Time-Triggered Mixed-Critical Scheduler [1]

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Verimag - Université Joseph Fourier - Grenoble

Workshop on Mixed Criticality Systems

[1] The research leading to these results has received funding from the European Community's Seventh Framework Programme [FP7/2007-2013] under grant agreement no. 288175 [Certainty].

Schedulability
in Dual Critical Systems

- scheduling is a major challenge of Mixed Critical System design
- finite set of jobs in dual critical systems:
  - every job is is classified as critical (HI) or non-critical (LO)
  - every job is labeled with two Worst Case Execution Times:

    LO WCET computed with industrial standard tools (realistic estimation)

    HI WCET computed with Certification Authority tools (very pessimistic estimation)
  - both HI and LO jobs are Hard Real-Time

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- the scheduling problem is NP-complete

Basic scenario

- an execution where all jobs terminates after executing for $C(LO)$ before a *switch time* t_s and for $C(HI)$ after t_s is called basic scenario
- analyzing basic scenario is enough
- we call a basic scenario LO if no jobs run for $C(HI)$
  $HI - J_s$ if J_s is the first job to execute for more than $C(LO)$

Example of scheduling problem

- Let us apply different scheduling to the instance:

Job	A	D	χ	$C(LO)$	$C(HI)$
1	0	1	LO	1	1
2	0	3	LO	1	1
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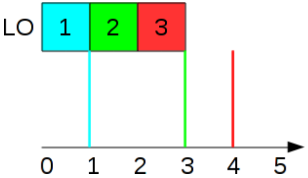

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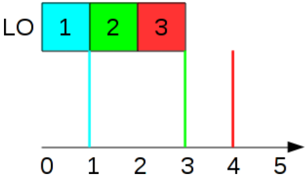

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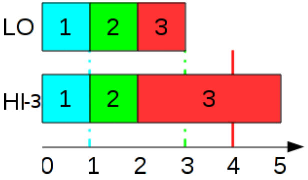

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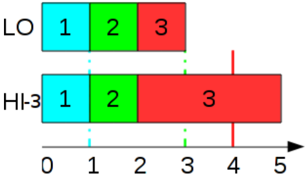

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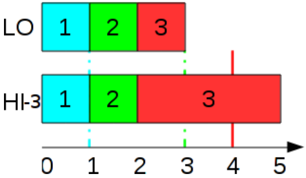

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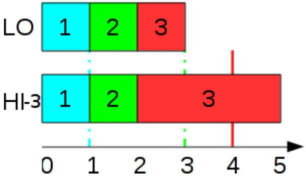

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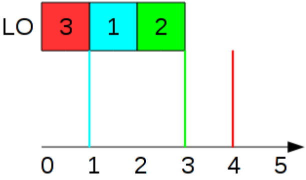

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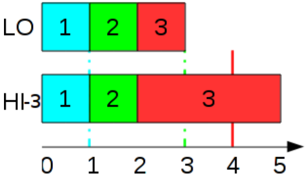

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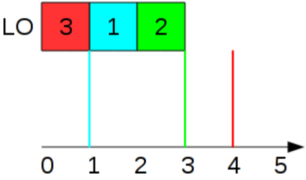

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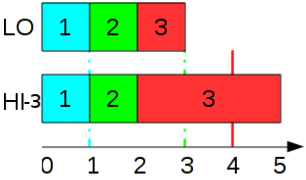

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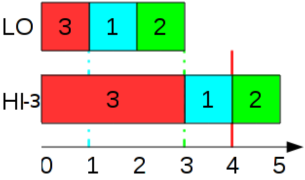

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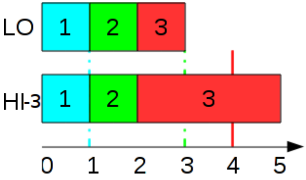

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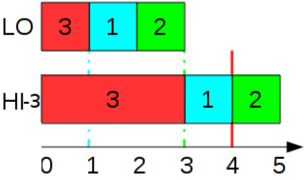

