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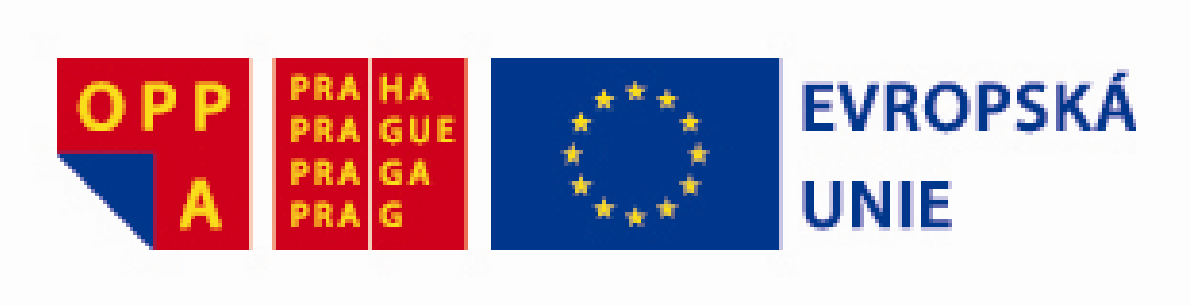

Evropský sociální fond
Praha & EU: Investujeme do vaší budoucnosti

Department of Distributed and Dependable Systems D3S

Embedded and Real-time Systems

Scheduling – Basic Concepts

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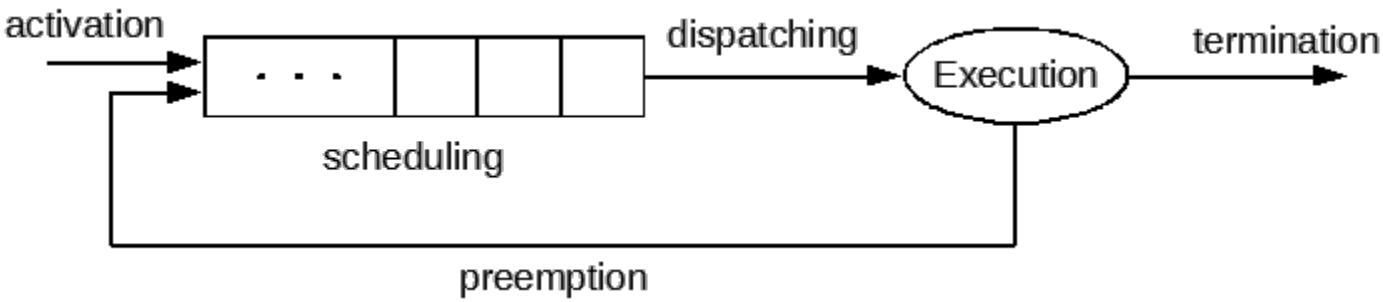
Faculty of Mathematics and Physics

Short summary of lecture 1

- Real-time systems
  - Correctness of the system depends on time
  - Close interaction with the environment (via sensors and actuators)
  - Real-time ≠ fast, real-time = predictable
  - Handling of several activities at the same time
  - Possibility to prioritize among activities
- Some classification of real-time systems
  - Event triggered / time triggered
  - Hard / soft

Tasks and scheduling

- RT system is typically responsible for a number of concurrent activities
- Each activity has its deadline
  - Activity ~ Task
- The key problem in RT systems is how to schedule the tasks such as each meets the deadline

