TECHNISCHE UNIVERSITÄT KAISERSLAUTERN

Schedule Table Generation for Time-Triggered Mixed Criticality Systems

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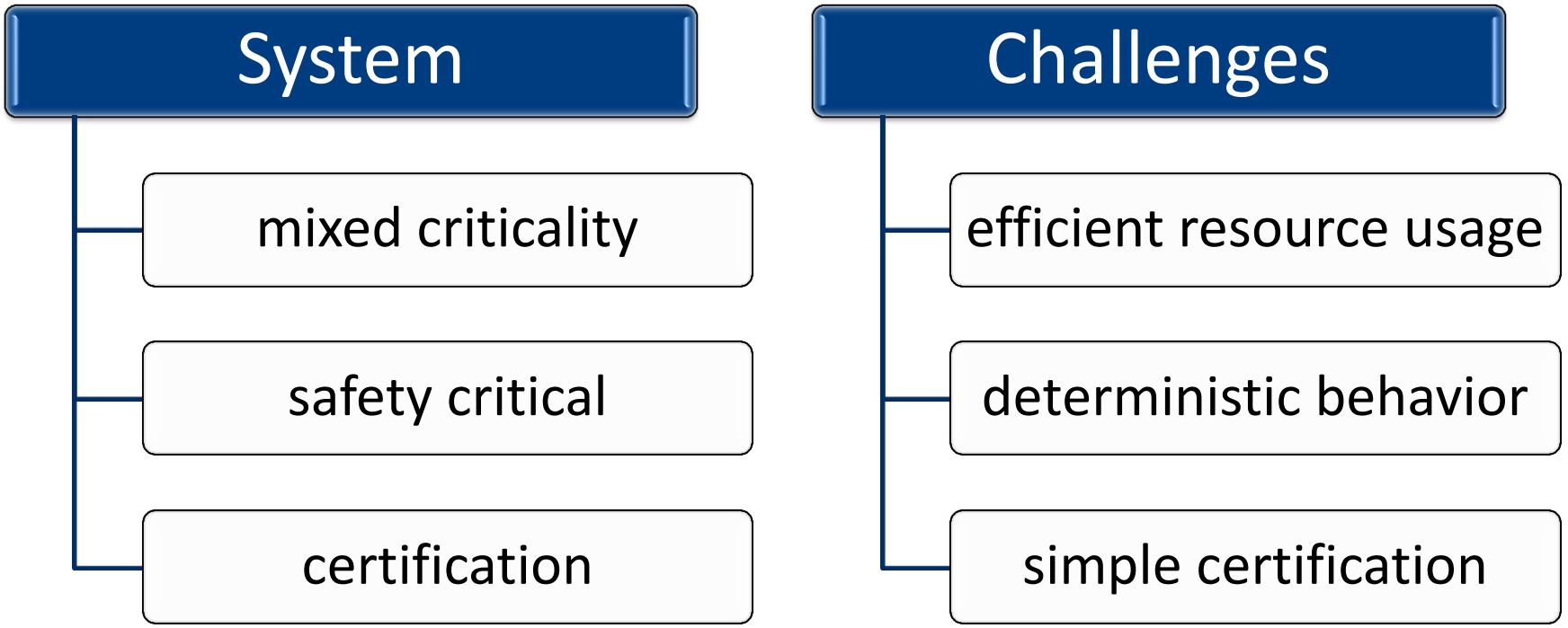
Introduction



Job Model

Vestal-model for dual criticality jobs

r_i release time

d_i deadline

$\chi_i \in \{\mathrm{LO}, \mathrm{HI}\}$ criticality levels

$C_i(\mathrm{LO}), C_i(\mathrm{HI})$ worst case execution time (WCET) for LO and HI

$C_i(\mathrm{LO}) = C_i(\mathrm{HI})$, if $\chi_i = \mathrm{LO}$

$C_i(\mathrm{LO}) \leq C_i(\mathrm{HI})$, if $\chi_i = \mathrm{HI}$

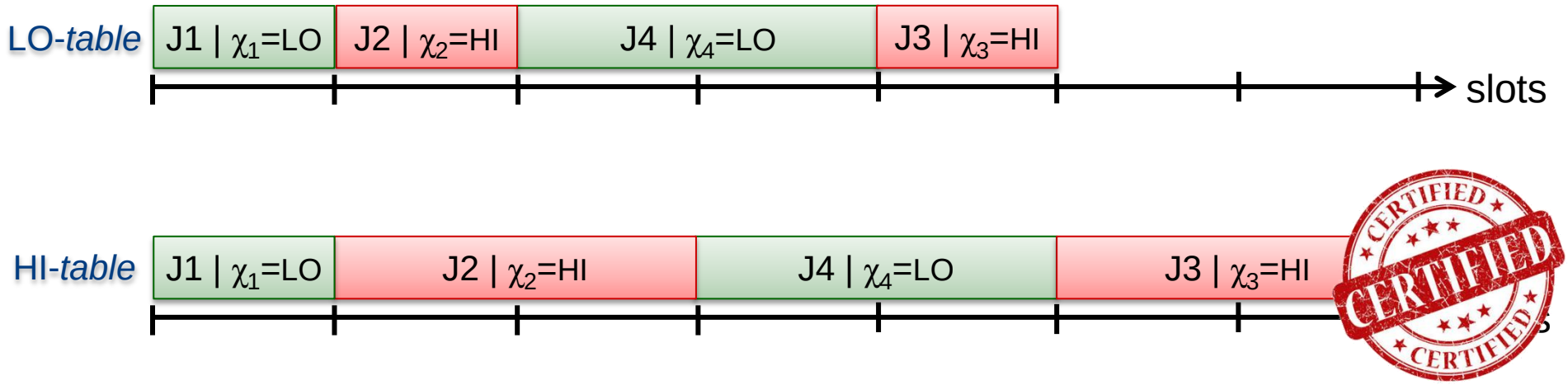
under certification authorities' (CAs) assumptions

under designers' assumptions

Time-Triggered (TT) Mode Changes

- approach by Baruah and Fohler – proof of concept

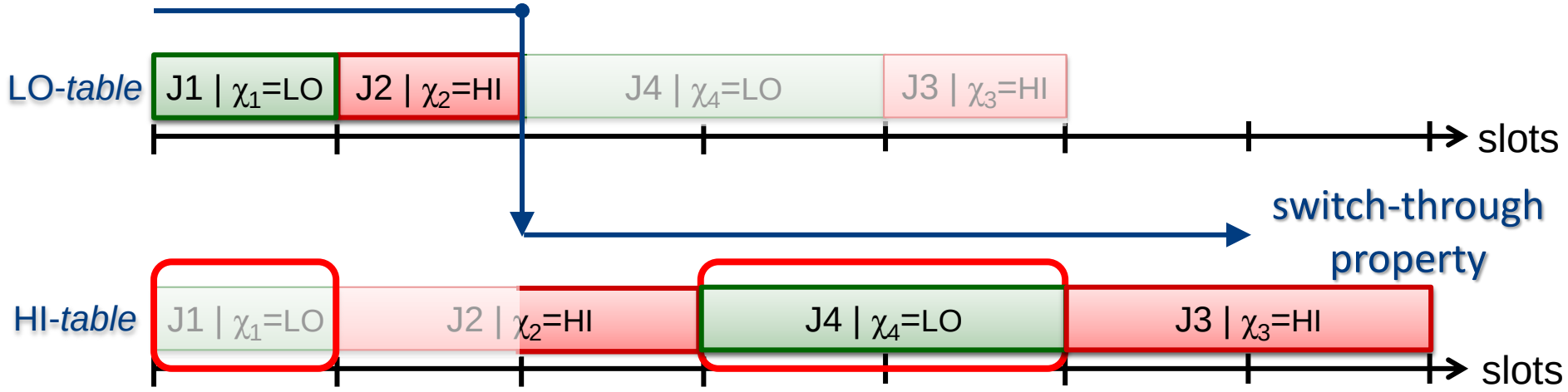
  TT schedule tables:



