Common Approaches to Real-Time Scheduling

- **Clock-driven** (time-driven) schedulers
- **Priority-driven** schedulers
- Examples of priority driven schedulers
- Effective timing constraints
- How to reason about Schedulers: The Earliest-Deadline-First (EDF) Scheduler and its optimality

Common Approaches to Real-Time Scheduling

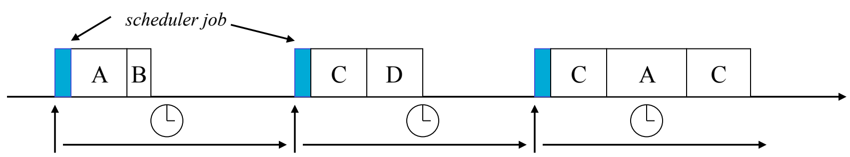
Clock-driven (time-driven) schedulers
- Scheduling decisions are made at specific time instants, which are typically chosen *a priori*.

Priority-driven schedulers
- Scheduling decisions are made when particular events in the system occur, *e.g.*
  - a job becomes available
  - processor becomes idle
- **Work-conserving**: processor is busy whenever there is work to be done.

Clock-Driven (Time-Driven) -- Overview

- **Scheduling decision time:** point in time when scheduler decides which job to execute next.

- Scheduling decision time in clock-driven schedulers is defined *a priori*.
- For example: Scheduler periodically wakes up and generates a portion of the schedule.



- Special case: When job parameters are known *a priori*, schedule can be pre-computed off-line, and stored as a table (table-driven schedulers).

Priority-Driven -- Overview

Basic rule: Never leave processor idle when there is work to be done. (Such schedulers are also called **work conserving**)

Based on list-driven, greedy scheduling.

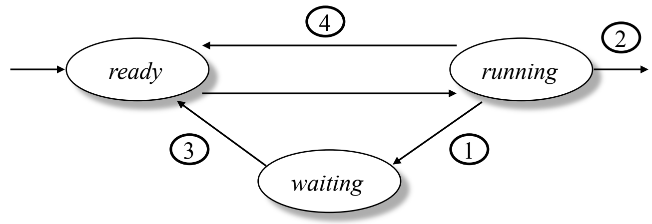
Examples: FIFO, LIFO, SET, LET, EDF.

Possible implementation of preemptive priority-driven scheduling:

1. Assign priorities to jobs.
2. Scheduling decisions are made when
   - Job becomes ready
   - Processor becomes idle
   - Priorities of jobs change
3. At each scheduling decision time, choose ready task with highest priority.

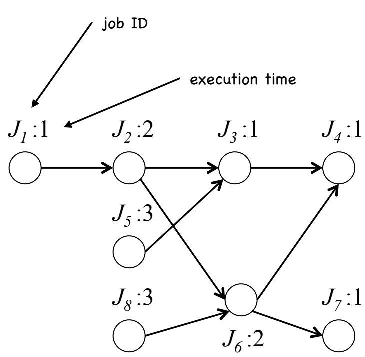
In non-preemptive case, scheduling decisions are made only when processor becomes idle.

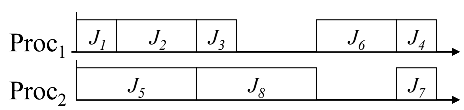
Scheduling Decisions



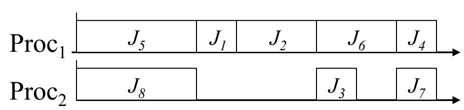
- Scheduling decision points:
  1. The running process blocks, i.e. changes from *running* to *waiting* (current CPU burst of that thread is over).
  2. The running thread terminates.
  3. A waiting thread becomes ready (new CPU burst of that thread begins).
  4. The current thread is preempted, i.e. switches from *running* to *ready* .

Example: Priority-Driven Non-Preemptive Schedules

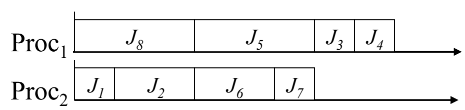




$L = (J_1, J_2, J_3, J_4, J_5, J_6, J_7, J_8)$



$LET = (J_5, J_8, J_2, J_6, J_1, J_3, J_4, J_7)$



$L = (J_8, J_1, J_2, J_3, J_4, J_5, J_6, J_7)$

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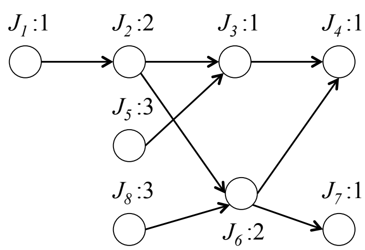