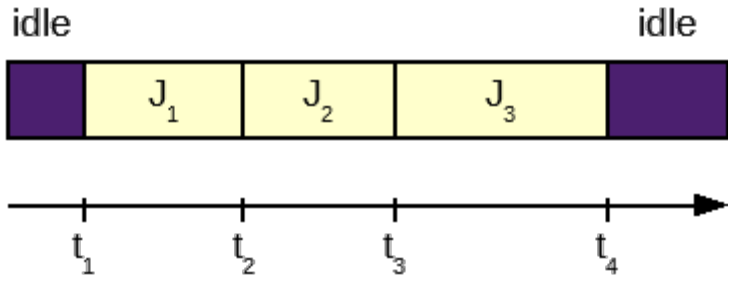


Tasks and scheduling

- Tasks compete for processor(s)
- They run according to a schedule
  - assigns a particular task to a particular processor at given time
- Formally (for uniprocessor):
  - Given a set of tasks, $J = \{J_1, \ldots, J_n\}$, a schedule is an assignment of tasks defined as a function $\sigma: \mathbb{R}^+ \longrightarrow \mathbb{N}$ such that $\forall t \in \mathbb{R}^+, \exists t_1, t_2$ such that $t \in [t_1, t_2)$ and $\forall t' \in [t_1, t_2): \sigma(t) = \sigma(t')$
  - $\sigma(t) = k$ with $k > 0$ means that task J_k is executing at time t, while $\sigma(t) = 0$ means that the CPU is idle

Tasks and scheduling

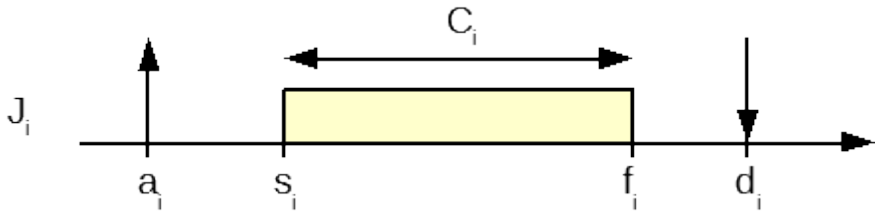
- At time t_1, t_2, t_3, and t_4, the processor performs a context switch
- If the intervals were disjointed – preemptive schedule



- A schedule is feasible is all tasks can be completed according to a set of specified constraints
- A set of tasks is schedulable, if there exists at least one algorithm that can produce a feasible schedule

Timing constraints

- Arrival time a_i – time at which a task becomes ready for execution (also called release time – r_i)
- Computation time C_i – time necessary for executing the task without interruption (typically determined by WCET analysis)
- Absolute deadline d_i – time before which a task should be completed
- Relative deadline D_i – equals to $d_i - r_i$
- Start time s_i – time at which a task starts its execution
- Finishing time f_i – time at which a task finishes its execution



Timing constraints

- Response time R_i – difference $f_i - r_i$
- Lateness L_i – equals to $f_i - d_i$, represents the delay of a task completion with respect to its deadline
  - if a task completes in time, it is negative
- Tardiness (Exceeding time) E_i – equals to $\max(0, L_i)$, is the time a task stays active after its deadline
- Laxity (Slack time) X_i – equals to $d_i - a_i - C_i$, is the maximum time a task can be delayed to still complete within deadline

Regularity of the activation

- Periodic task
  - consists of an infinite sequence of identical activities (instances or jobs) activated regularly at a constant rate
  - denoted π_i
  - activation time of the first instance – phase Φ_i
  - period of the task T_i
  - activation time of k_{th} instance is $\Phi_i + (k-1)T_i$
- Aperiodic task
  - also infinite number of instances, however activation is not regular
  - jobs with minimum inter-arrival time are called sporadic

Periodic task execution

- Typically realized this way:
  - RTOS kernels with support for periodic tasks

```
period_T = 50;
void task_T() {
  /* do some work */
}
```