TT Mode Changes

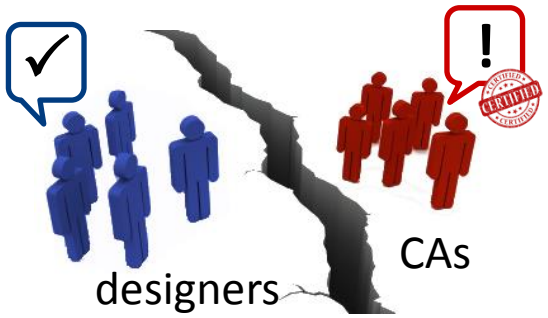
- approach by Baruah and Fohler – proof of concept

  mode switch at runtime:

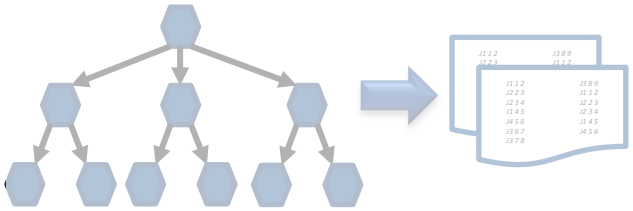


➔ **switch-through obtained by inserting LO-criticality jobs in** HI-*table* **at cost of utilization**

Basic Idea



separate designers' and CAs' WCET-assumptions



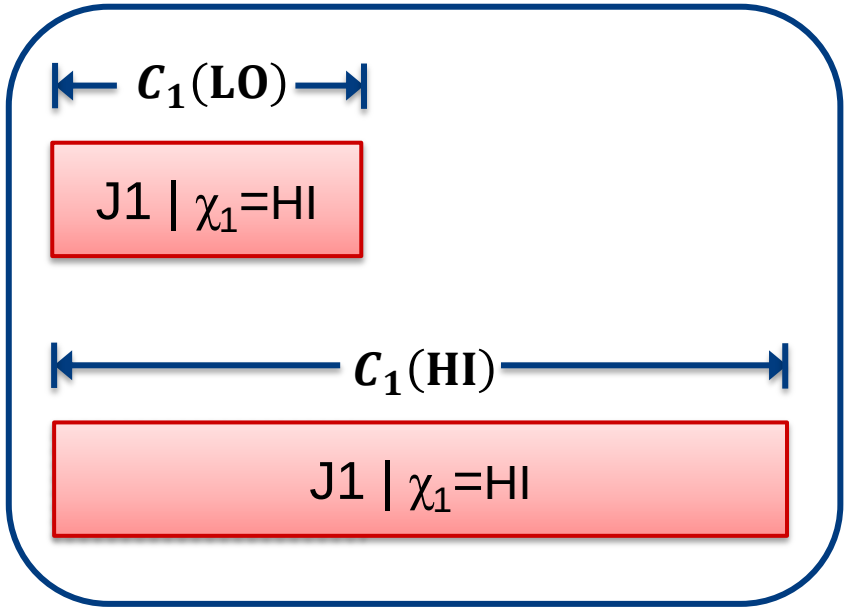
use heuristic tree search

to generate two time-triggered (TT) schedule tables

Separate WCET Assumptions

- separate demand based on designer assumptions from additional demand by CAs' pessimism

  → split HI-criticality jobs



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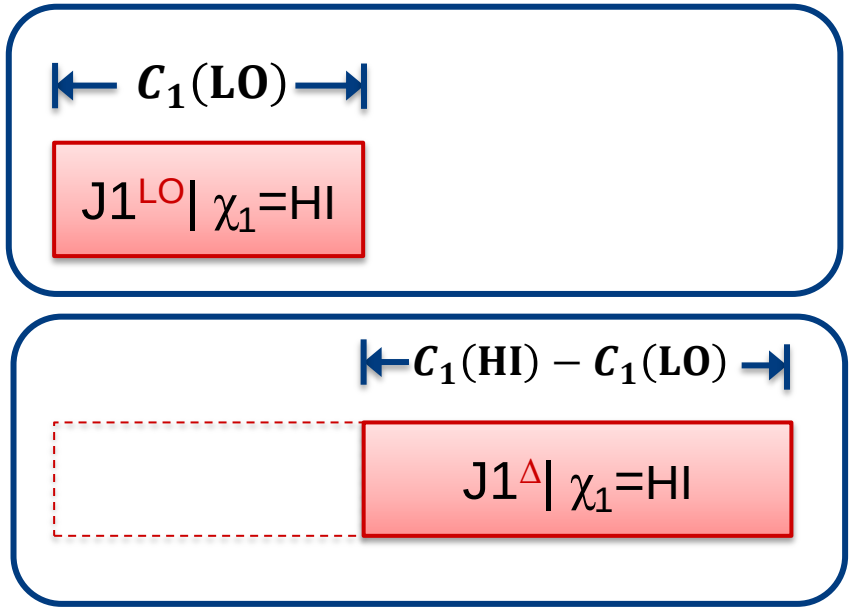
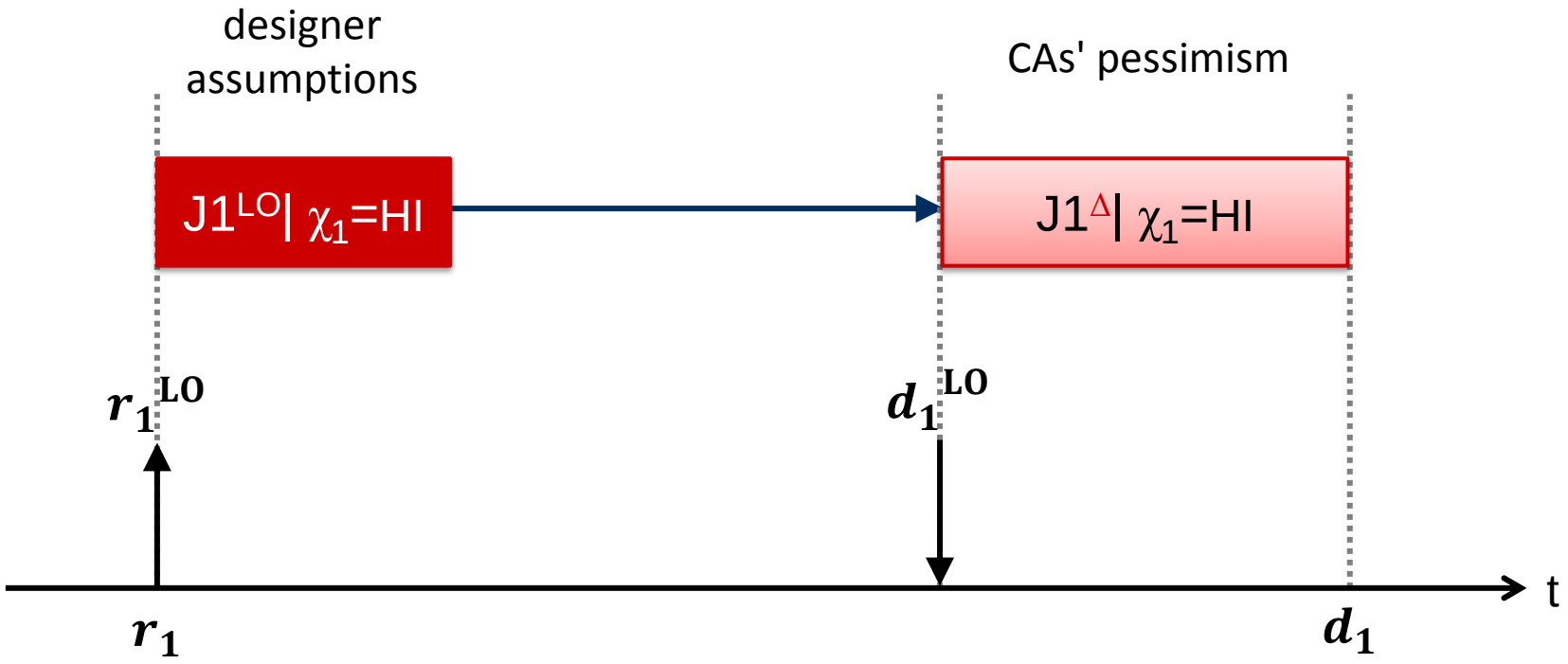


