SUPSI

Real-time Operating Systems

Operating Systems

Amos Brocco, Lecturer & Researcher

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Objectives

- Study the basic operation of real-time systems
- Study some basic scheduling algorithms for real-time systems

Browsing

- Get a rapid overview.

Reading

- Read it and try to understand the concepts.

Studying

- Read in depth, understand the concepts as well as the principles behind the concepts.

You are also encouraged to try out (compile and run) code examples!

Time precision: a simple experiment

- `date +"%T. %6N"; sleep 1; date +"%T. %6N"`

Print current time, with nanoseconds | Wait 1 second | Print current time, with nanoseconds

```
attila@blackbird:~$ date +"%T. %6N"; sleep 1; date +"%T. %6N"
10:56:35. 304852
10:56:36. 310406
```

+ 5554 ns ?

* What is a nanosecond? https://www.youtube.com/watch?v=9eyFDBPk4Yw (Admiral Grace Hopper Explains the Nanosecond)

Situation

What if our life depends on those nanoseconds?

Realtime scheduling

- (RTOS – Real Time Operating System)

- What's a real-time operating system?
  - It's a multitasking operating system for applications with real-time requirements

- In a real-time application the correctness depends not only on the **logical result** but also on the **time** those results are given.

Answer

Characteristics of a real-time system

- A real-time system must be **predictable**:
  - Must satisfy scheduling time constraints: there should be a schedule that satisfies such constraints (in such case we say that the system is **schedulable**)
  - If the process pool is dynamic, it must verify that scheduling constraints are always fulfilled

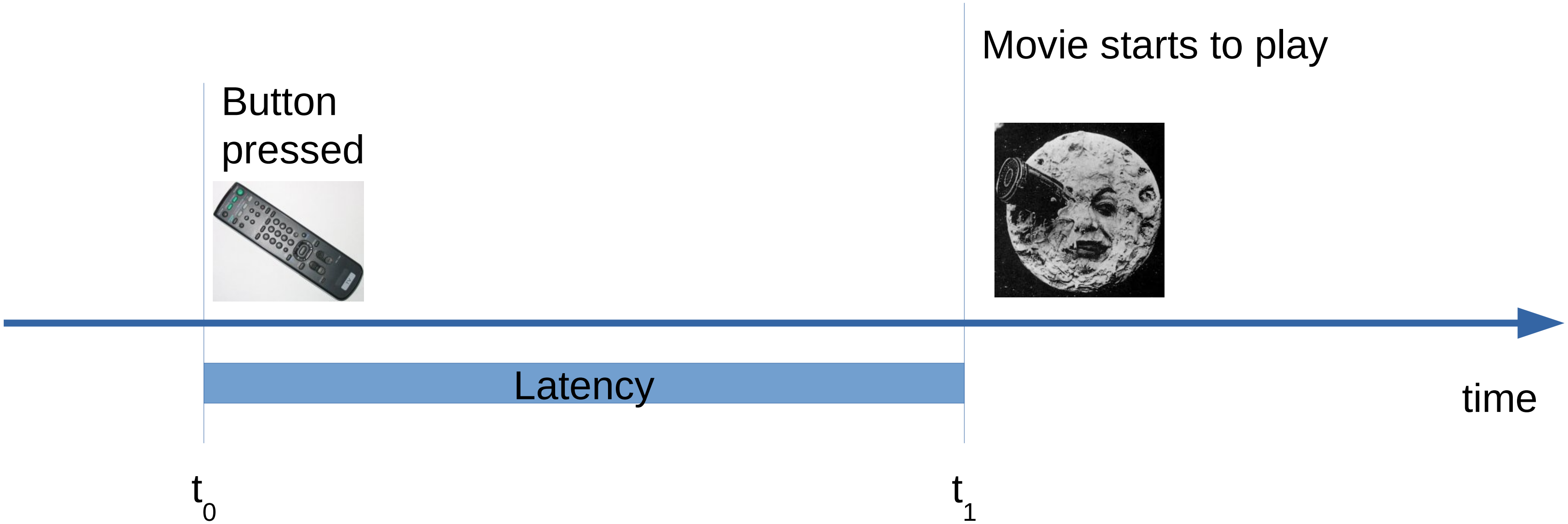
Why we sometimes lose time?