  - RTOS kernels with no support for periodic tasks

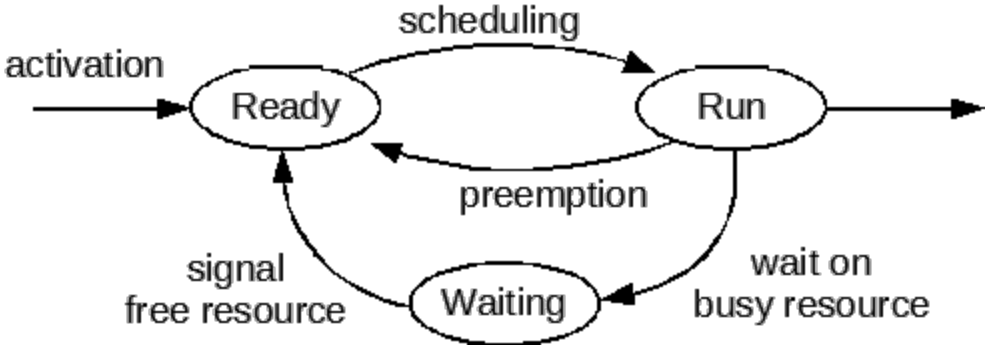
```
void task_T() {
  while (1) {
    /* do some work */
    /* wait until next period */
  }
}
```

Precedence constraints

- Sometimes there is a precedence constraint between tasks
  - one task must complete before other task may start running
  - e.g. low-level image processing task may start only after task for image acquisition completes

Resource constraints

- Resource is any software structure that can be used by the process to advance its execution
- Mutually exclusive resources must not be used by two tasks at the same time
- Critical section
- Job must wait for the resource to become available



General scheduling problem

- A set of n tasks $J = \{J_1, J_2, \dots, J_n\}$,
  a set of m processors $P = \{P_1, P_2, \dots, P_m\}$,
  a set of r resources $R = \{R_1, R_2, \dots, R_r\}$,
  precedence relations in the form of an acyclic graph, timing on tasks
- Scheduling means assigning processors from P and resources from R to tasks from J in order to complete all tasks under the imposed constraints
- In general form, NP-complete

Classification of scheduling algorithms

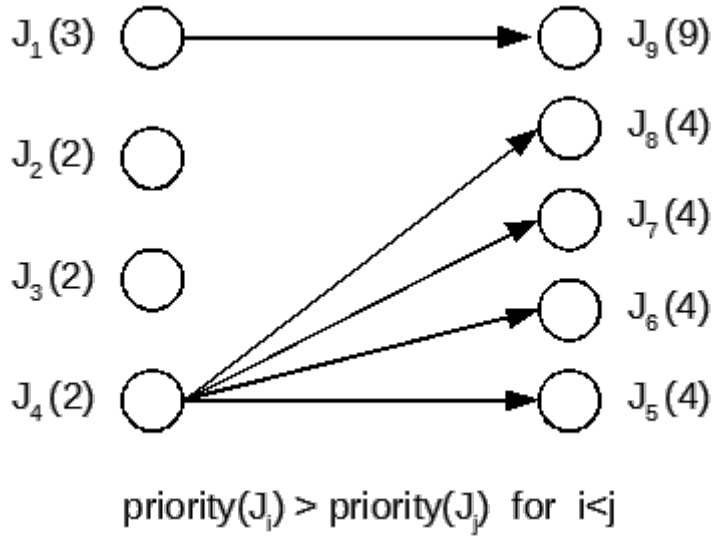
- **Preemptive** – a running task can be interrupted at any time
- **Non-preemptive** – a task once started is executed until completion
- **Static** – scheduling decisions are based on fixed parameters
- **Dynamic** – parameters of scheduling decisions may changes during runtime
- **Off line** – scheduling algorithm executed on the entire task set before actual task activation (schedule determined in advance)
  - stored in a table
- **On line** – scheduling algorithm decides at runtime every time a new task enters the system or when running task terminates
- **Optimal** – minimizes some given cost functions, when no cost function is given it is optimal if it always finds a feasible schedule provided such schedule exists