job with designer assumptions

job representing CAs' pessimism

Parameter Derivation of Split Jobs

- add a precedence constraint
- derive new parameters for the split jobs



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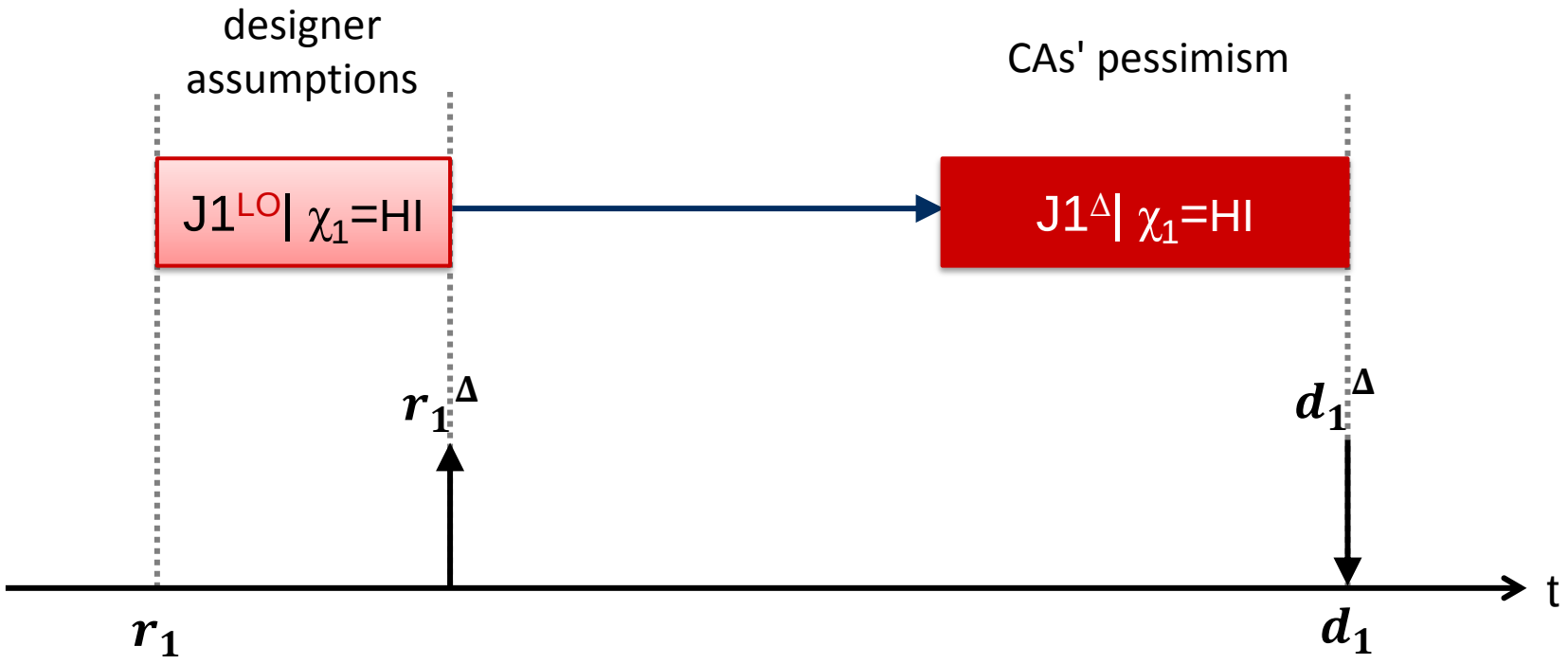


Job Parameters Overview

- job parameters for scheduling:

  <u>for all jobs with $\chi_i = \mathrm{LO}$:</u>

  $$J_i = \langle r_i, d_i, C_i(\mathrm{LO}) \rangle$$

  <u>for all jobs with $\chi_i = \mathrm{HI}$:</u>

  $$\begin{cases} {J_i}^{\mathrm{LO}} = \langle {r_i}^{\mathrm{LO}}, {d_i}^{\mathrm{LO}}, {C_i}^{\mathrm{LO}}(\mathrm{LO}) \rangle \\ {J_i}^{\Delta} = \langle {r_i}^{\Delta}, {d_i}^{\Delta}, {C_i}^{\Delta}(\mathrm{HI}) \rangle \end{cases}$$

Job Allocation to Modes

- job allocation to modes:

LO-*table*

$J_i \mid \chi_i = LO$

$J_i^{LO} \mid \chi_i = HI$

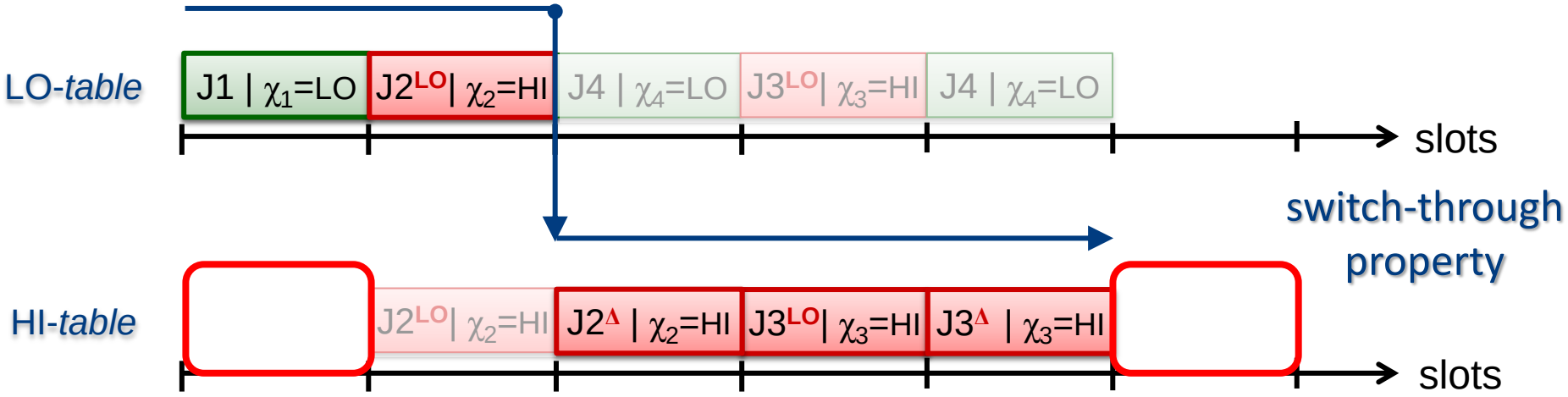
HI-*table*

$J_i^{LO} \mid \chi_i = HI$

$J_i^{\Delta} \mid \chi_i = HI$

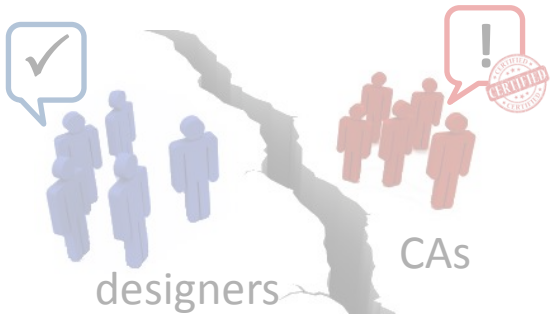
TT Mode Changes after Splitting

- precedence constraints used to reduce utilization in HI-*table*

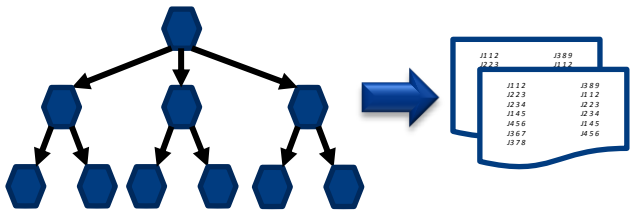


➔ **switch-through obtained by splitting HI-criticality jobs**

Basic Idea



separate designers' and CAs' WCET-assumptions

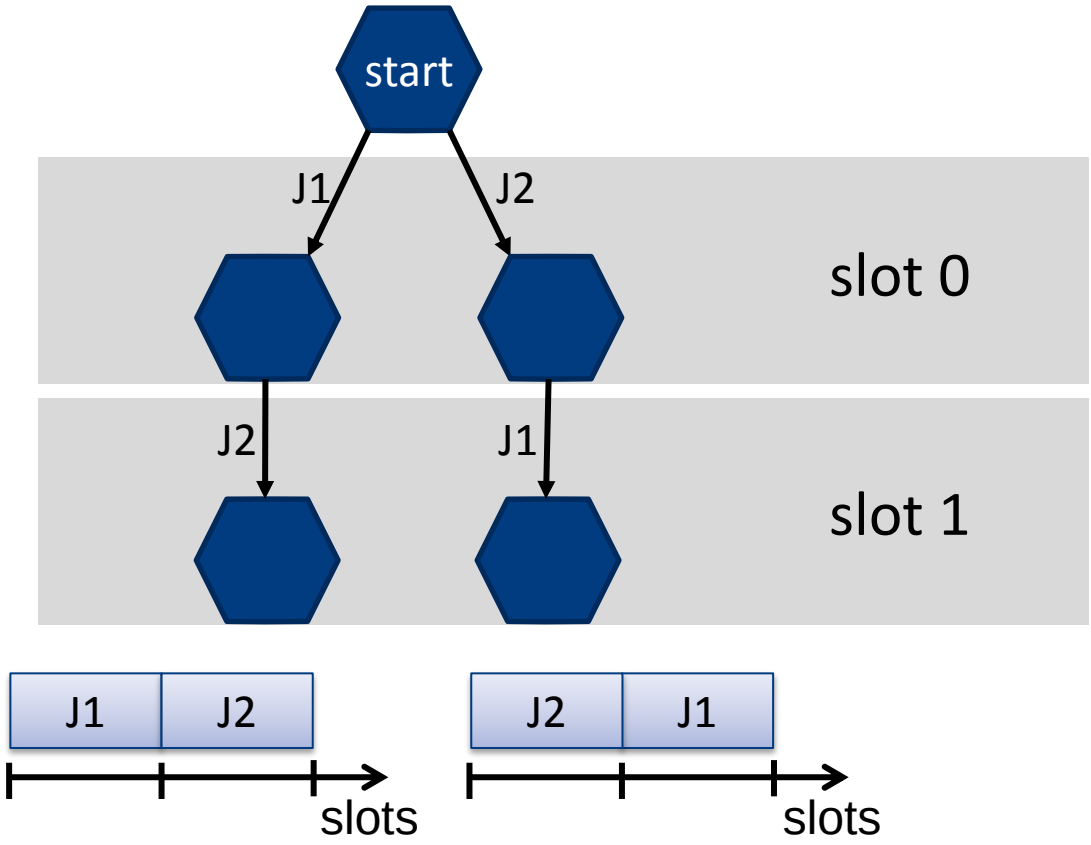


use heuristic tree search

to generate two time-triggered (TT) schedule tables

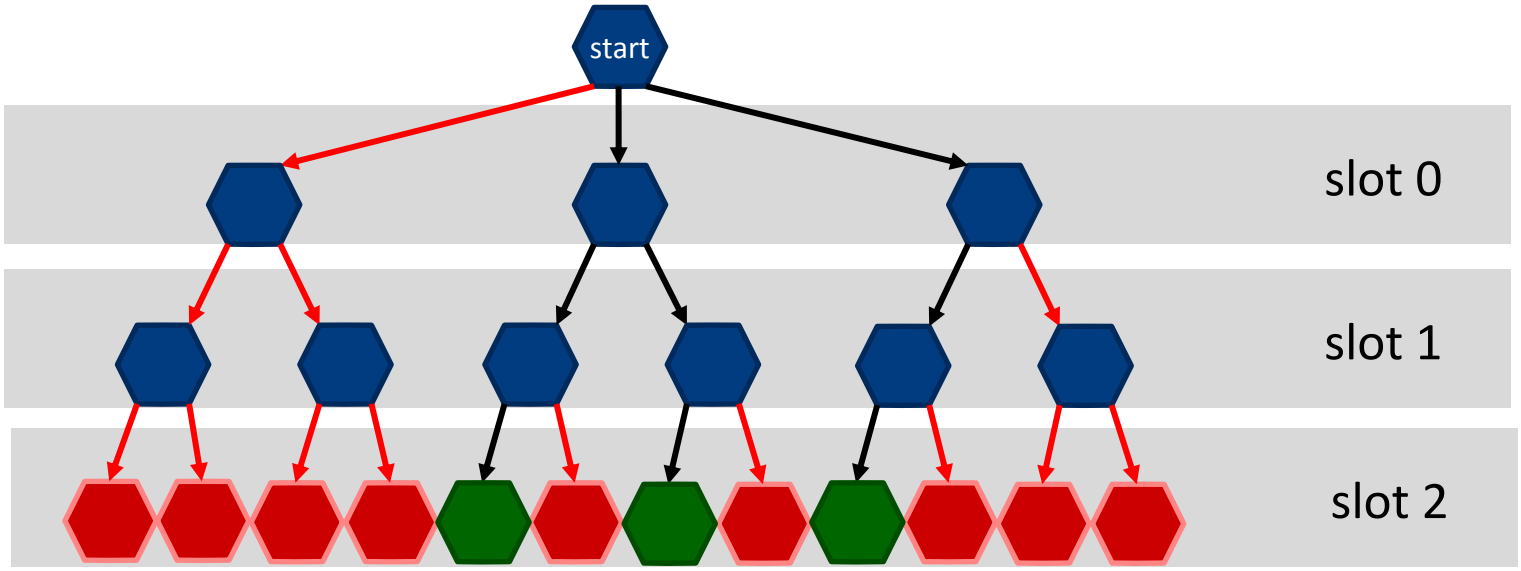
General Tree Search

Example with 2 jobs



Schedule Tables Construction

How can we reduce the search space?



partial schedule feasible schedule infeasible schedule path to infeasible schedule

Guiding the Search

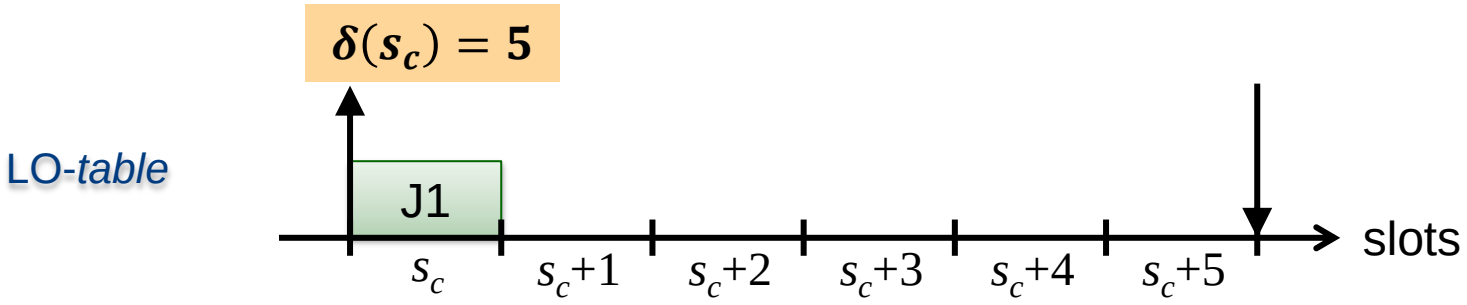
- Heuristic function:

  The ***leeway $\delta(s)$ of a slot s*** **in** LO-table determines how many slots we can delay the job scheduled in that slot.

