS

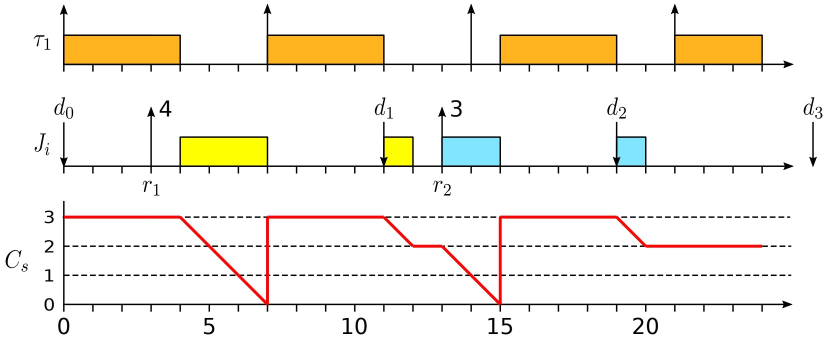
CBS: operating rules

1. maximum budget Q_s, period T_s and current budget c_s
2. server bandwidth: $U_s = Q_s / T_s$
3. at every time, the k-th calculated deadline $d_{s,k}$ is the current deadline of the CBS
4. by definition $d_{s,0} = 0$
5. at each job $J_{i,j}$ it is assigned the deadline $d_{i,j} = d_{s,k}$
6. the current budget c_s decreases of one unit for each time unit of execution
7. when $c_s = 0$ the budget is refilled (i.e., it is set $c_s = Q_s$), and a new deadline is computed as $d_{s,k+1} = d_{s,k} + T_s$

CBS: operating rules

1. the server is *active* when there are pending aperiodic jobs, *idle* otherwise
2. when the server is active, a new aperiodic job $J_{i,j}$ is queued with arbitrary policy to the queue of pending requests
3. when the server is idle, for a job $J_{i,j}$ such as $c_s \geq (d_{s,k} - r_{i,j})U_s$, the server computes a new deadline $d_{s,k+1} = r_{i,j} + T_s$, the value of c_s is set equal to Q_s, otherwise $J_{i,j}$ is served with deadline $d_{s,k}$ and budget c_s
4. when a job finishes, the next one is served with deadline $d_{s,k}$ and budget c_s
5. if no more tasks are present in the queue, the server becomes idle

CBS: example



$$c_s \geq (d_{s,0} - r_1)U_s \Rightarrow 3 \geq (0-3)0.375$$

$$c_s < (d_{s,2} - r_2)U_s \Rightarrow 2 < (19-13)0.375 = 2.25$$

$\tau_1 = (7, 4)$ $\quad\quad$ $C_s = 3 \quad T_s = 8 \quad U_s = 0.375$

CBS: schedulability analysis

- let U_p be the utilization of periodic tasks
- the utilization of a CBS is always $U_s = Q_s/T_s$ independently from the timing parameters of aperiodic jobs
- the system is schedulable iif $U_p + U_s \leq 1$
- since the budget c_s is never null, the CBS performs an automatic reclaiming of unused computing time in case of earlier termination of an aperiodic job

in case of m CBSs where the i-th server has utilization U_{s_i}, the system is schedulable iif

$$U_p + U_s \leq 1 \quad U_s = \sum_{i=1}^{m} U_{s_i}$$

Summary

TBS

- trivial operating rules
- good performance
- does not tolerate overloads

TBS*

- optimal response time
- higher complexity w.r.t. TBS
- trade-off can be established between response time and computational overhead

CBS

- bandwidth reservation in case of overload
- good performance (comparable with TBS)
- simple implementation