7. Operating System Support

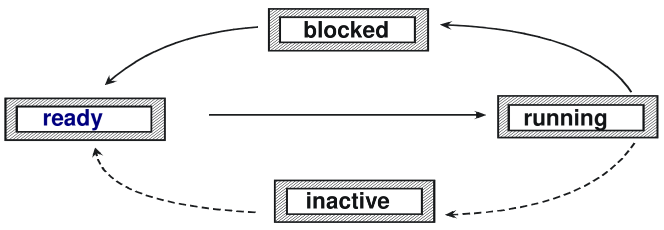
7.1 Real-time Operation

Management of processes in operating systems

Logical resources (i.e., processes) are mapped onto physical resources (e.g., central processing unit (CPU) and memory).

A process can have four states:

- **running**: it is allocated to a processor
- **ready**: it holds all operating resources except the processor
- **blocked**: it is waiting for the occurrence of an event (e.g., the termination of an output to disk)
- **inactive**: the process is not assigned to an application program.



Scheduler and Dispatcher

The **scheduler** decides which of the *inactive* processes will be moved to the *ready* state.

The **dispatcher** decides which process to move next from state *ready* to state *running*.

In conventional operating systems, **neither** scheduler **nor** dispatcher **are capable of real-time processing.**

Requirements for Multimedia

Processing of continuous data streams

The data to be processed appears in **periodic** time-intervals.

Typical operations on multimedia data are:

- Creation and playout of audio and video packets,
- Transmission of audio and video packets,
- Compression and decompression of audio and video packets.

Real-time requirements:

- Processing must be completed by a specific time (**deadline**)
- Processing of a multimedia data packet takes approximately the same amount of resources in each time period.

Light-weight Processes (threads)

Concept

- Concurrent (parallel) activities are carried out **within one address space.**
- Each concurrent activity is called a **thread.**
- Data transfer between threads is efficient (just a copy operation).
- A "context switch" (i.e., a switch between different threads) is much more efficient than a switch between normal, heavy-weight operating system processes.

But:

There is **no access protection** between threads provided by the operation system (same address space for all threads)!

Reservation of Resources

Pessimistic (deterministic) reservation

- Takes the worst case into consideration
- Generally reserves too many resources most of the time, and thus leads to sub-optimal use of the resources

Optimistic (stochastic) reservation

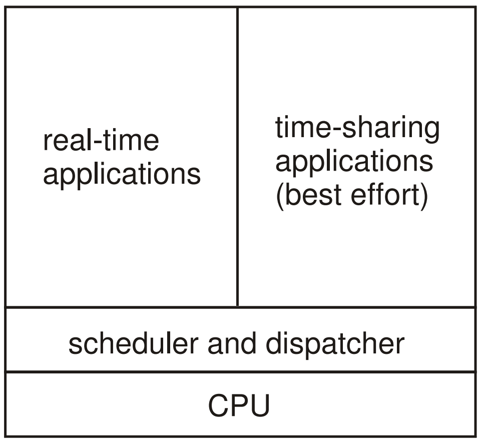
- Reservation is made for the expected value (mean value) of the processing resources
- Leads to good usage of the resources
- But can lead to an overload of the resources (blocking or sub-optimal execution of a process)
- Role of a run-time monitor:
  - Monitors resource usage
  - In case of overload, initiates suitable action, such as scaling (QoS adaptation) or blocking of the process and withdrawal of the resource.

Real-time Process Specification for Multimedia

Traditional systems usually have

- *either* a scheduling mechanism for time-sharing applications
- *or* a scheduling mechanism for real-time applications

In multimedia systems, a scheduler for both types of applications is required.



Real-time Applications vs. Multimedia Applications

Data in traditional real-time applications (e.g., in process automation and control) typically have **hard** real-time requirements.

Multimedia data is generally intended for presentation to the human being as the data sink. This means:

- **Rare violations of deadlines are acceptable**. For example, a macro block decoding failure in a video that is caused by late-coming and thus rejected data might be tolerated; the decoder repeats the corresponding macro block of the previous frame.
- In traditional real-time systems, operations are not always periodic. Multimedia data is periodic. Scheduling and dispatching algorithms can take advantage of the periodicity. Resource requirements are easier to predict.

