Deadlines and Aperiodic Servers

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Lecture #8

Outline

- Dealing with Interrupts
- Dealing with Deadline ≠ Period
  - Deadline-monotonic scheduling
  - Deadlines > period
- Aperiodic Tasks
  - Deferrable Servers
  - Sporadic Servers

Modeling Pre-period Deadlines

- Suppose a task τ, with a worst-case computation time of C and a period of T, has a "pre-period" deadline D (i.e. $D < T$).
- Compare total utilization to modified bound:

$$U_{total} = \frac{C_1}{T_1} + \ldots + \frac{C_n}{T_n} \le U(n, \Delta_i)$$

where Δ_i is the ratio D_i / T_i.

$$U(n, \Delta_i) = \begin{cases} n((2\Delta_i)^{1/n} - 1) + 1 - \Delta_i, & \frac{1}{2} < \Delta_i \le 1.0 \\ \Delta_i, & \Delta_i \le \frac{1}{2} \end{cases}$$

Deadline-Monotonic Scheduler

- Assign fixed priority based on D (and not T)
  - Shorter the relative deadline, higher the priority.
- Optimal fixed-priority preemptive scheduling policy for periodic tasksets where $D \le T$
  - i.e. the relative deadline of each task is not greater than the task period
- When $D = T$, RMS and DMS are one and the same
  - When $\Delta_i = (D_i / T_i)$ is constant across all tasks, RMS and DMS are also the same.
- When $D > T$, neither RMS nor DMS is the optimal fixed-priority scheduler!

Notes on Fixed-Priority Scheduling Policies

- Both RMS and DMS are fixed-priority scheduling policies. Hence, the exact response-time test can be used to verify the schedulability of tasksets using RMS, DMS or any other fixed-priority policy.
  - Compute the worst-case completion time and check whether the completion time is not greater than the deadline.
  - Does NOT work for case when $D > T$.
    - One has to check for a longer duration.
- Hence, the general set of principles for analyzing fixed-priority preemptive scheduling policies is called **RMA** (**Rate-Monotonic Analysis**).

Schedulability with Interrupts

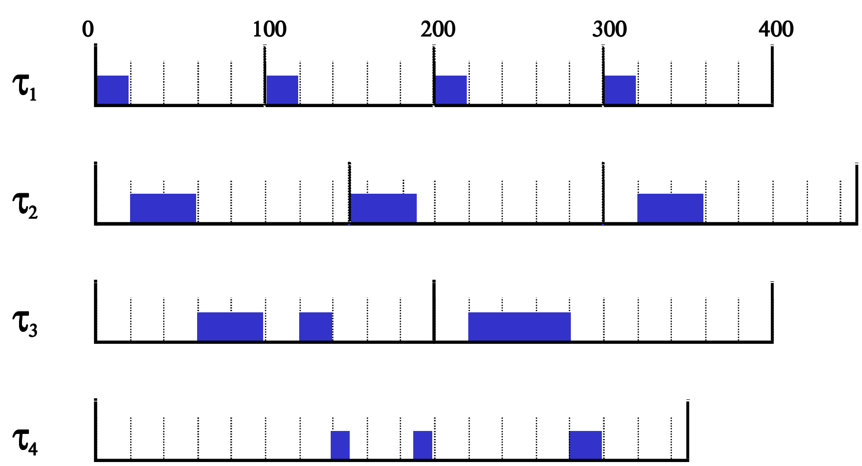
- Interrupt processing can be inconsistent with rate-monotonic priority assignment.
  - interrupt handler executes with high priority despite its longer period
  - interrupt processing may delay execution of tasks with shorter periods
- Effects of interrupt processing must be taken into account in schedulability model.
- Question is: how to do that?

Example: Determining Schedulability with Interrupts

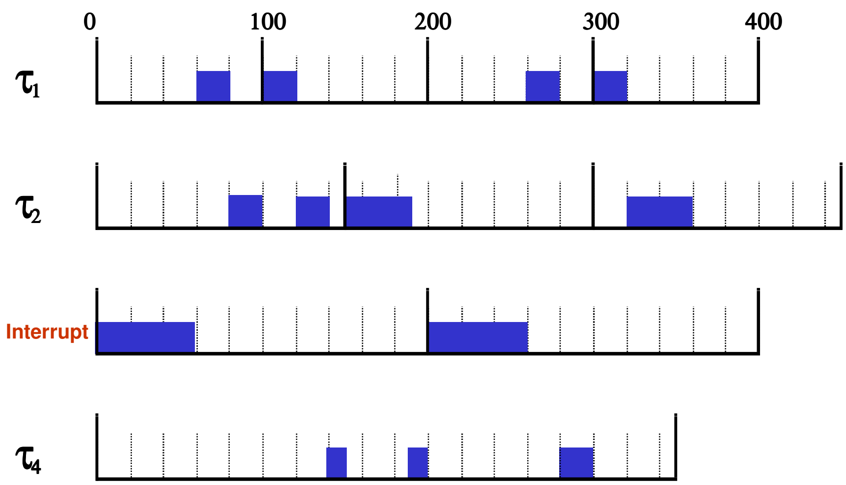
Task	*C*	*T*	*U*
τ_1	20	100	0.200
τ_2	40	150	0.267
τ_3	60	200	0.300
τ_4	40	350	0.115