Question

Latency

- Time between the occurring of an event (*stimulus*) and the response by the software

  Example: a DVD Player



Answer

Sources of latency

- **Hardware**:
  - Interrupt generation
  - Electric signal propagation
- **Software**:
  - Interrupt handling routines
  - Scheduling
  - Preemption / Context switching
  - User application
  - Swapping

Preemption

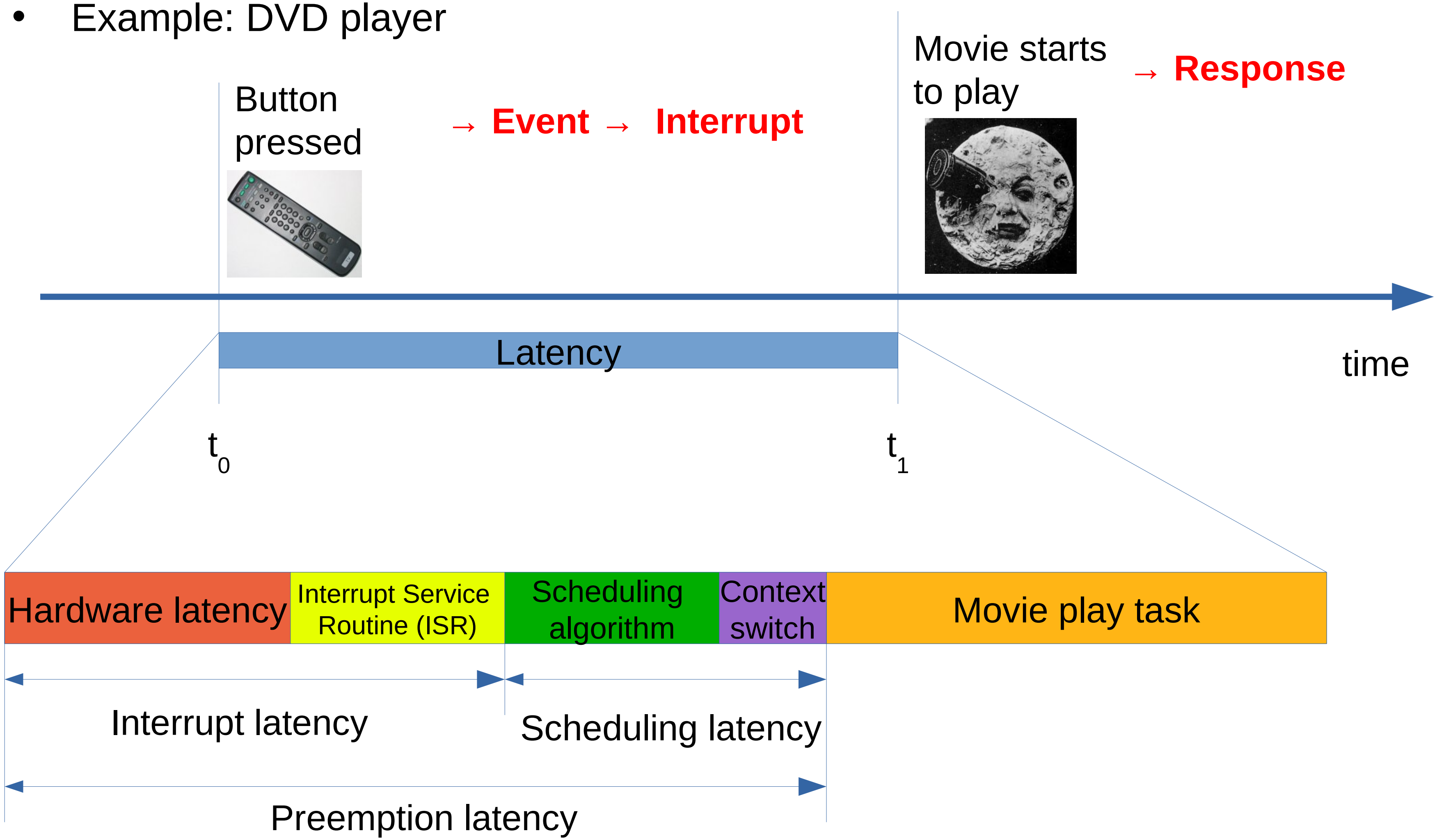
- In an multitasking operating system some other task may be running when an event occurs: **preemption** is necessary.
- Preemption means the **ability of the operating system to preempt** or stop a **currently scheduled task** in order **to execute a higher priority task**.

