Scheduling Basics

Real-Time Operative Systems Course

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Last lecture

- Computation models and Real-Time Kernels and Operating Systems
- Computation models:
  - Tasks with specific temporal constraints;
  - The Event- and Time-Trigger paradigms
- Real-Time OSs and kernels:
  - General architecture
  - Task states
  - Basic components

Agenda for today

Scheduling basics

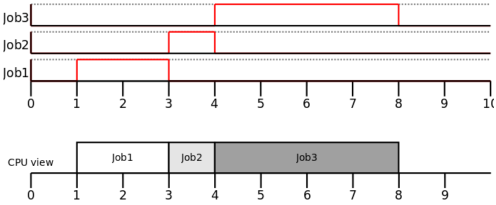
- Task scheduling - basic concepts and taxonomy
- Basic scheduling techniques
- Static cyclic scheduling

1. Preliminaries
2. **Basic concepts**
3. Scheduling Algorithms
4. Static Cyclic Scheduling

Scheduling Definition

Task scheduling (also applies to messages, with due adaptations)

- Sequence of task executions (jobs) in one or more processors
- Application of $\mathbb{R}^+$ (time) in $\mathbb{N}_0$ (task set), assigning to each time instant "t" a task/job "i" that executes in that time instant
  $$\sigma(t) : \mathbb{R}^+ \rightarrow \mathbb{N}_0$$
  $i = \sigma(t), t \in \mathbb{R}^+$, i=0 means that the processor is idle
- $\sigma(t)$ is a step function, which can be expressed e.g. as a Gantt graph



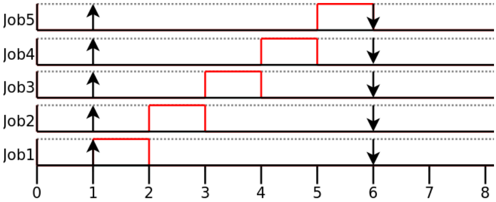
Scheduling Definition

- A schedule is called **feasible** if it fulfills all the task requirements
  - temporal, non-preemption, shared resources, precedences, ...
- A task set is called **schedulable** if there is at least one feasible schedule for that task set

The scheduling problem: easy to formulate, but hard to solve!

- Given:
  - A task set
  - Requirements of the tasks (or cost function)
- Find a time attribution of processor(s) to tasks so that:
  - Tasks are completely executed, and
  - Meet they requirements (or minimize the cost function)

E.g. $J = J_i(C_i = 1, a_i = 1, D_i), i = 1..5)$



Scheduling problem

Exercise:

- Build a Gantt diagram for the execution of the following periodic tasks, admitting $D_i = T_i$ and no preemption.
  - $\tau = (1, 5)(6, 10)$
- Is the execution order important? Why?

Scheduling algorithms

- A **scheduling algorithm** is a method for solving the scheduling problem.
  - Note: don't confuse scheduling algorithm (the process/method) with schedule (the result)
- Classification of scheduling algorithms:
  - Preemptive vs non-preemptive
  - Static vs dynamic (priorities)
  - Off-line vs on-line
  - Optimal vs sub-optimal
  - With strict guarantees vs best effort

A short note on temporal complexity

- Measurement of the **growth** of the execution time of an algorithm as a function of the problem size (e.g. the number of elements of a vector, the number of tasks of a real-time system)
- Expressed via the $O()$ operator (big O notation)
- $O()$ arithmetic, n=problem dimension, k=constant
  - $O(k) = O(1)$
  - $O(kn) = O(n)$
  - $O(k_1 \cdot n^m + k_2 \cdot n^{m-1} + ... + k_{m+1}) = O(n^m)$

Compl. $= O(N)$

```
for (k=0;k<N;k++)
    a[k]=0;
```

Compl. $= O(N^2)$

```
for (k=0;k<N-1;k++)
    for (m=k;m<N;m++)
        if a[k]<a[m]
            swap(a[k],a[m]);
```

Compl. $= O(N^N)$

Computation of the permutations of a set $A = a_i, i = 1..N$

Basic algorithms

EDD - Earliest Due Date (Jackson, 1955)

- Single instance tasks fired synchronously:$J = Ji(Ci, (ai = 0,)Di), i = 1..n$
- Executing the tasks by non-decreasing deadlines minimizes the maximum lateness ($L_{max}(J) = max_i(f_i - d_i)$)
- Complexity: O(n.log(n))

E.g. $J = \{J_1(1, 5), J_2(2, 4), J_3(1, 3), J_4(2, 7)\}$
Determine the maximum lateness!