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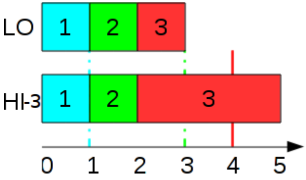

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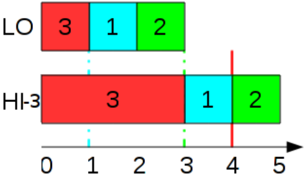

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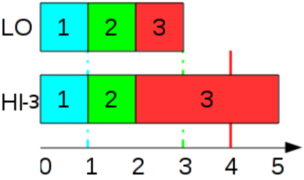

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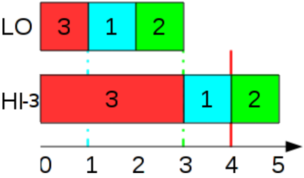

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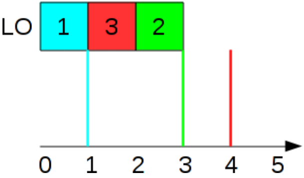

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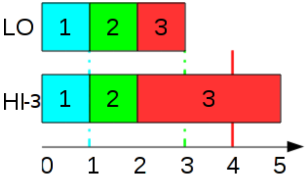

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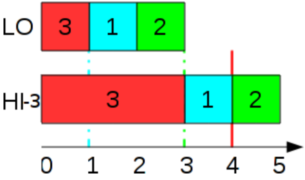

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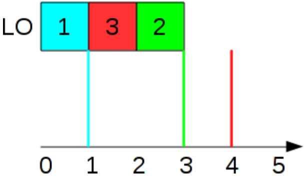

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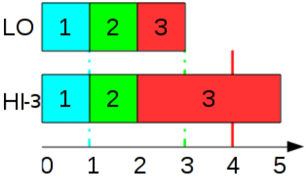

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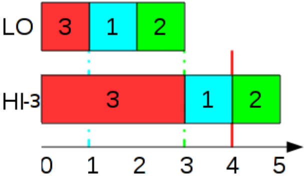

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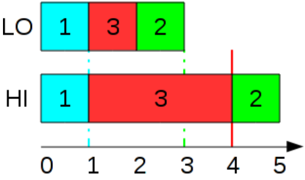

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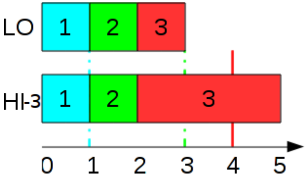

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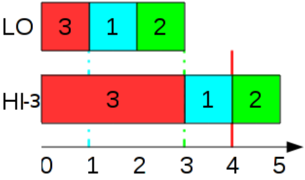

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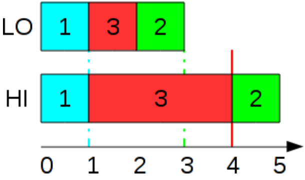

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[1] S. Baruah and G. Fohler. "Certification-Cognizant Time-Triggered Scheduling of Mixed-Criticality Systems". In: *Real-Time Systems Symposium (RTSS), 2011 IEEE 32nd*.

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$$Alg: FPM \mapsto STTM$$

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- We generate table **LO** by simulating the execution of the LO scenario

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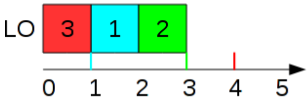

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generation of HI*

- Let at time t:
  - $T_j^{LO}(t)$ (resp. $T_j^{HI*}(t)$) = progress of J_j in **LO** (resp. **HI***)
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Generate **HI*** by simulation of HI jobs:

- each job executes for $C(\mathrm{HI})$ time units
- the jobs are scheduled according to PT_{HI}
- a job is enabled by one of the following *rules*:

$$T_j^{LO}(t) = C_j(\mathrm{LO})$$

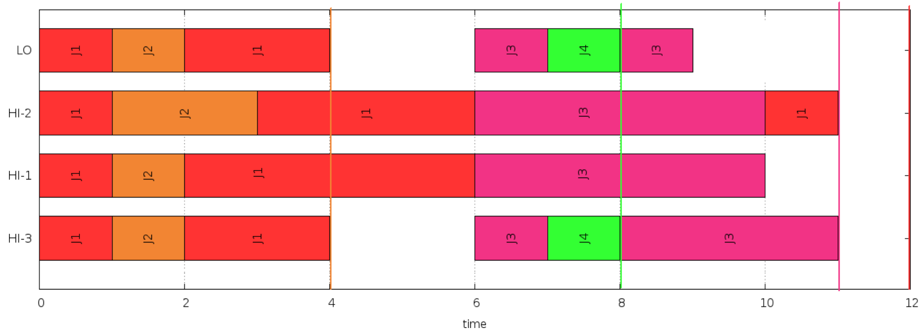
$$T_j^{HI*}(t) < T_j^{LO}(t)$$

$$T_j^{HI*}(t) = T_j^{LO}(t) \ \wedge E^{LO}(t) = J_j$$

Example

Job	A	D	χ	$C(LO)$	$C(HI)$
1	0	12	HI	3	5
2	1	4	HI	1	2
3	6	11	HI	2	4
4	7	8	LO	1	1

$$PT_{LO} = J_4 \succ J_2 \succ J_3 \succ J_1$$
$$PT_{HI} = J_2 \succ J_3 \succ J_1$$



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$$PT_{HI} = J_2 \succ J_3 \succ J_1$$

$$T_j^{LO}(t) = C_j(\mathrm{LO}) \qquad (1)$$

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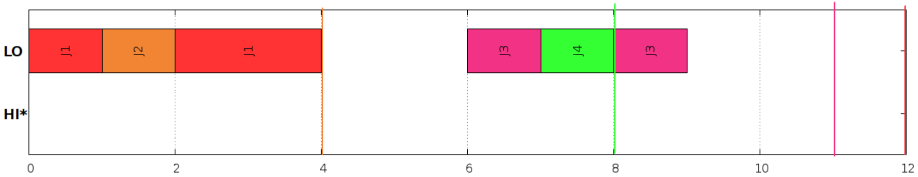

$t = 0$ $E^{LO}(t) = J_1$

Job	STATUS	$T^{HI*}(t)$	$T^{LO}(t)$	$C(\mathrm{LO})$	$C(\mathrm{HI})$	(1)	(2)	(3)
1	Enabled	0	0	3	5			✓
2								
3								

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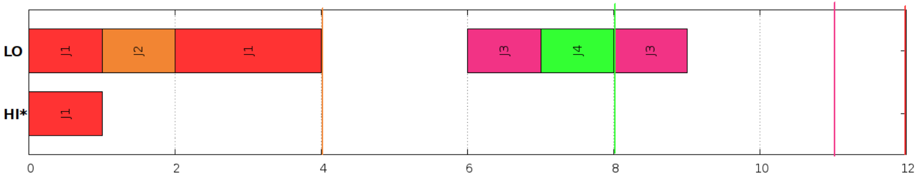

$t = 1 \qquad E^{LO}(t) = J_2$

Job	STATUS	$T^{HI*}(t)$	$T^{LO}(t)$	$C(\text{LO})$	$C(\text{HI})$	(1)	(2)	(3)
1	Disabled	1	1	3	5			
2	Enabled	0	0	1	2			✓
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$$T_j^{HI*}(t) < T_j^{LO}(t) \quad (2)$$

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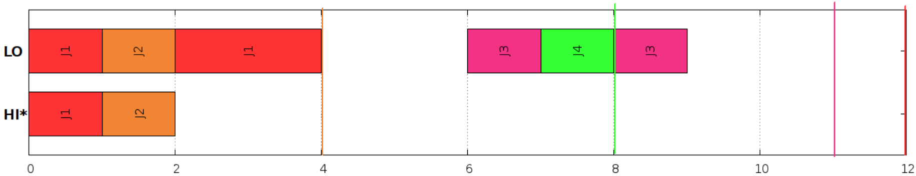

