Real-time Scheduling of Aperiodic and Sporadic Tasks (1)

Advanced Operating Systems
Lecture 4
Lecture Outline

• Aperiodic and sporadic tasks
  • System model
  • Acceptance test concept

• Scheduling aperiodic jobs
  • Background execution
  • Polling server
  • Deferrable server
Aperiodic Tasks

- Recall: if jobs have unpredictable release times, a task is termed *aperiodic*
- Problem is to schedule their jobs without disrupting correctness of the system
- Aperiodic jobs are always accepted
Sporadic Tasks

• Recall: a sporadic task is an aperiodic task where jobs have deadlines once released

• Cannot guarantee systems with sporadic tasks are correct without bounding release or execution time

  • Based on the execution time and deadline of each newly arrived sporadic job, decide whether to accept or reject the job
    • Accepting the job implies that the job will complete within its deadline, without causing any periodic task or previously accepted sporadic job to miss its deadline
    • Do not accept a sporadic job if cannot guarantee it will meet its deadline; the remainder of the system can still be scheduled

  • If accepted, schedule their jobs without disrupting correctness of rest of the system
System Model

Single processor; independent, preemptable, periodic tasks can be scheduled in absence of aperiodic and sporadic jobs

Aperiodic and sporadic jobs are preemptable and independent
Scheduling Aperiodic Jobs

- Consider the simple case: scheduling aperiodic jobs along with a system of periodic jobs
  - Ignore sporadic jobs for now

- Two basic approaches:
  - Background execution
  - Execution using a periodic server
Background Execution of Aperiodic Jobs

- Aperiodic jobs are scheduled and executed only at times when there are no periodic or sporadic jobs ready for execution
  - Clearly produces correct schedules; extremely simple to implement in clock-driven and priority-driven schedulers
  - Not optimal since it is almost guaranteed to delay execution of aperiodic jobs in favour of periodic and sporadic jobs, giving unduly long response times for the aperiodic jobs

$$T_1 = (3, 1)$$
$$T_2 = (10, 4)$$
$$A : e_a = 0.7$$

Response time = 7.7

RM schedule of $T_1$ and $T_2$
Periodic Servers

- A periodic server is a task that behaves much like a periodic task, but created to execute aperiodic jobs
  - A periodic server, $T_{ps} = (p_{ps}, e_{ps})$ never executes for more than $e_{ps}$ units of time within each period $p_{ps}$
    - The budget of the server is $e_{PS}$
    - Budget consumed when the server is executing, and replenished periodically
  - A periodic server is backlogged if the aperiodic job queue is nonempty
  - A periodic server is scheduled as any other periodic task, except it only executes when scheduled and when it is backlogged and has non-zero budget
Periodic Servers: Polling

• A common way to schedule aperiodic jobs is using a polling server – simplest periodic server
  • A periodic server $T_{ps} = (p_s, e_s)$ is scheduled
  • When executed, it examines the aperiodic job queue:
    • If an aperiodic job is in the queue, it is executed for up to $e_s$ time units
    • If the aperiodic queue is empty when polled, the server suspends and gives up its budget
    • The budget is replenished to $e_s$ every $p_s$ time units (and doesn’t carry over to next period)

• Simple to prove correctness – treat as periodic task
  • For clock-driven or fixed-priority systems; dynamic-priority systems might suffer scheduling anomalies
  • Gives slow response for tasks that arrive just after the polling instant
Periodic Servers: Deferrable

- An alternative periodic server

Budget consumption and replenishment:

- The budget is consumed when the server executes
- Once scheduled, unused budget is retained throughout the period, to be used whenever there are aperiodic jobs to execute – i.e., if a job misses the polling instant, it can be scheduled later in the period
- The budget is replenished to $es$ at multiples of the period, but cannot carry over budget from period to period

- Improves response time of aperiodic jobs
Deferrable Server: Example with RM

Periodic tasks $T_1$ and $T_2$ are scheduled according to the rate monotonic algorithm.
Add the deferrable server, scheduled according to the rate monotonic priority, but with the budget consumption and replenishment rules affecting its execution time.