- Event ► Interrupt ► Interrupt handling ► Preemption of current task ►Task Switching ► Response

Explaination

Preemption latency

- Example: DVD player



Explaination

What can a RTOS offer us?

Question

Real-time requirements

- **Hard Real-Time**
  - Tasks **must** be completed within a deadline.
  - Failure to meet a deadline cannot be tolerated: a response coming too late is not only useless but may also be **dangerous**.
  - Examples: critical systems supervision and control (airplanes autopilot, nuclear reactors control,...)

Answer

Real-time requirements

- **Soft Real-Time**
  - Tasks must be completed within a deadline, but exceptions are tolerated. Task is allowed to finish behind the deadline.
  - Missing of a deadline does not produce serious or disastrous consequences
  - Examples: DVD Player (missing a deadline may just cause a degradation in the image, slow downs, fewer frames-per-second)

Answer

Real-time requirements

- **Firm Real-Time**
  - Missing a deadline is not dangerous: a response coming too late is just useless.
  - Task is not allowed to continue after the deadline: if the task has not finished the result is discarded.
  - Examples: videoconferencing (live audio-video transmission)

Answer

How can a RTOS ensure that it has "enough" time?

Schedulability

- **Schedulability** is achieved when deadlines are met for each task → important role played by the **scheduling policy/algorithm**

- Soft real-time:
  - Priority scheduling
- Hard real-time:
  - Dynamic scheduling
  - Static scheduling

Answer

What type of RTOS can we design?

Question

Real-time system design

- **Event driven design**:
  - Priority scheduling
  - Tasks are executed in response to events
  - Higher priority tasks pre-empt lower priority ones
- **Time sharing design**:
  - Round robin scheduling
  - ”More deterministic”

Answer

...and the corresponding task types

- **Event triggered**
  - Tasks that are executed in response to an (external) event (**aperiodic** tasks)

    Example: the user pushes a button, a valve is opened
- **Time triggered**
  - Tasks are executed at a certain time or at regular intervals (**periodic** tasks)

    Example: read the sensor value every *t* seconds

How to schedule tasks in a RTOS?

Static scheduling

- The number of tasks and the scheduling order are defined *a priori*: at runtime, scheduling is simple and takes little time, but...
- The system **is not flexible**
  - Limited to periodic (time triggered) tasks
  - Cannot add or remove new tasks
  - Changes require an off-line re-evaluation of the schedule
- ... but its behavior is easier to model and understand

Dynamic scheduling

- Tasks can be added or removed dynamically to the scheduling queue: the **scheduling order** is determined **at runtime**
  - The system must ensure the validity of the queue at each change (*"is the system still schedulable?"*)
- This approach is **flexible** but...
  - It is hard to ensure correctness

Answer

Priority scheduling

- Each task is scheduled according to its priority
  - Priorities can be adjusted at run-time
- Provides ”best-effort” performances, but...
  - The outcome of the scheduling is **unpredictable**

Answer

How to evaluate a RT scheduling algorithm?