$t = 2 \qquad E^{LO}(t) = J_1$

Job	STATUS	$T^{HI*}(t)$	$T^{LO}(t)$	$C(\text{LO})$	$C(\text{HI})$	(1)	(2)	(3)
1	Enabled	1	1	3	5			✓
2	Enabled	1	1	1	2	✓		
3								

Example

$$T_j^{LO}(t) = C_j(\text{LO}) \quad (1)$$

$$PT_{HI} = J_2 \succ J_3 \succ J_1$$

$$T_j^{HI*}(t) < T_j^{LO}(t) \quad (2)$$

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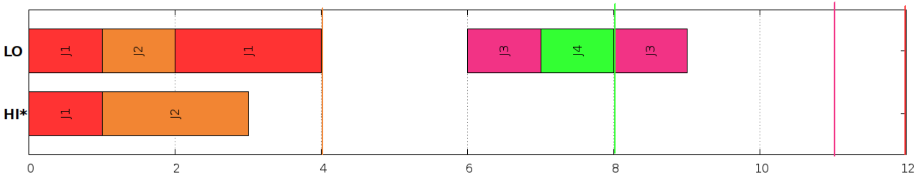

$t = 3$ $\quad E^{LO}(t) = J_1$

Job	STATUS	$T^{HI*}(t)$	$T^{LO}(t)$	$C(\text{LO})$	$C(\text{HI})$	(1)	(2)	(3)
1	Enabled	1	2	3	5		✓	
2	Term.	2	1	1	2			
3								

Example

$$T_j^{LO}(t) = C_j(\mathrm{LO}) \quad (1)$$

$$T_j^{HI*}(t) < T_j^{LO}(t) \quad (2)$$

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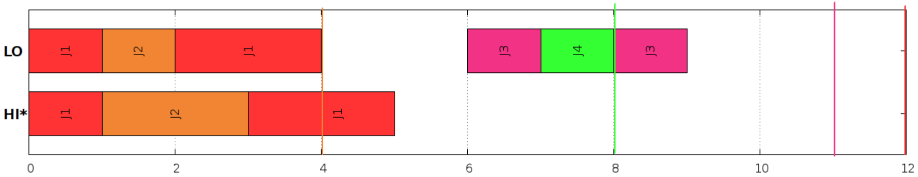
$$PT_{HI} = J_2 \succ J_3 \succ J_1$$



$t = 5 \qquad E^{LO}(t) = \perp$

Job	STATUS	$T^{HI*}(t)$	$T^{LO}(t)$	$C(\mathrm{LO})$	$C(\mathrm{HI})$	(1)	(2)	(3)
1	Enabled	3	3	3	5	✓		
2	Term.	2	1	1	2			
3								

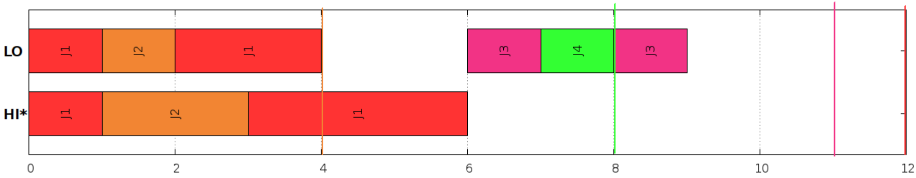
Example

$$T_j^{LO}(t) = C_j(\text{LO}) \quad (1)$$

$$PT_{HI} = J_2 \succ J_3 \succ J_1$$

$$T_j^{HI*}(t) < T_j^{LO}(t) \quad (2)$$

$$T_j^{HI*}(t) = T_j^{LO}(t) \ \wedge E^{LO}(t) = J_j \quad (3)$$



$t = 6$ $\quad E^{LO}(t) = J_3$

Job	STATUS	$T^{HI*}(t)$	$T^{LO}(t)$	$C(\text{LO})$	$C(\text{HI})$	(1)	(2)	(3)
1	Enabled	4	3	3	5	✓		
2	Term.	2	1	1	2			
3	Enabled	0	0	2	4			✓