- Backtracking

Leeway

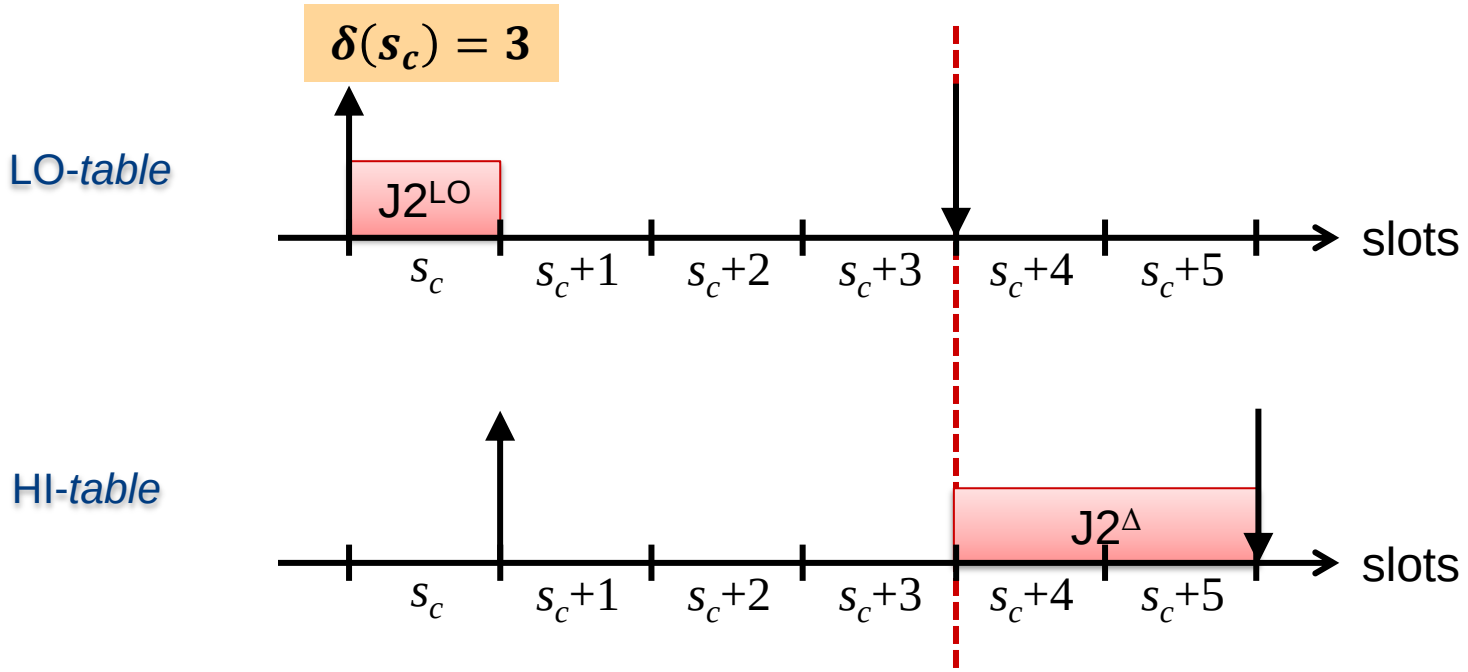
leeway $\delta(s)$ of jobs with $\chi_i = \mathrm{LO}$:



Leeway

leeway $\delta(s)$ of jobs with $\chi_i = \mathrm{HI}$:

(*more details considering several HI-criticality jobs in the paper)*

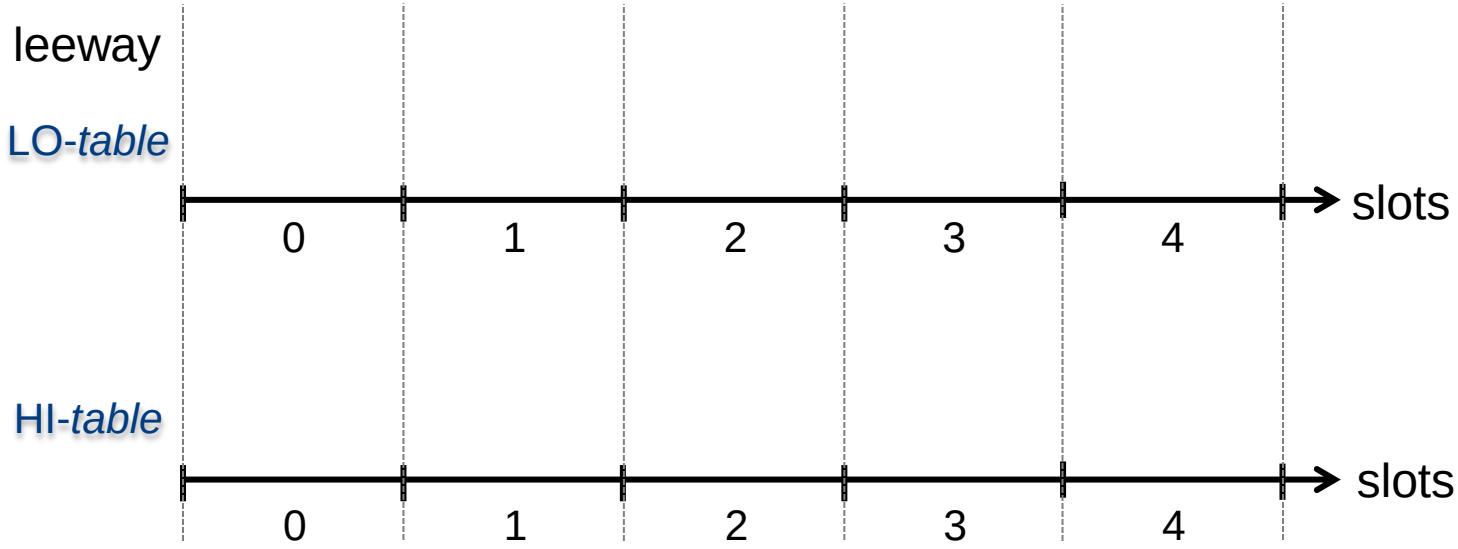


Schedule Tables Generation

search tree 

LO-table: according to EDF

HI-table: depending on criticality level in LO-*table*
- LO: Δ-fraction job by EDF
- HI: same job as in LO-*table*