Study of some periodic scheduling algorithms

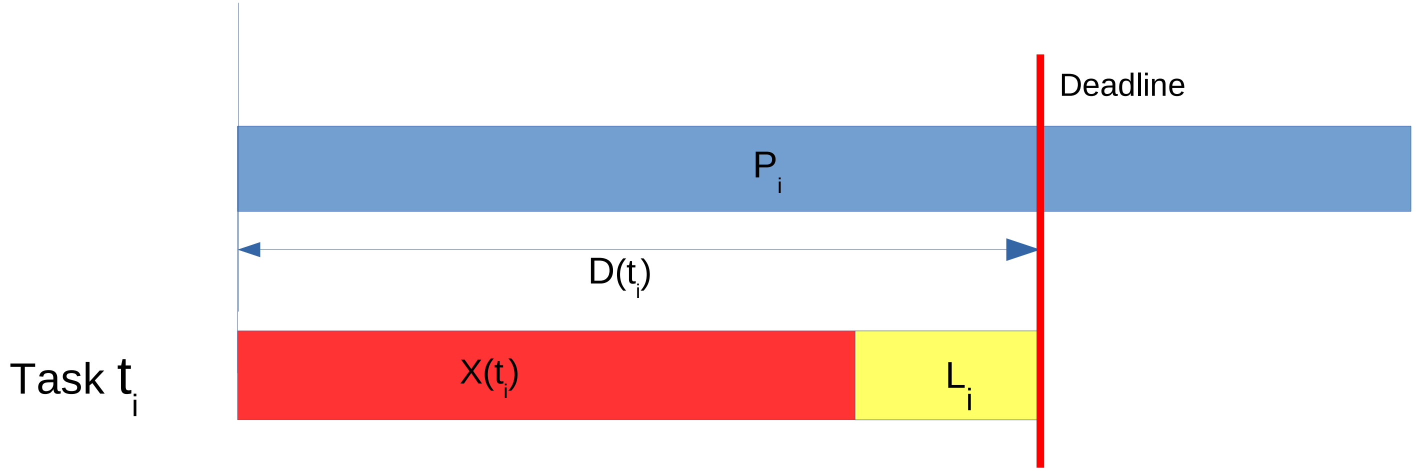
- We consider periodic tasks $\mathbf{t_i}$ with hard time constraints (*deadlines*)
- Tasks do not depend on each other and have a **known execution time X($\mathbf{t_i}$)**
- Each task is **scheduled periodically** with period $\mathbf{P_i}$, with a **deadline interval D($\mathbf{t_i}$)** (i.e. it has at most D(t_i) time to complete each execution)

Answer

Study of some periodic scheduling algorithms

- We define the **slack** or **laxity time** $\mathbf{L_i}$ as

$$\mathbf{L_i = D(t_i) - X(t_i)}$$



Answer

Schedulability condition

- If we consider $\mathbf{D(t_i) = P_i}$ we can determine if the set of tasks is schedulable on m processors/cores by computing the **accumulated utilization u** as:

$$u = \sum_{i}^{n} X(t_i)/P_i$$

- If the system has m processors/cores we have schedulability if **u ≤ m**

Answer

How to schedule a fixed set of periodic tasks?

Question

Rate Monotonic Scheduling (RMS)

- Static priority scheduling:
  - Each task has an a priori (at design time) priority
- The rate monotonic scheduling algorithm (RMS) assigns fixed priorities to periodic tasks in order to maximize their "schedulability"
- Basic idea: *”assign the priority of each task according to its period, so that* ***the shorter the period the higher the priority****”*

Answer

Rate Monotonic Scheduling (RMS): assumptions

- Assumptions:
  - Tasks are independent and periodic
  - The deadline interval has the same length as the scheduling period ($D_i = P_i$)
  - The execution time is known and constant
  - Context switch latency is negligible

Accumulated utilization for n tasks

$$u = \sum_{i}^{n} X(t_i)/P_i \leqslant n\left(2^{1/n} - 1\right)$$

Schedulability condition for RMS

Explaination

Optimality of RMS

- RMA is the **optimal static-priority algorithm**:
  – If a task set cannot be scheduled using the RMA algorithm, it cannot be scheduled using any other static-priority algorithm.