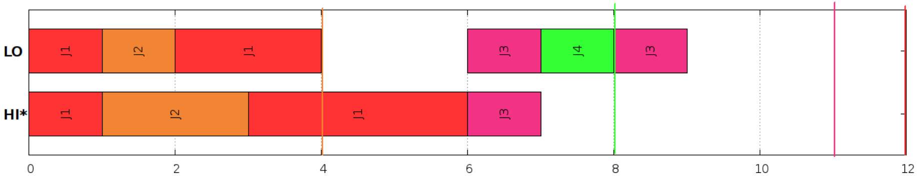
Example

$$T_j^{LO}(t) = C_j(\mathrm{LO}) \qquad (1)$$

$$PT_{HI} = J_2 \succ J_3 \succ J_1$$

$$T_j^{HI*}(t) < T_j^{LO}(t) \qquad (2)$$

$$T_j^{HI*}(t) = T_j^{LO}(t) \ \wedge E^{LO}(t) = J_j \qquad (3)$$



$t = 7 \qquad E^{LO}(t) = J_4$

Job	STATUS	$T^{HI*}(t)$	$T^{LO}(t)$	$C(\mathrm{LO})$	$C(\mathrm{HI})$	(1)	(2)	(3)
1	Enabled	4	3	3	5	✓		
2	Term.	2	1	1	2			
3	Disabled	1	1	2	4			

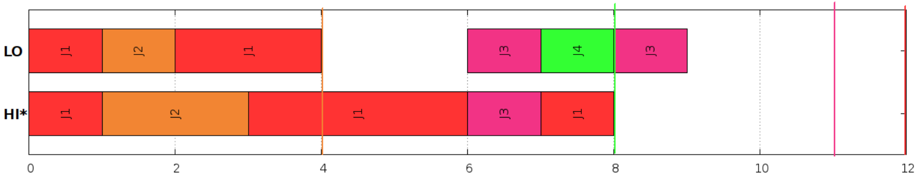
Example

$$PT_{HI} = J_2 \succ J_3 \succ J_1$$

$$T_j^{LO}(t) = C_j(\mathrm{LO}) \qquad (1)$$

$$T_j^{HI*}(t) < T_j^{LO}(t) \qquad (2)$$

$$T_j^{HI*}(t) = T_j^{LO}(t) \ \wedge E^{LO}(t) = J_j \qquad (3)$$



$t = 8 \qquad E^{LO}(t) = J_3$

Job	STATUS	$T^{HI*}(t)$	$T^{LO}(t)$	$C(\mathrm{LO})$	$C(\mathrm{HI})$	(1)	(2)	(3)
1	Term.	5	3	3	5			
2	Term.	2	1	1	2			
3	Enabled	1	1	2	4			✓

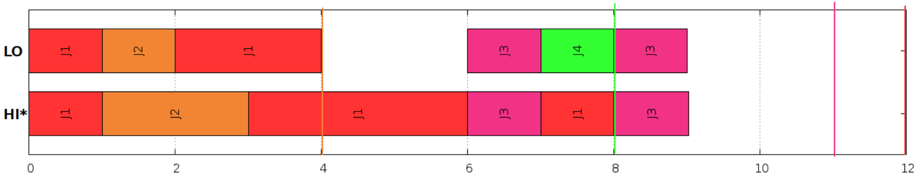
Example

$$PT_{HI} = J_2 \succ J_3 \succ J_1$$

$$T_j^{LO}(t) = C_j(\mathrm{LO}) \qquad (1)$$

$$T_j^{HI*}(t) < T_j^{LO}(t) \qquad (2)$$

$$T_j^{HI*}(t) = T_j^{LO}(t) \ \wedge E^{LO}(t) = J_j \qquad (3)$$



$t = 9 \qquad E^{LO}(t) = \perp$

Job	STATUS	$T^{HI*}(t)$	$T^{LO}(t)$	$C(\mathrm{LO})$	$C(\mathrm{HI})$	(1)	(2)	(3)
1	Term.	5	3	3	5			
2	Term.	2	1	1	2			
3	Enabled	2	1	2	4	✓		