The deferrable server is usually run at highest priority, but this is not strictly required.
Deferrable Server: Scheduling in RM (1)

- Maximum utilisation test fails
  - Utilisation varies depending on arrival times of jobs executed by server
  - Use time demand analysis based on critical instants to determine if the system can be scheduled

- Finding the critical instants:
  - Assume a fixed-priority system $T$ in which $D_i \leq p_i \ \forall \ i$ scheduled with a deferrable server $(p_S, e_S)$ that has the highest priority among all tasks
  - A critical instant of every periodic tasks $T_i$ occurs at a time $t_0$ when all of the following are true:
    - One of its jobs $J_{i,c}$ is released at $t_0$
    - A job in every higher-priority periodic task is released at $t_0$
    - The budget of the server is $e_S$ at $t_0$, one or more aperiodic jobs are released at $t_0$, and they keep the server backlogged hereafter
    - The next replenishment time of the server is $t_0 + e_S$
Deferrable Server: Scheduling in RM (2)

- The definition of critical instant is identical to that for the periodic tasks without the deferrable server + the worst-case requirements for the server

- The time-demand function is:

  \[ w_i(t) = e_i + \sum_{k=1}^{i-1} \left\lceil \frac{t}{p_k} \right\rceil e_k + e_s + \left\lfloor \frac{t - e_s}{p_s} \right\rfloor e_s \]

  - Execution time of job \( J_i \)
  - Execution time of deferrable server
  - Execution time of higher priority jobs started during this interval

- To determine whether the task \( T_i \) is can be schedule, we simply have to check whether \( w_i(t) \leq t \) for some \( t \leq D_i \)

- Remember, this is a sufficient condition, not necessary – i.e., if this condition is not true, the schedule might still be correct
Deferrable Server: Scheduling in RM (3)

- In general, no maximum utilisation test for a fixed-priority system with a deferrable server.

- One special case: a system of $n$ independent, preemptable periodic tasks, whose periods satisfy $p_s < p_1 < p_2 < \ldots < p_n < 2p_s$ and $p_n > p_s + e_s$, where the relative deadlines equal their respective periods, can be scheduled rate-monotonically with a deferrable server provided $U < U_{RM/DS}(n)$ where:

$$U_{RM/DS}(n) = (n - 1) \left[ \left( \frac{u_s + 2}{u_s + 1} \right)^{\frac{1}{n-1}} - 1 \right]$$
Deferrable Server: Scheduling in EDF

• It is easier to reason about the schedulability of a deadline-driven system with a deferrable server
  
  • The deadline of a deferrable server is its next replenishment time
  
  • A periodic task $T_i$ in a system of $N$ independent, preemptable, periodic tasks is schedulable with a deferrable server with period $p_s$, execution budget $e_s$ and utilization $u_s$, according to the EDF algorithm if:

\[
\sum_{k=1}^{N} \frac{e_k}{\min(D_k, p_k)} + u_s \left( 1 + \frac{p_s - e_s}{D_i} \right) \leq 1
\]

• Must be calculated for each task in the system, since $D_i$ included

• Example: tasks $T_1=(3, 0.6)$, $T_2=(5.0, 0.5)$, $T_3=(7, 1.4)$ scheduled with a deferrable server $p_s=4$, $e_s=0.8$

• The left-hand side of the above inequality is 0.913, 0.828 and 0.792 respectively; hence the three tasks can be scheduled
Summary

• Aperiodic and sporadic tasks
• System model – acceptance tests
• Approaches to scheduling aperiodic tasks
  • Background execution
  • Polling server – simple; inefficient
  • Deferrable server – more efficient; too complex to prove correctness for RM; effective for EDF systems