Schedule Tables Generation

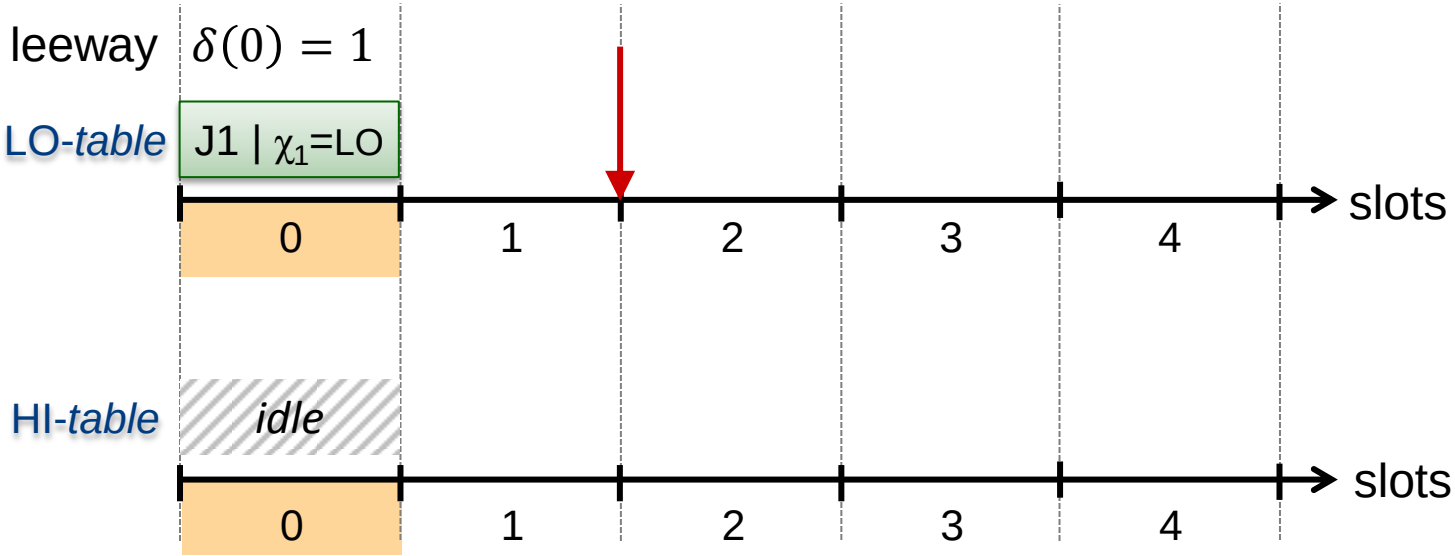
search tree

LO-table: select job by EDF

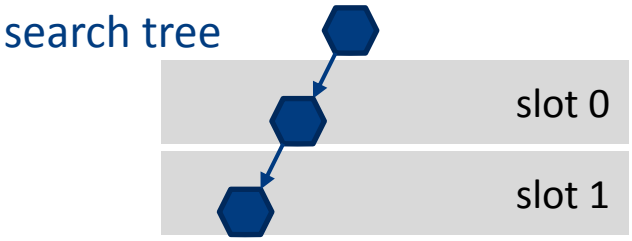
→ J1

HI-table: select Δ-fraction job by EDF

→ idle slot



Schedule Tables Generation

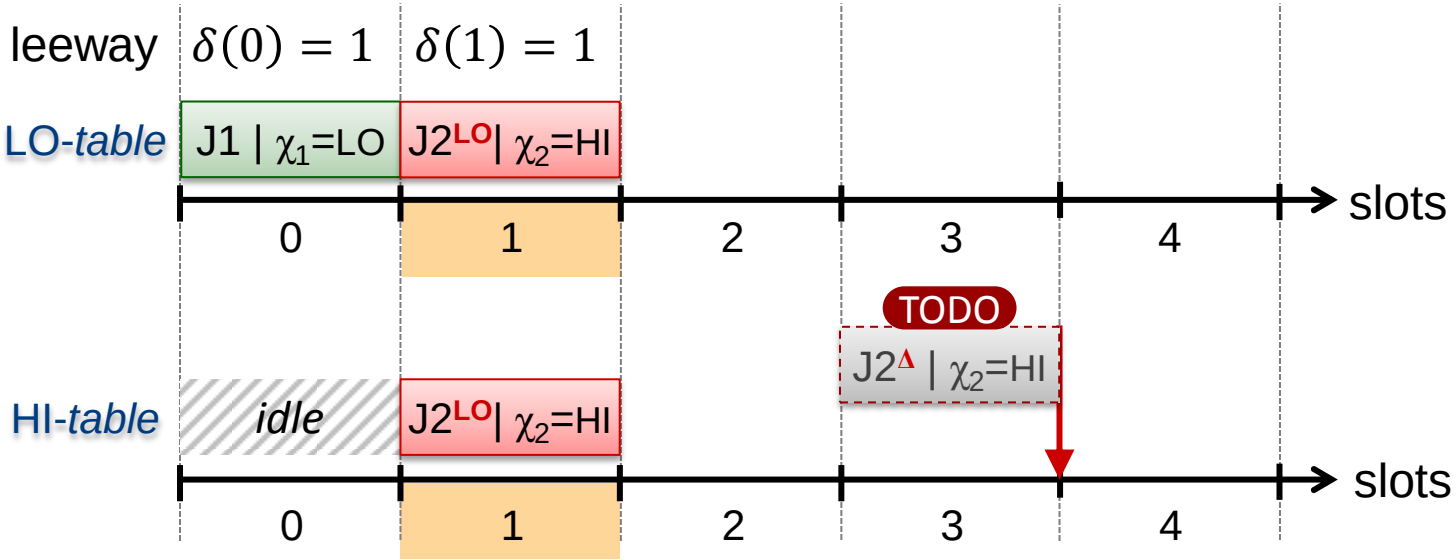


LO-table: select job by EDF

→ $J2^{LO}$

HI-table: schedule same job as in LO-table

→ $J2^{LO}$



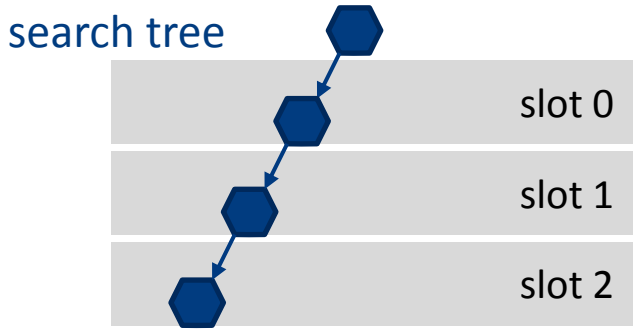
Schedule Tables Generation

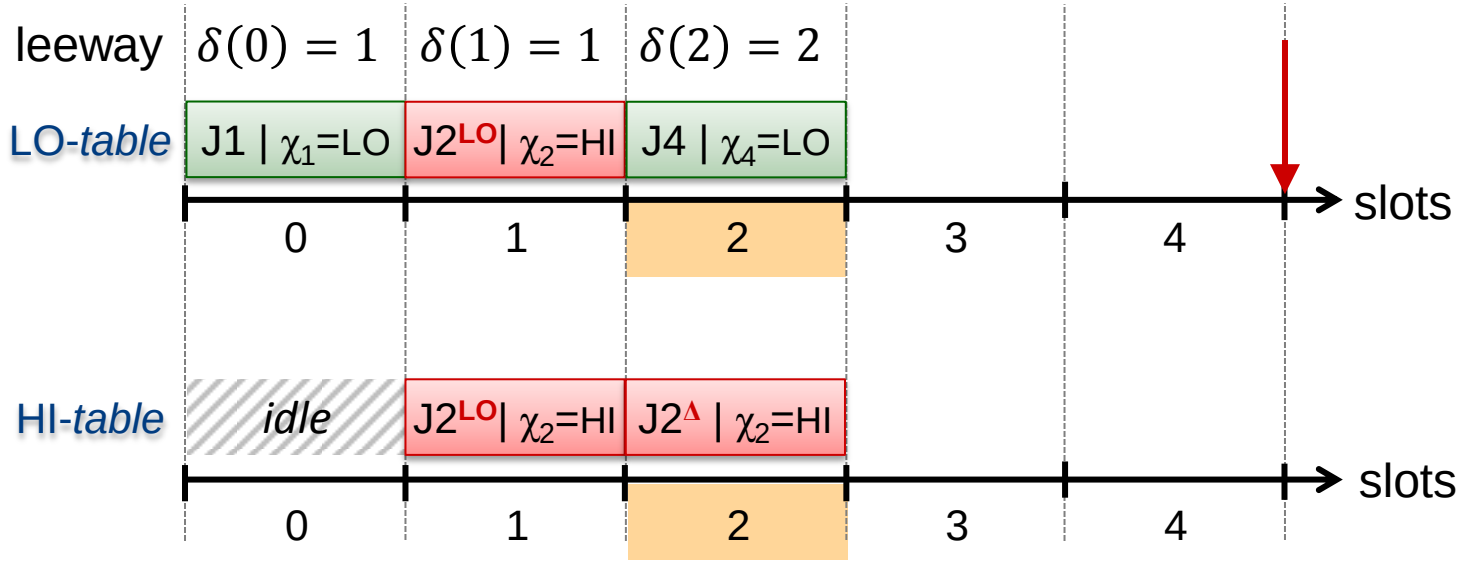
LO-table: select job by EDF