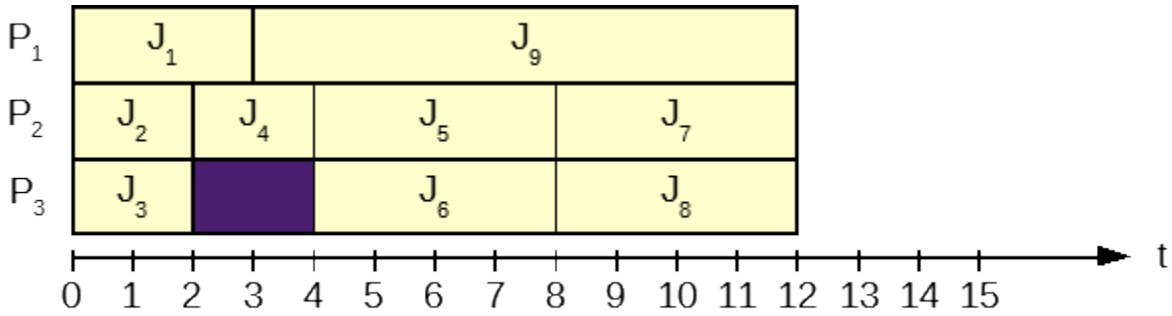
Scheduling Anomalies

- Theorem (Graham)
  - If a task set is optimally scheduled on a multiprocessor with some priority assignment, a fixed number of processors, fixed execution times, and precedence constraints, then increasing the number of processors, reducing execution times, or weakening the precedence constraints can increase the schedule length.