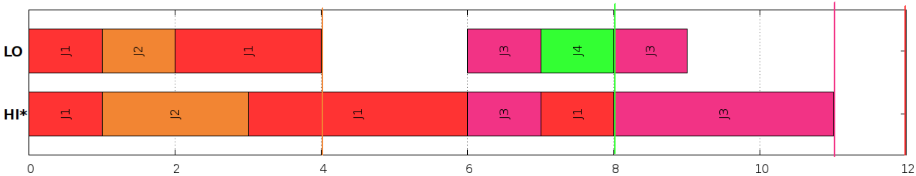
Example

$$T_j^{LO}(t) = C_j(\text{LO}) \quad (1)$$

$$PT_{HI} = J_2 \succ J_3 \succ J_1$$

$$T_j^{HI*}(t) < T_j^{LO}(t) \quad (2)$$

$$T_j^{HI*}(t) = T_j^{LO}(t) \ \wedge E^{LO}(t) = J_j \quad (3)$$



$t = 11 \qquad E^{LO}(t) = \perp$

Job	STATUS	$T^{HI*}(t)$	$T^{LO}(t)$	$C(\text{LO})$	$C(\text{HI})$	(1)	(2)	(3)
1	Term.	5	3	3	5			
2	Term.	2	1	1	2			
3	Term.	4	1	2	4			

Proof of correctness

Theorem

If the FPM policy leads to a feasible schedule, then a switched time triggered schedule that uses **LO** *and* **HI*** *as, respectively, LO-mode and HI-mode table, is a feasible schedule as well.*

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the proof is based on the followings:

Lemma

If at any time we switch from **LO** *to* **HI***, *then all the unterminated jobs will have enough time reserved in* **HI*** *to terminate their work.*

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Theorem

For all HI jobs J there exists a basic scenario of the FPM scheduling where J terminates no earlier than in **HI***

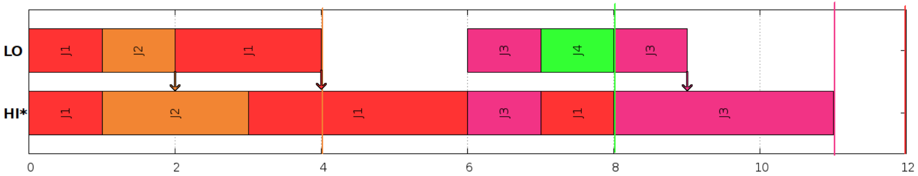
correctness of example

It is easy to show that the lemma is true for our example

Lemma

*If at any time we switch from **LO** to **HI***, then all the unterminated jobs will have enough time reserved in **HI*** to terminate their work.*

$C_1(\mathrm{HI}) = 5$ $C_2(\mathrm{HI}) = 2$ $C_3(\mathrm{HI}) = 4$



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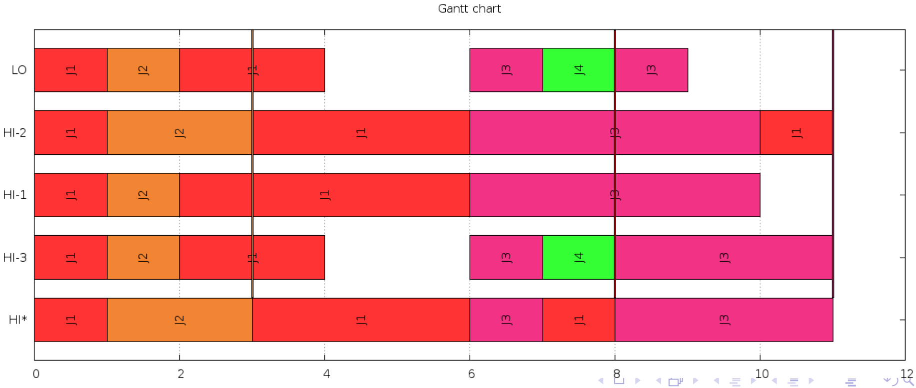

- Conclusions
  - Proof that $FPM \subset STTM$
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    - this can make certification easier

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- Future work
  - More than two criticality levels
  - Multiprocessor