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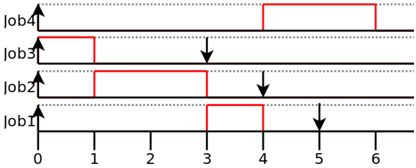

Lmax,EDD(J) = -1

Basic algorithms

EDF - Earliest Deadline First (Liu and Layland, 1973; Horn, 1974)

- Single instance or periodic, asynchronous arrivals, preemptive: $J = J_i(C_i, a_i, D_i), i = 1..n$
- Always executing the task with shorter absolute deadline minimizes the maximum latency $L_{max}(J) = max_i(f_i - d_i)$
- Complexity: $O(n.log(n))$, **Optimal** among all scheduling algorithms of this class

E.g. $J = \{J_1(1,0,5), J_2(2,1,5), J_3(1,2,3), J_4(2,1,8)\}$
Determine the maximum lateness!

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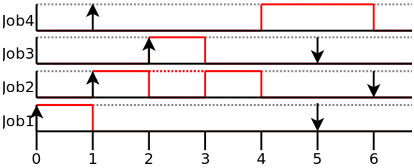

Lmax,EDD(J) = -2

Basic algorithms

BB – Branch and Bound (Bratley, 1971)

- Single instance or periodic tasks, asynchronous arrivals, non-preemptive: $J = J_i(C_i, a_i, D_i), i = 1..n$
- Based on building an exhaustive search in the permutation tree space, finding all possible execution sequences:
- Complexity: O(n!)

E.g. $J = \{J_1(1, 0, 5), J_2(2, 1, 3), J_3(1, 2, 4), J_4(2, 1, 7)\}$

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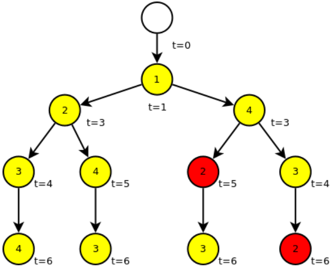


Periodic task scheduling

Periodic tasks

- The release/activation instants are known **a priori**
- $\Gamma = \{\tau_i(C_i, \phi_i, T_i, D_i)\}, i = \{1...n\}$
- $a_{i,k} = \phi_i + (k-1) \cdot T_i, k = 1, 2, ...$

Thus, in this case the schedule can be built:

Online
: Tasks to execute are selected as they are released and finish, during normal system operation (addressed in next class)

Offline
: The task execution order is computed before the system enters in normal operation and stored in a table, which is used at runtime time to execute the tasks (static cyclic scheduling).

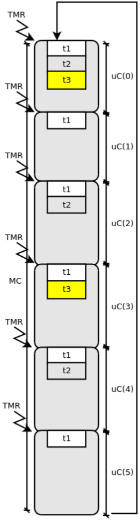
Static cyclic scheduling

- The table is organized in micro-cycles (μC) with a fixed duration. This way it is possible to release tasks periodically
- The micro-cycles are triggered by a Timer
- Scanning the whole table repeatedly generates a periodic pattern, called macro-cycle (MC)

$$\Gamma = \{\tau_i(C_i, \phi_i, T_i, D_i)\}, i = \{1...n\}$$
$$\mu C = GCD(T_i); MC = mCM(T_i)$$

Example:

- $\phi_i = 0$
- $T_1 = 5ms; T_2 = 10ms; T_3 = 15ms$



Static cyclic scheduling

Pros

- Very simple implementation (timer+table)
- Execution overhead very low (simple dispatcher)
- Permits complex optimizations (e.g. jitter reduction, check precedence constraints)

Cons

- Doesn't scale (changes on the tasks may incur in massive changes on the table. In particular the table size may be prohibitively high)
- Sensitive to overloads, which may cause the "domino effect", i.e., sequence of consecutive tasks failing its deadlines due to a bad-behaving task.

Static cyclic scheduling - Algorithm

How to build the table:

- Compute the micro and macro cycles (μC and MC)
- Express the periods and phases of the tasks as an integer number of micro-cycles
- Compute the cycles where tasks are activated
- Using a suitable scheduling algorithm, determine the execution order of the ready tasks
- Check if all tasks scheduled for a give micro-cycle fit inside the cycle. Otherwise some of them have to be postponed for the following cycle(s)
- It may be necessary to break a task in several parts, so that that each one of them fits inside the respective micro-cycle

Summary

- The concept of temporal complexity
- Definition of schedule and scheduling algorithm
- Some basic scheduling techniques (EDD, EDF, BB)
- The static cyclic scheduling technique

Homework

Consider the following message set (syntax (C,T), with D=T):

$$\Gamma = \{(1,5);(2,10);(3,10);(4,20)\}$$

- Compute the utilization of each task and the global utilization
- Compute the micro and macrocycle
- Build the scheduling table