Scheduling Anomalies – Example I

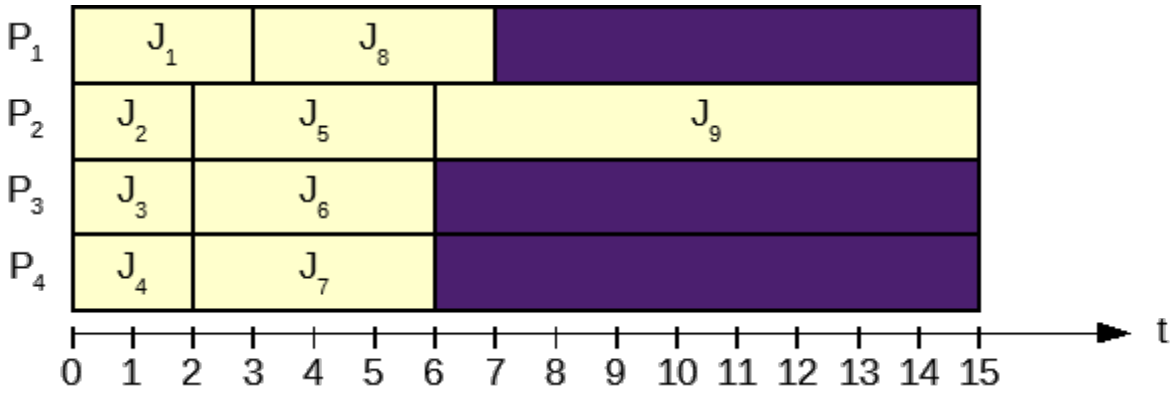
- Original optimal schedule





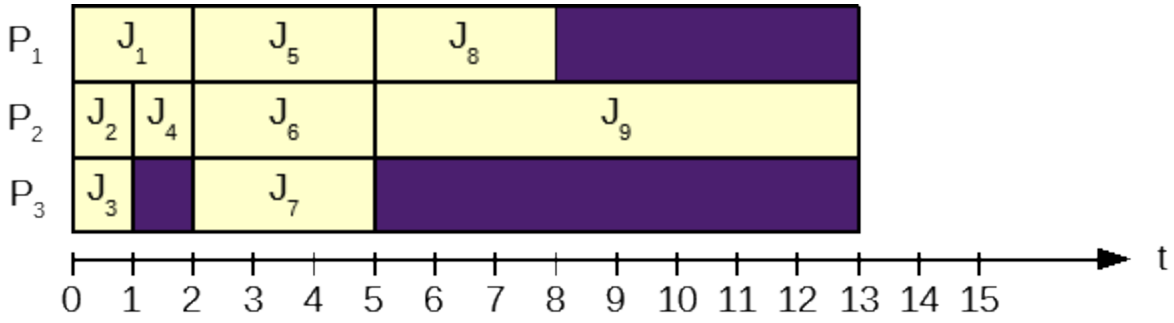
Scheduling Anomalies – Example I

- Number of processors increased



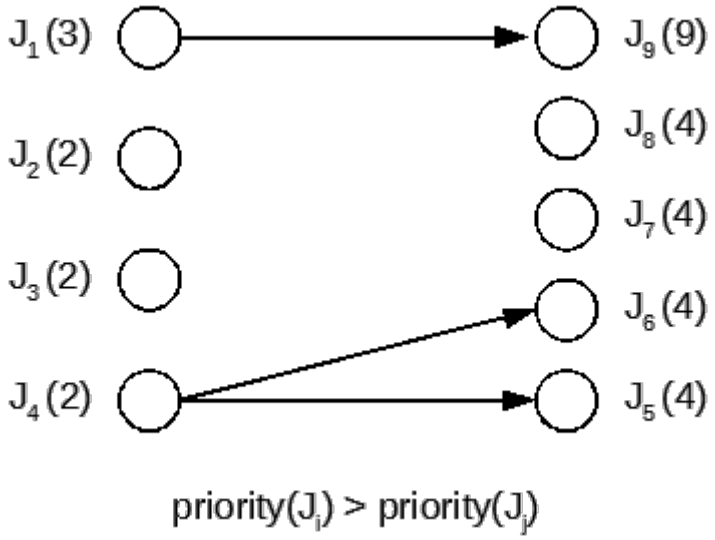
Scheduling Anomalies – Example I

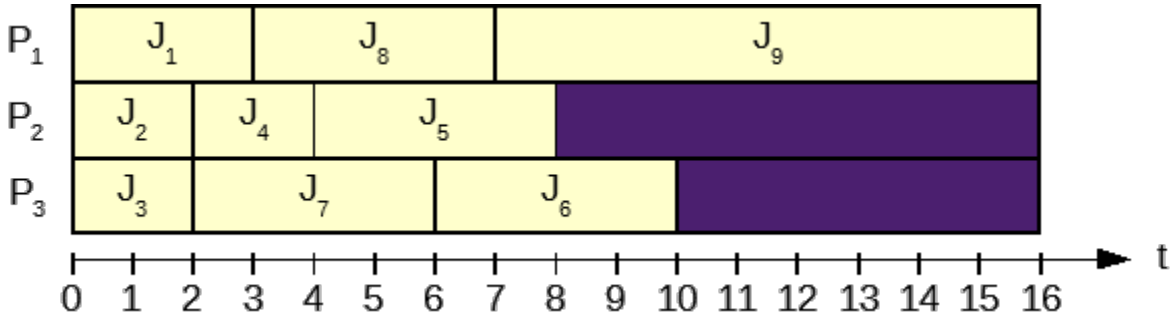
- Computation times reduced



Scheduling Anomalies – Example I

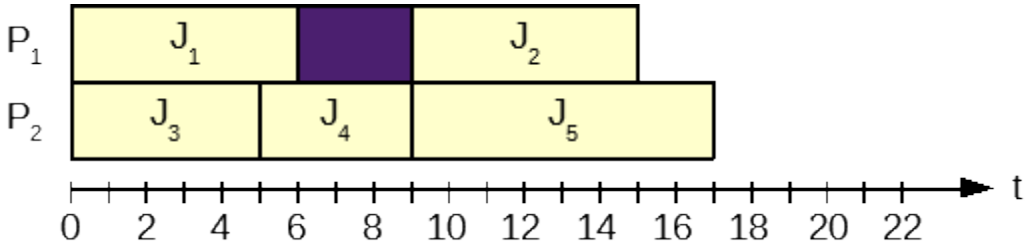
- Precedence constraints weakened





Scheduling Anomalies – Example II

- Anomalies under resource constraints
  - J2 and J4 share the same resource



  - When computation time of J1 is reduced