- Worst case bound for 1 CPU and n tasks: $W_s = n(2^{1/n} - 1)$
  $n \rightarrow \infty$, $W_s \rightarrow 69\%$

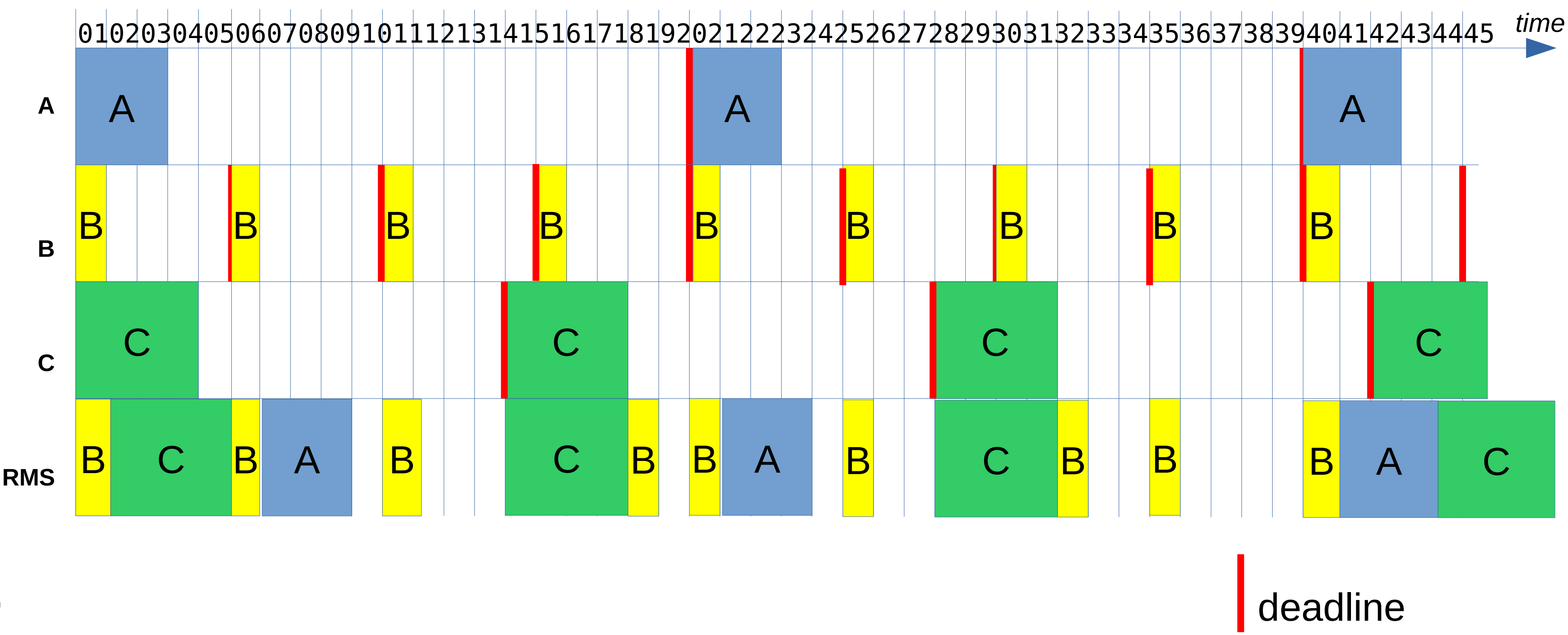
Explaination

Scheduling example with RMS (1)