→ J4

HI-table: select Δ-fraction job by EDF

→ $J2^{\Delta}$





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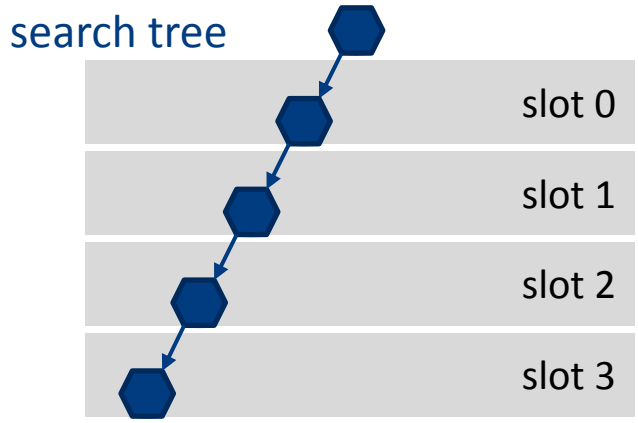
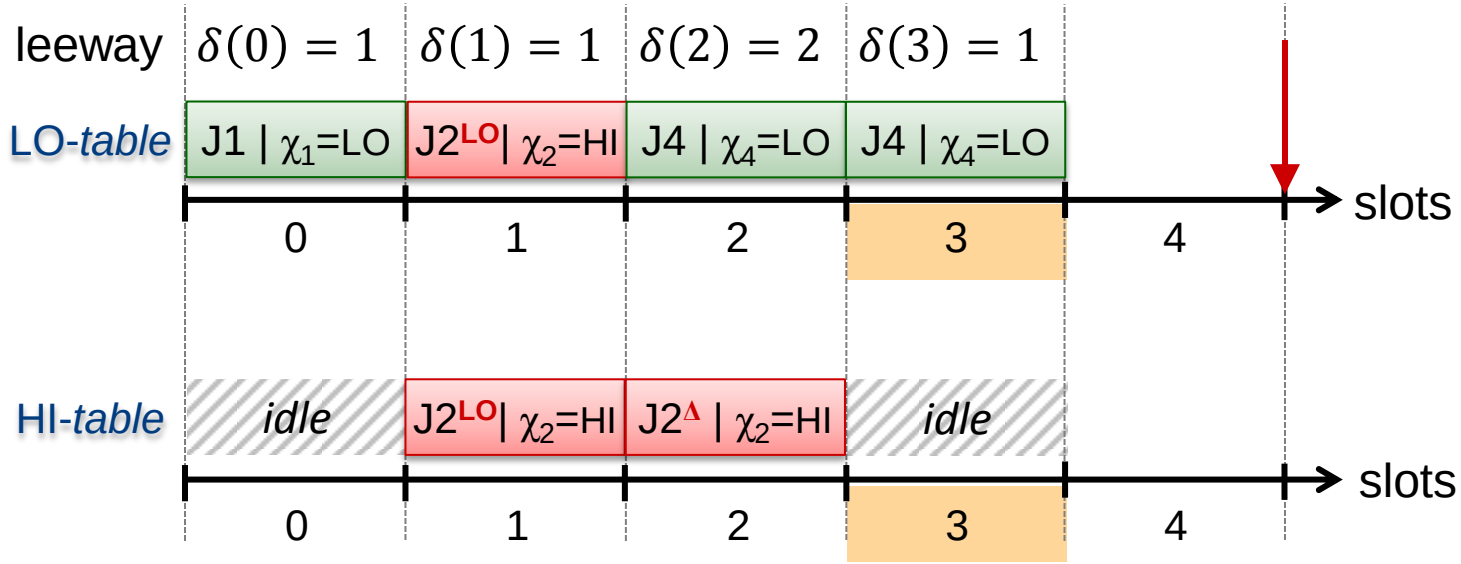
HI-table: select Δ-fraction job by EDF

→ idle slot



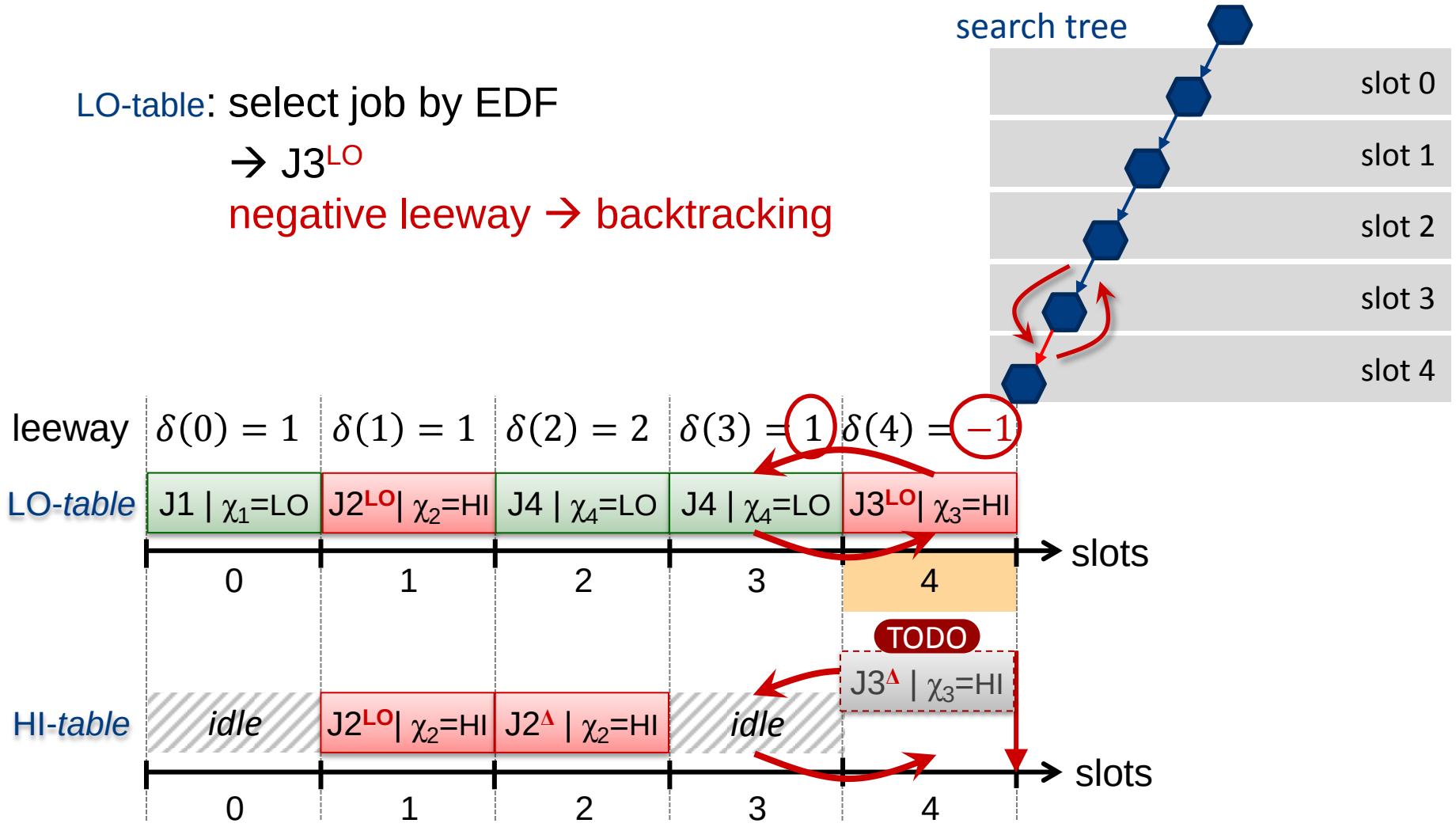


Schedule Tables Generation

LO-table: select job by EDF

→ $J3^{LO}$

negative leeway → backtracking



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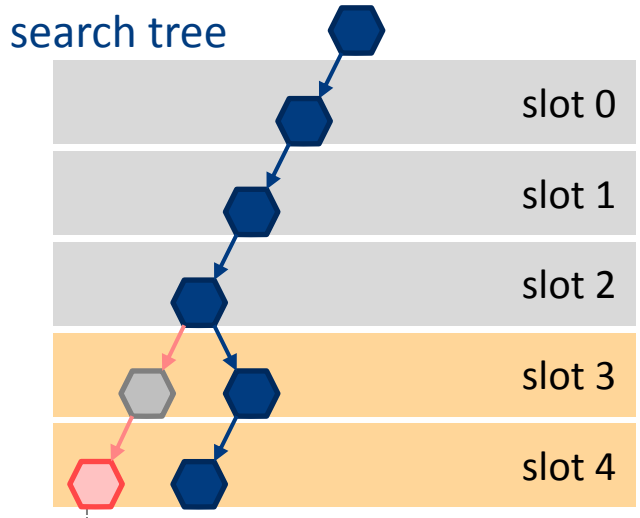