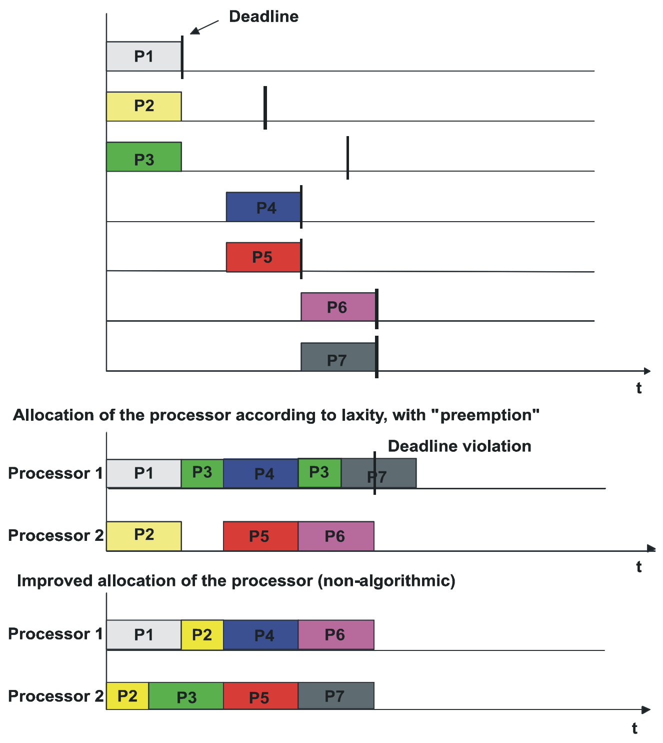
Process Scheduling Goals

The main goal of process scheduling and dispatching is to ensure that **all** deadlines of **all** processes are satisfied. Additional optimization goals are:

- A high average utilization of the resources, leading to high throughput
- fast computation of the resource allocation (an efficient algorithm).

The allocation does not necessarily have to be **optimal**. Complexity theory tells us that the computation of optimal schedules is NP-complete.

Scheduling Problem: An Example


Deadline
P1
P2
P3
P4
P5
P6
P7
t
Allocation of the processor according to laxity, with "preemption"
Deadline violation
Processor 1
P1
P3
P4
P3
P7
Processor 2
P2
P5
P6
t
Improved allocation of the processor (non-algorithmic)
Processor 1
P1
P2
P4
P6
Processor 2
P2
P3
P5
P7
t

7.2 Scheduling Algorithms

Requirements

- All deadlines must be met.
- Resource utilization should be high.
- Best-effort requests should not starve.
- The algorithm should be efficient, i.e., not use too much CPU time itself.

The scheduler can take advantage of the **periodicity** of continuous data streams.

Preemptive vs. Non-preemptive Scheduling

Preemptive scheduling

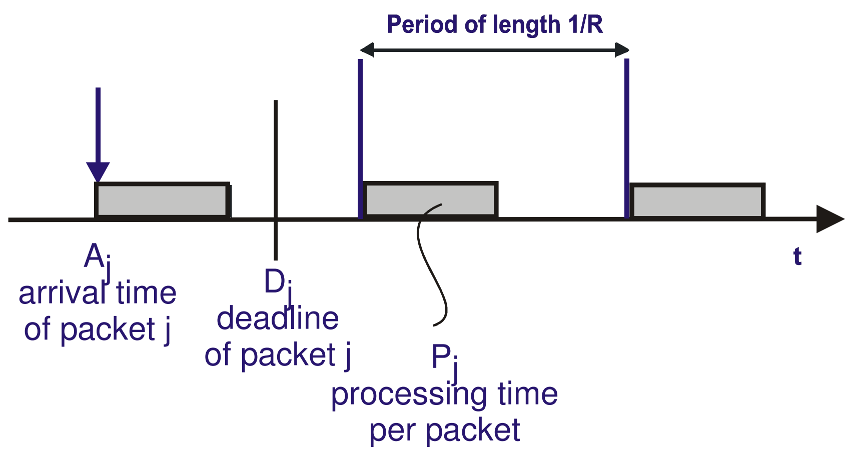
- If a process with higher priority requests a resource, the currently active (running) process is moved to the READY state, the high-priority process gets the CPU, i.e., is moved to the RUNNING state.
- There are many more process switches, process management overhead is high.

Non-preemptive scheduling

- Active processes are not interrupted by high-priority requests.
- Process switching occurs less frequently, overhead is lower.

Non-preemptive scheduling generally performs well for processes with short execution times.