- 3 periodic tasks: A (run time 3) ,B (1) ,C (4)
- Periods: A = 20, B = 5, C = 14
- Priority: A = 1/20, B = 1/5, C = 1/14 (order B,C,A)
- U = 3 / 20 + 1 / 5 + 4 / 14 = ~0.63 = 63%

The shorter the period, the higher the priority

≤ 1 i.e. schedulable on 1 CPU,
≤ 0.77 i.e. schedulable with RMS
(3 *(2 ^ (1/3) – 1)) = 0.77

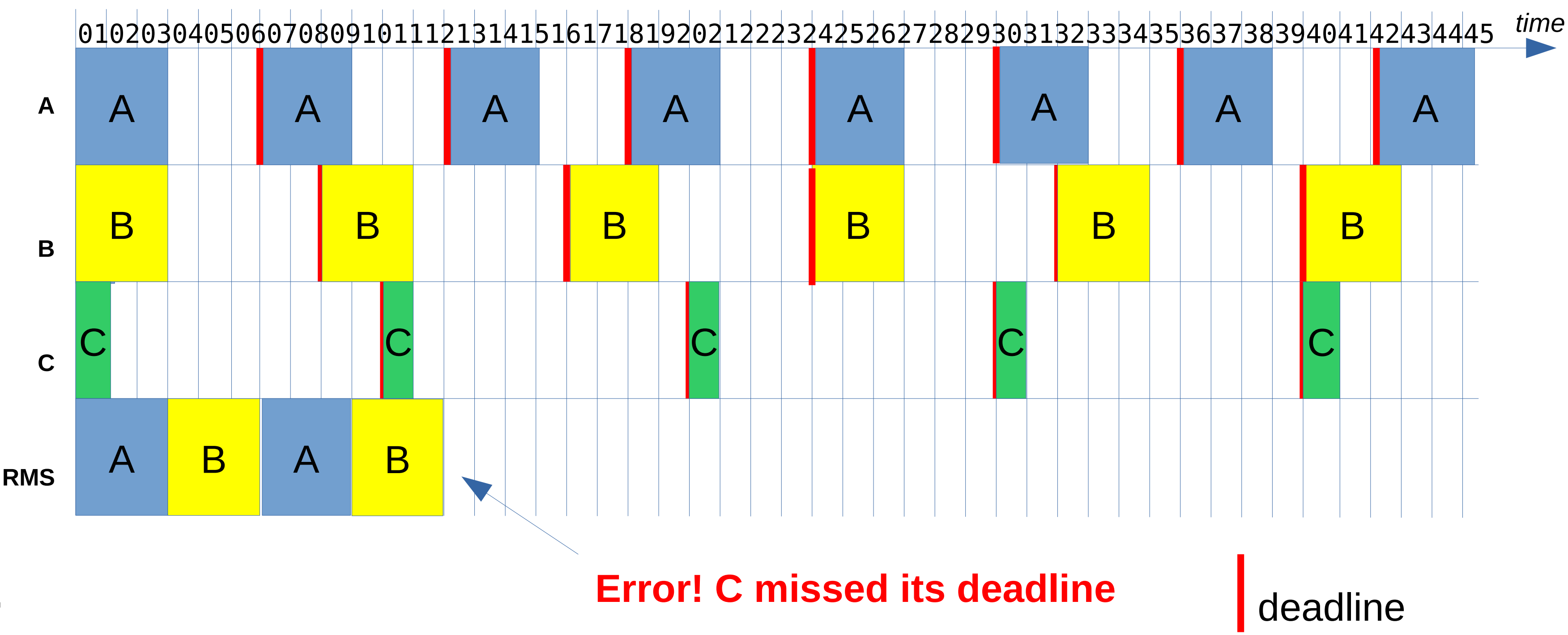


Explainaition

Scheduling example with RMS (2)

- 3 periodic tasks: A (3) ,B (**3**) ,C (1)
- Periods: A = **6**, B = **8**, C = **10**
- Priority: A = 1/**6**, B = 1/**8**, C = 1/**10** (order A,B,C)
- U = 3 / **6** + **3** / 8 + 1 / **10** = ~0.97 = 97%

≤ 1 i.e. schedulable on 1 CPU, > 0.77 i.e. **NOT SCHEDULABLE** with RMS



Is there some other scheduling algorithm worth noting?