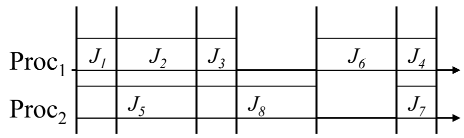

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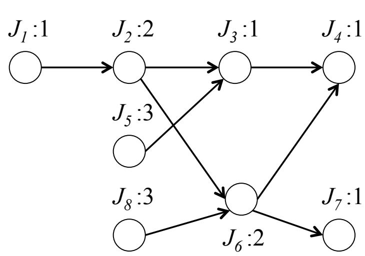

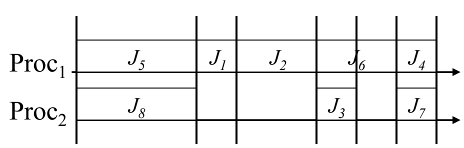

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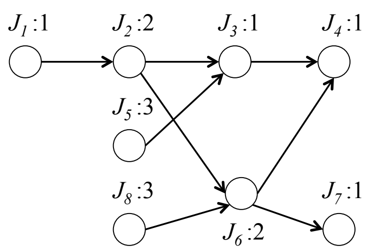
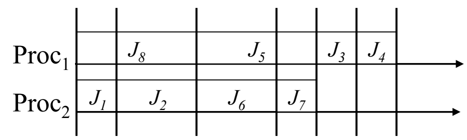
Example: Priority-Driven Non-Preemptive Schedules





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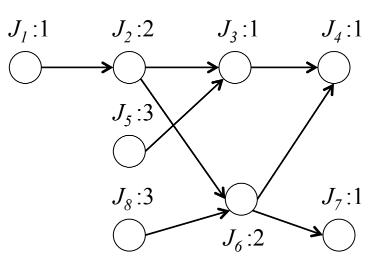

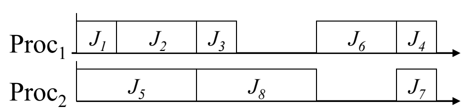

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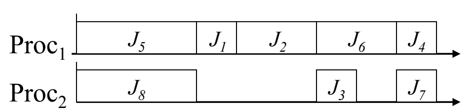

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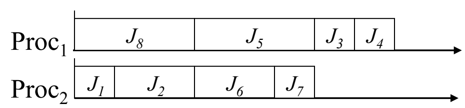


$L = (J_8, J_1, J_2, J_3, J_4, J_5, J_6, J_7)$

Interlude 1: The EDF Algorithm

The EDF (Earliest-Deadline-First) Algorithm:

At any time, execute that available job with the earliest deadline.

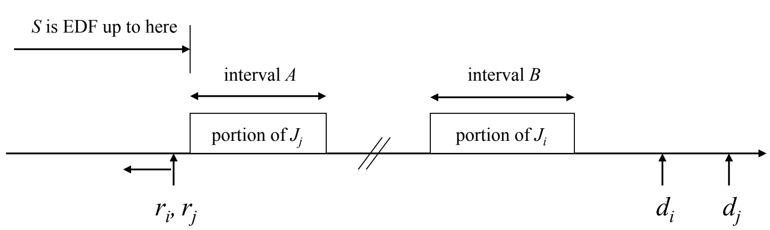
Theorem: (Optimality of EDF)

In a system one processor and with preemptions allowed, EDF can produce a feasible schedule of a job set J with arbitrary release times and deadlines iff such a schedule exists.

Proof: By schedule transformation.

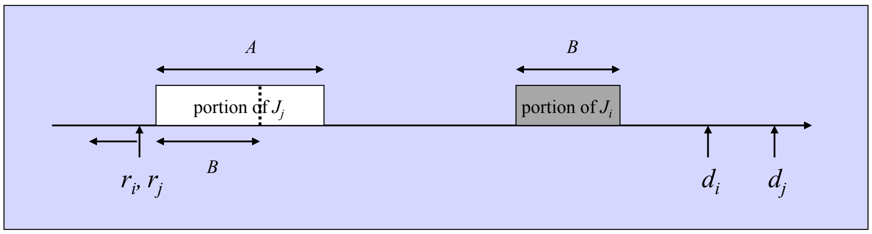
Proof of Optimality of EDF

- Assume that arbitrary schedule *S* meets timing constraints.
- For *S* to *not* be an EDF schedule, we must have the following situation:



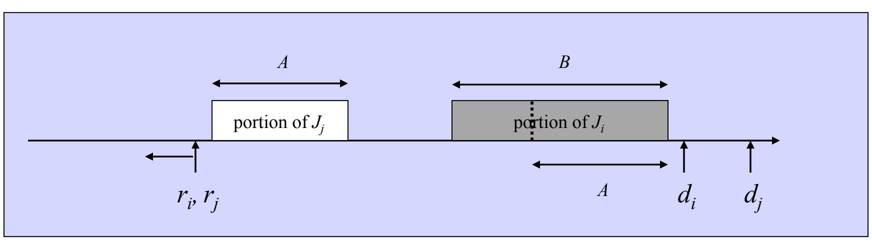
Proof of Optimality of EDF (2)

- We now have two cases.
- Case 1: $L(A) > L(B)$



Proof of Optimality of EDF (3)

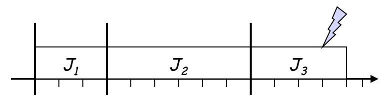
- We now have two cases.
- Case 2: $L(A) <= L(B)$



EDF Not Always Optimal

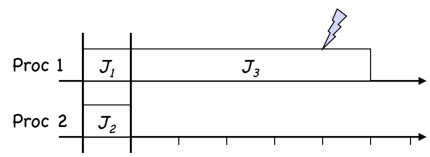
- Case 1: When preemption is not allowed:

$$
\begin{array}{lcl}
 & & \quad\; r_i \quad\; d_i \quad\; C_i \\
J_1 & = & (\; 0, \; 10, \; 3 \;) \\
J_2 & = & (\; 2, \; 14, \; 6 \;) \\
J_3 & = & (\; 4, \; 12, \; 4 \;)
\end{array}
$$



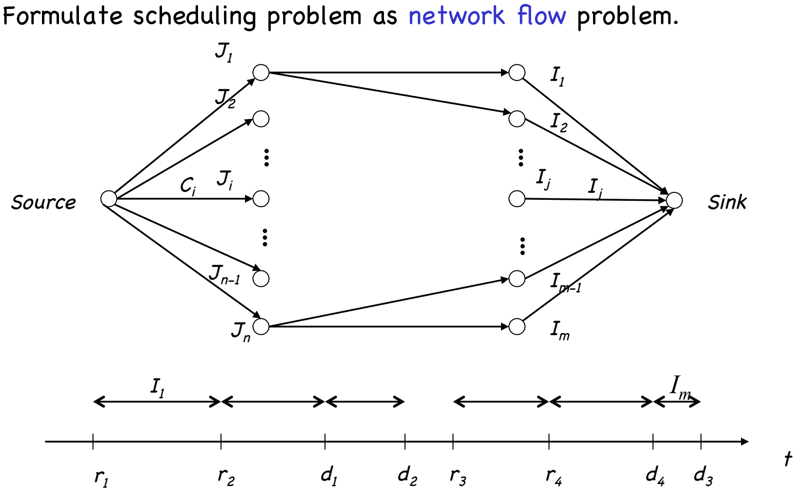
- Case 2: On a multiprocessor:

$$
\begin{array}{lcl}
 & & \quad\; r_i \quad d_i \quad C_i \\
J_1 & = & (\; 0, \; 4, \; 1 \;) \\
J_2 & = & (\; 0, \; 4, \; 1 \;) \\
J_3 & = & (\; 0, \; 5, \; 5 \;)
\end{array}
$$



Interlude 2: Preemptive Scheduling of Jobs with Arbitrary Release Times, Deadlines, Execution Times

- Determine schedule over a hyperperiod (if necessary).
- Formulate scheduling problem as network flow problem.



Interlude 3: NP Completeness of Non-Preemptive Deadline Scheduling

Theorem: The problem of scheduling a non-preemptable set of jobs $J_1, \ldots, J_i, \ldots J_n$, each with release time r_i, deadline d_i, and execution time C_i, is *NP*-complete.

Proof: Transformation from PARTITION [Garey/Johnson,1979]

Given: Finite set ***A = {A₁, ..., Aᵢ, ..., Aₘ}***, each element of size a_i.

Let $B = \sum_{i=1}^{m} a_i$

Partition ***A*** into two sets, each of same size.

Define a job set $J_1, \ldots, J_{m+1}$, as follows:

$$\text{for } i \le i \le m, \text{ define } J_i = \begin{cases} r_i &= 0 \\ d_i &= B+1 \\ e_i &= a_i \end{cases}, J_{m+1} = \begin{cases} r_{m+1} &= \lceil B/2 \rceil \\ d_{m+1} &= \lceil (B+1)/2 \rceil \\ e_{m+1} &= 1 \end{cases}$$