Model of a Periodic Data Stream

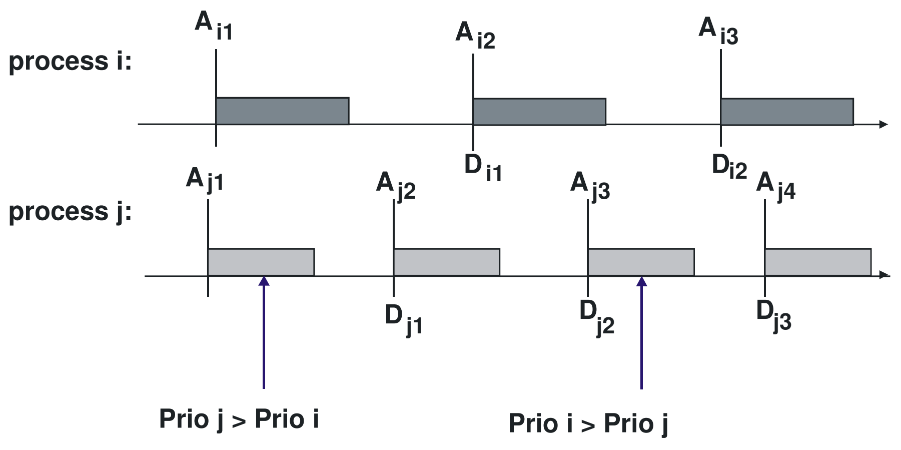


- R: Arrival rate
- P_j: Processing time
- D_j: Deadline for the termination of the process

These three parameters control the scheduling algorithm.

Algorithm 1: Earliest Deadline First (EDF)

The process with the **earliest deadline** is assigned the highest priority.



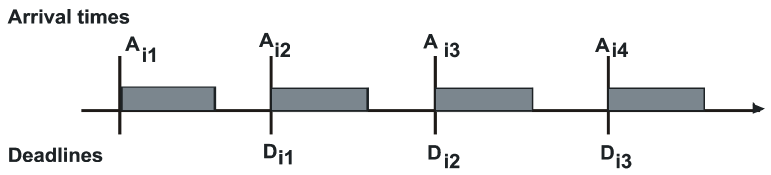
Process priorities vary over time.

One can show that the EDF algorithm always finds a valid schedule if there is one.

Resources can be used up to 100%.

EDF Scheduling

In most cases of **periodic** scheduling, the deadline of a request is identical to the end of the period since the data buffer is needed again.



Performance

Preemptive scheduling (Liu /Layland, 1973):

- maximum possible throughput:

$$\sum_{all\ streams\ i} R_i P_i \le 1$$

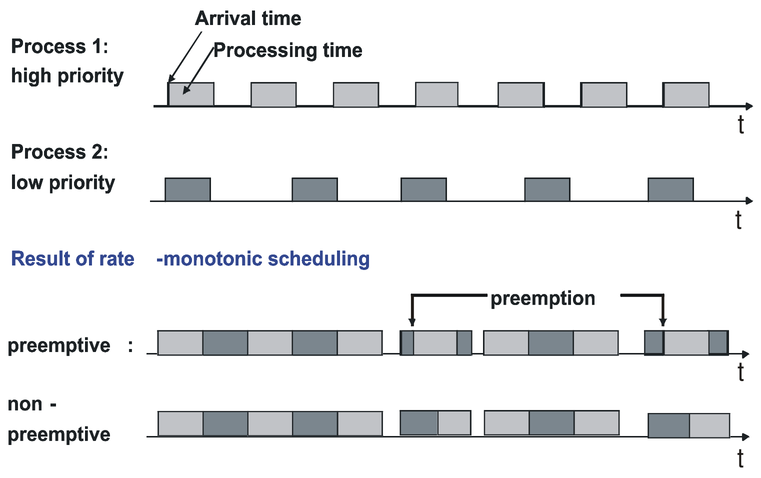
- delay of a packet <= $1/R_i$

Non-preemptive scheduling (Nagarajan/Vogt, 1992)

- same throughput as above
- delay of a packet <= $1/R_i + P_i$

Algorithm 2: Rate-Monotonic Scheduling (RM)

The process with the **highest packet rate** is assigned the highest priority.

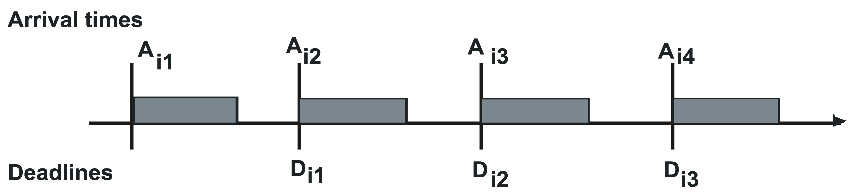


While streams are running priorities do not change; only when a new stream starts or when a stream ends, priorities are re-computed.

RM is an algorithm for **periodic** processes only.