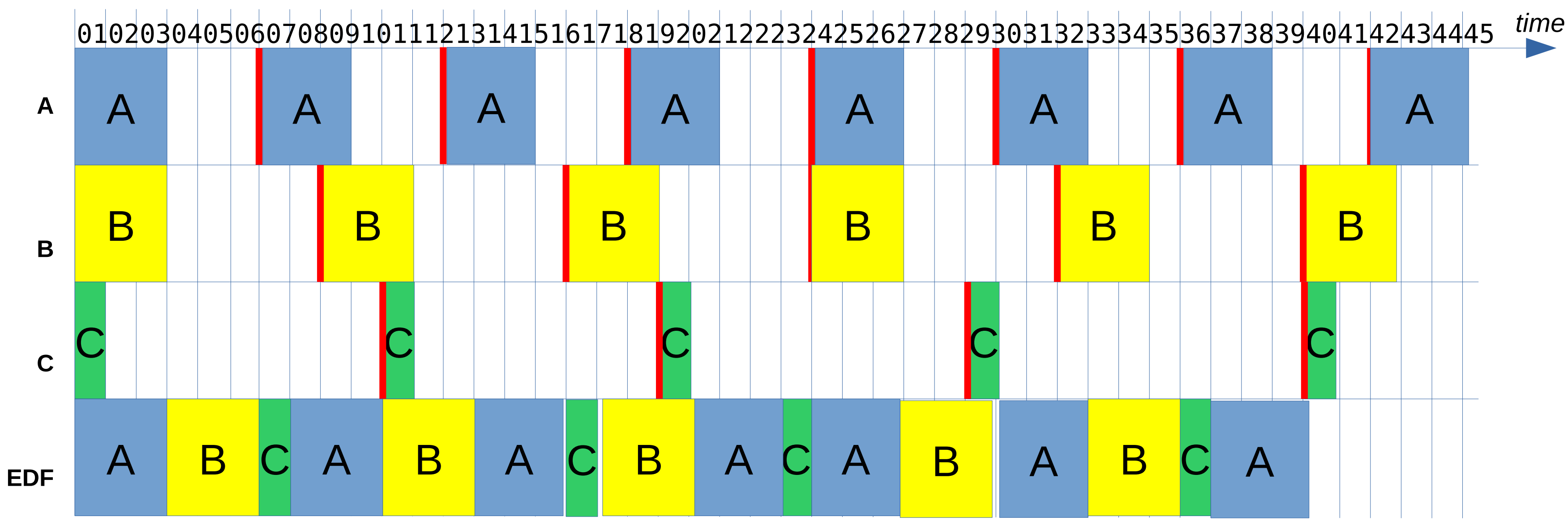
Scheduling Earliest Deadline First (EDF)

- Dynamic priority scheduling
- **Task with the earliest deadline has highest priority** → priorities change during execution
- Utilization bound is 100%: deadlines are guaranteed to be met if the CPU utilization is at most 100%
  - When the system is overloaded, the scheduling becomes impredictable
- Also works for non-periodic tasks

Scheduling example with EDF

- 3 periodic tasks: A (3) ,B (3) ,C (1)
- Periods: A = 6, B = 8, C = 10
- U = 3 / 6 + 3 / 8 + 1 / 10 = ~0.97 = 97%

≤ 1 i.e. Schedulable with 1 CPU



deadline

Explaination

Wrap Up