τ_3 is an interrupt handler

Example: Execution with Rate-Monotonic Priorities



Example: Execution with an Interrupt Priority



Resulting Table for Example

Task (i)	Period (T)	Execution Time (C)	Priority (P)	Deadline (D)
τ_3	200	60	Hardware (*highest*)	200
τ_1	100	20	*High*	100
τ_2	150	40	*Medium*	150
τ_4	350	40	*Low*	350

- For τ_1, τ_3 introduces priority inversion → $B_1 = 60$.
- For τ_2, τ_3 introduces priority inversion → $B_2 = 60$.
- For τ_3, it must satisfy its own deadline (60 < 200?).
- For τ_4, τ_3 looks like a normal higher priority task.

Concepts and Definitions

- Aperiodic task
  - runs at irregular intervals.
- Aperiodic deadline:
  - hard, minimum interarrival time
  - soft, best average response

Techniques

- Approaches to handle aperiodic tasks:
  - Background server:
    - Long response times
    - Tight guarantees are difficult
  - Slack stealing
    - Exploit the fact that jobs often do not execute up to their worst-case execution times
  - Periodic servers

Periodic Servers

- Polling Server
  - Simple
  - Commonly used
  - Executes at the "highest" priority
  - Provides a guaranteed fraction of the processor for dealing with aperiodic tasks
  - Worst-case response times can be long (why?)
- Deferrable Server
  - Improves on the response time of the polling server
  - Maintains its advantages
  - Cannot be generalized to multiple instances at different priority levels
- Sporadic Server
  - Improves upon the deferrable server and is very generalizable
  - Higher run-time complexity

Deferrable Server (DS)

- Create a high-priority "server" with an associated budget of *C* time-units and a period of *T* (i.e. $T_{DS} \leq$ shortest period of all the normal periodic tasks)
- When aperiodic tasks arrive, they check for any available server budget
  - If available, use the budget to execute at the highest priority
  - Budget is reduced correspondingly for every unit of server execution
  - If budget is depleted, aperiodic tasks can execute at background priority
- The budget of *C* gets replenished every *T* time-units
  - Unused budget does *not* get carried over
    - No "rollover" minutes

DS Example

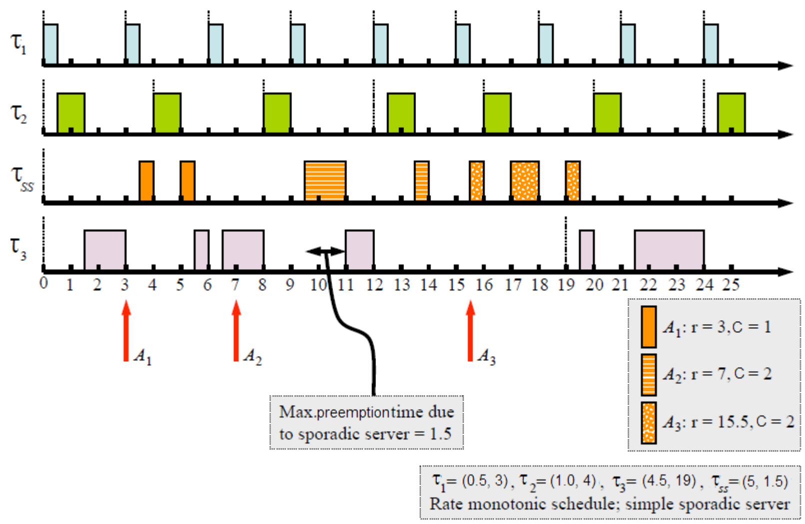
τ_1 preempted for 1.2 time-units even though C_{DS} is only 1.

- This is referred to as the "back-to-back execution" effect.
- Such an effect *cannot* happen with the RMS (Liu and Layland) model.