Rate-Monotonic Scheduling

Again, we set the deadline to the end of the period:



Performance

Preemptive scheduling (Liu/Layland, 1973):

- maximum possible throughput:

$$\sum_{all\ streams\ i} R_i P_i \leq \ln 2$$

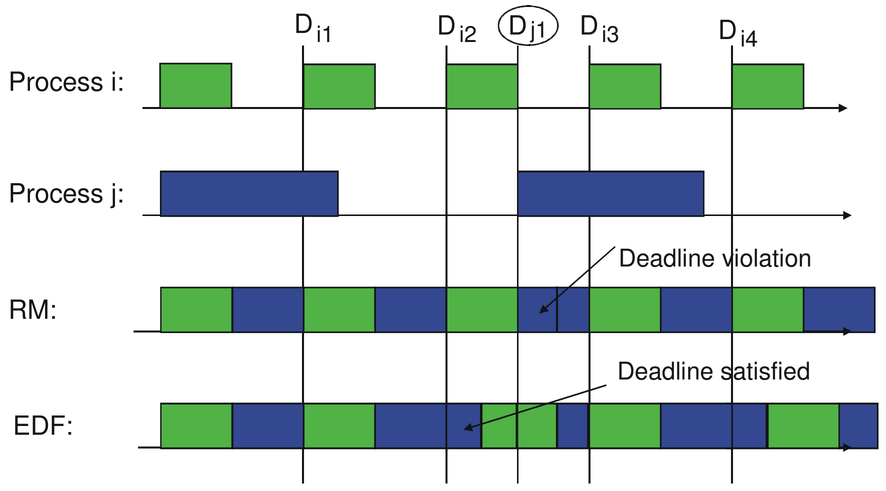
- delay of a packet <= $1/R_i$

Non-preemptive scheduling (Nagarajan/Vogt, 1992):

- highly sophisticated computation
- guaranteed throughput is much less

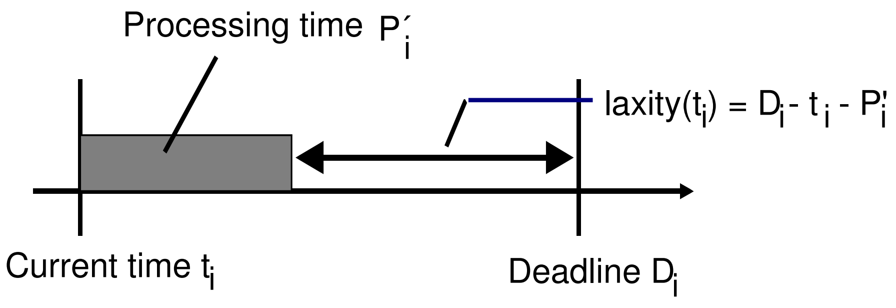
Examples for RM and EDF

With preemption



Other Scheduling Algorithms

Scheduling according to laxity



- **Laxity:** maximum allowed waiting time until processing begins
- The process with the smallest laxity is assigned the highest priority.
- Priorities must be updated continuously (large computational overhead).

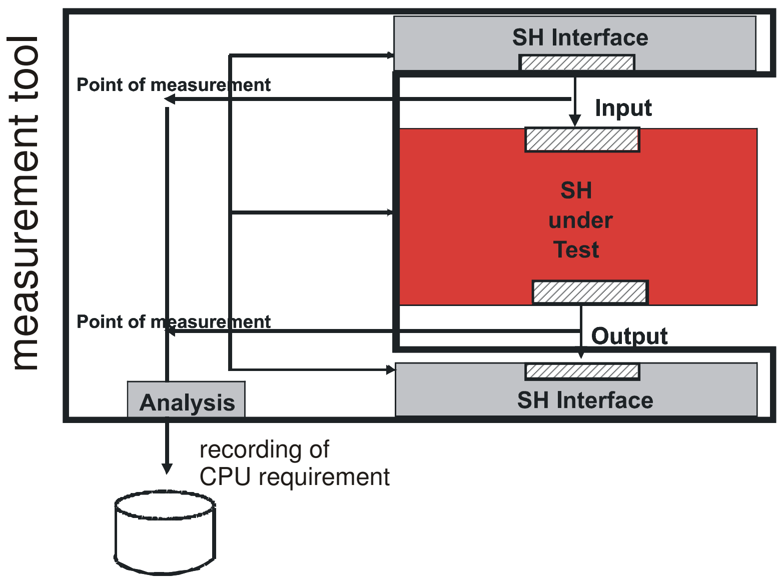
Determination of Processing Times

Problem

- For most scheduling algorithms, the actual processing time per packet on the current CPU must be known!
- An analytic computation is hardly possible.

A pragmatic approach: measurement and standardization.

Measurement of Processing Time



SH = Stream Handler