Sporadic Server (SS)

- A *sporadic server* is designed to eliminate the occurrence of "back-to-back" executions
  - More complex consumption and replenishment rules ensure that a sporadic server with period T_S and budget C_S never demands more processor time than a periodic task with the same parameters
- Server priority is based on T_S, just like periodic tasks.
- Budget replenishment occurs one "period" after **start** of use.
- Budget can be replenished earlier if sporadic server is preempted by a higher priority task
  - But not too early!
- Replenishment time $t_r = max(t_{r-1}, t_h) + T_s$
  - where t_h is the start of a higher (or equal priority) task running just before the SS
- There can be multiple "pieces" of budget with different replenishment times (these budgets can be combined later)

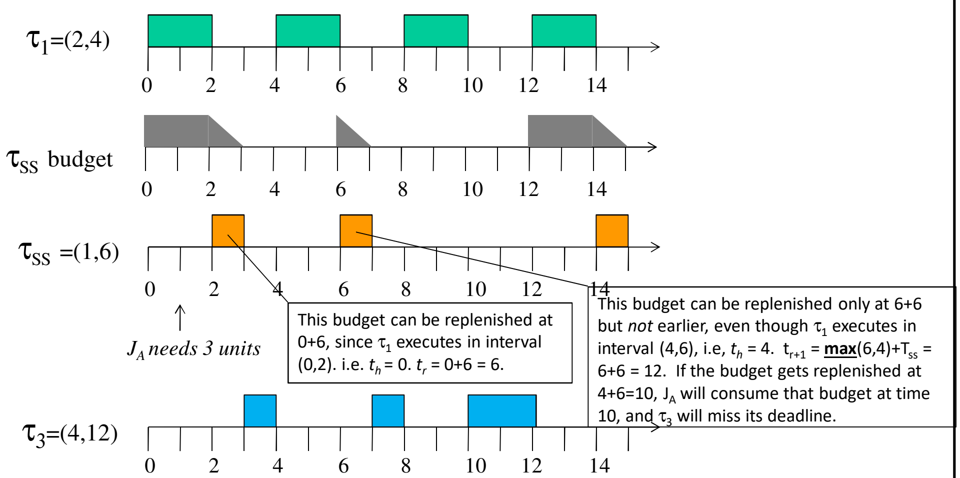
SS Example



Another Optimization

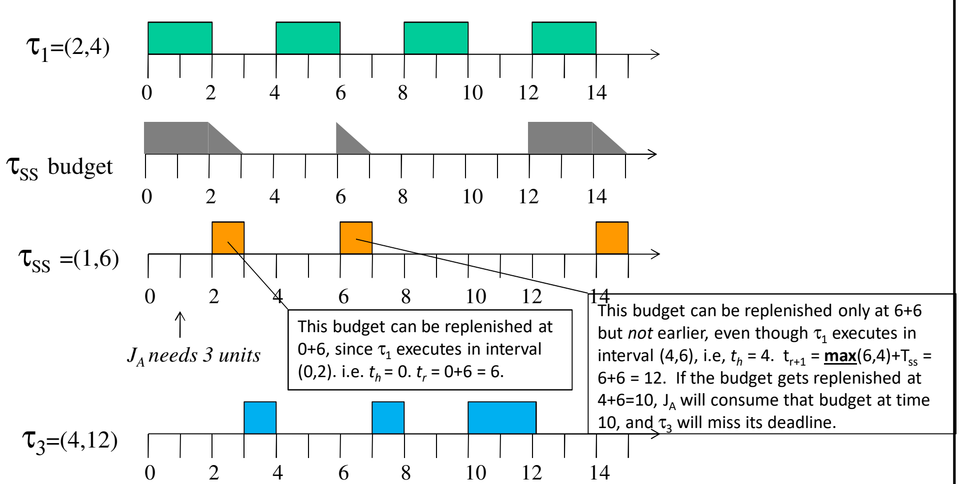
- If the CPU ever becomes idle, any SS capacity can be immediately replenished (to its original allocated budget).

Replenish Early but Not *Too* Early



$U = (2/4) + (1/6) + (4/12) = 100\%$

Replenish Early but Not *Too* Early



$U = (2/4) + (1/6) + (4/12) = 100\%$

A Sample Taskset

Periodic Tasks

- τ_1 = (20, 100)
- τ_2 = (40, 150)
- τ_3 = (100, 350)

Sporadic Task

- Emergency task: C= 5, D = 6, Minimum Inter-Arrival Time = 50

Create a sporadic server with C=5, T= 50. Completion = 5 < D

Aperiodic Task

User Input: C = 2, Minimum inter-arrival time = 40

Desired response time = 25 ms after arrival

Use simulation and queueing theory based on M/M/1 approximation: response time ~20ms

Summary

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  - Deferrable Servers
  - Sporadic Servers