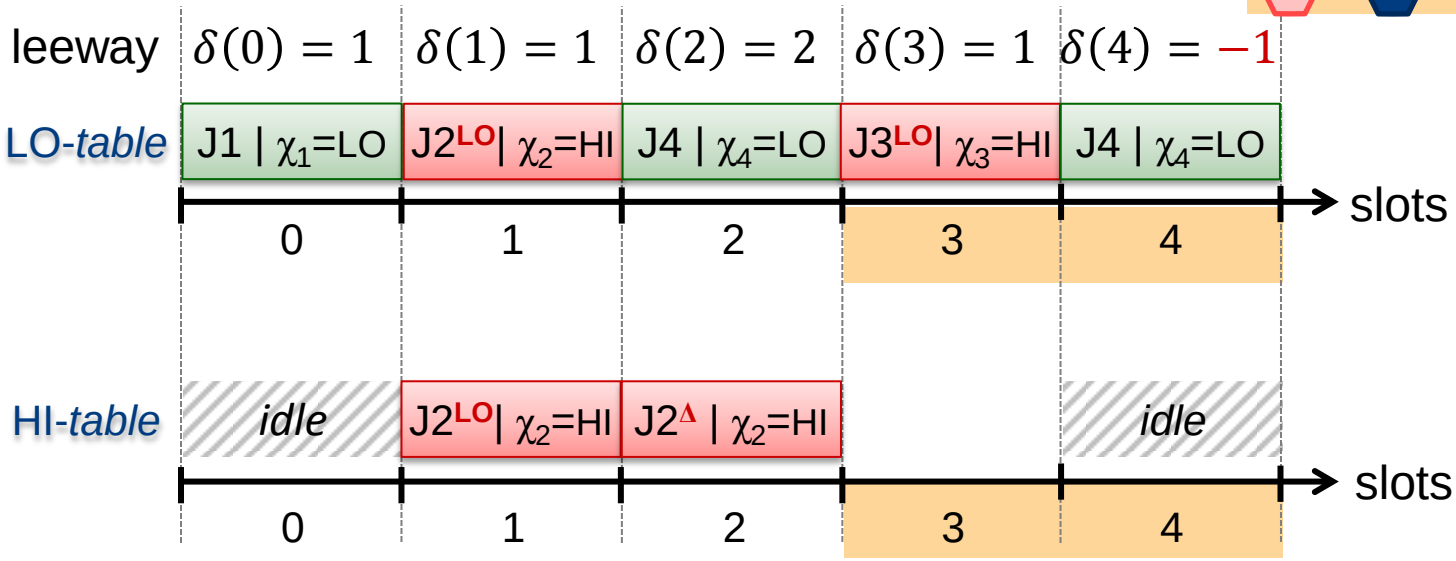

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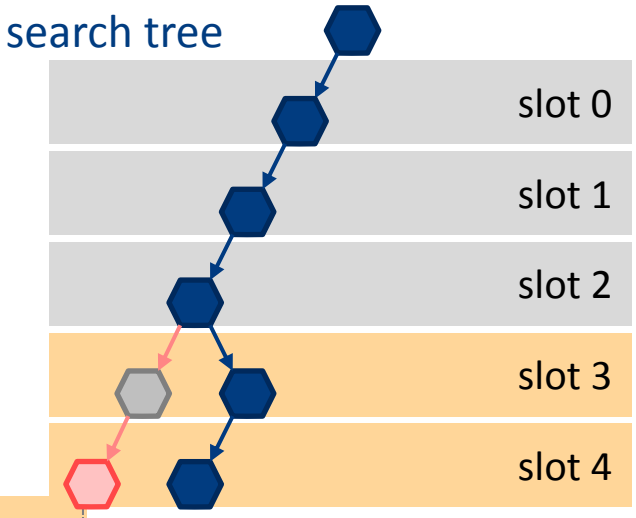

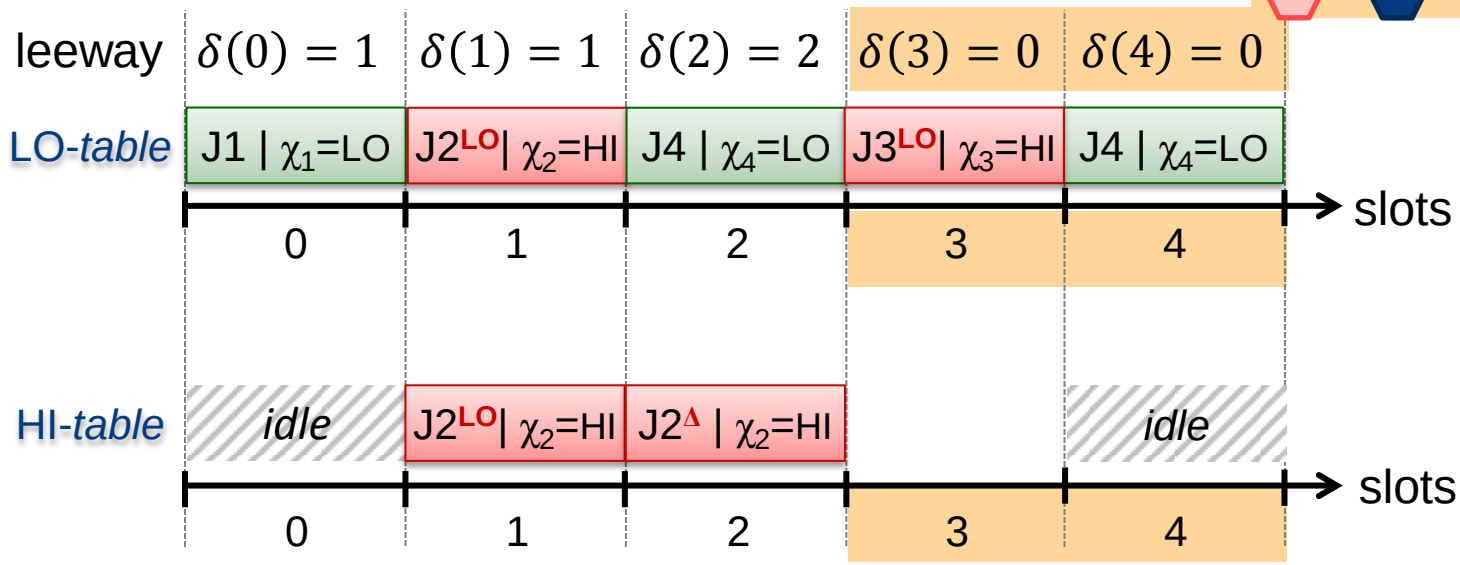

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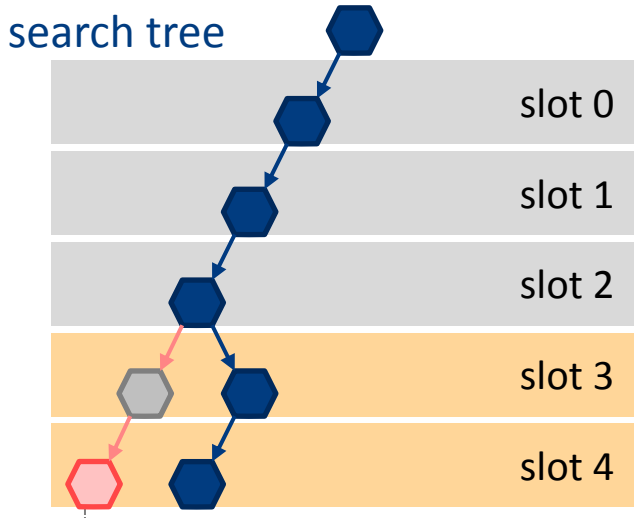
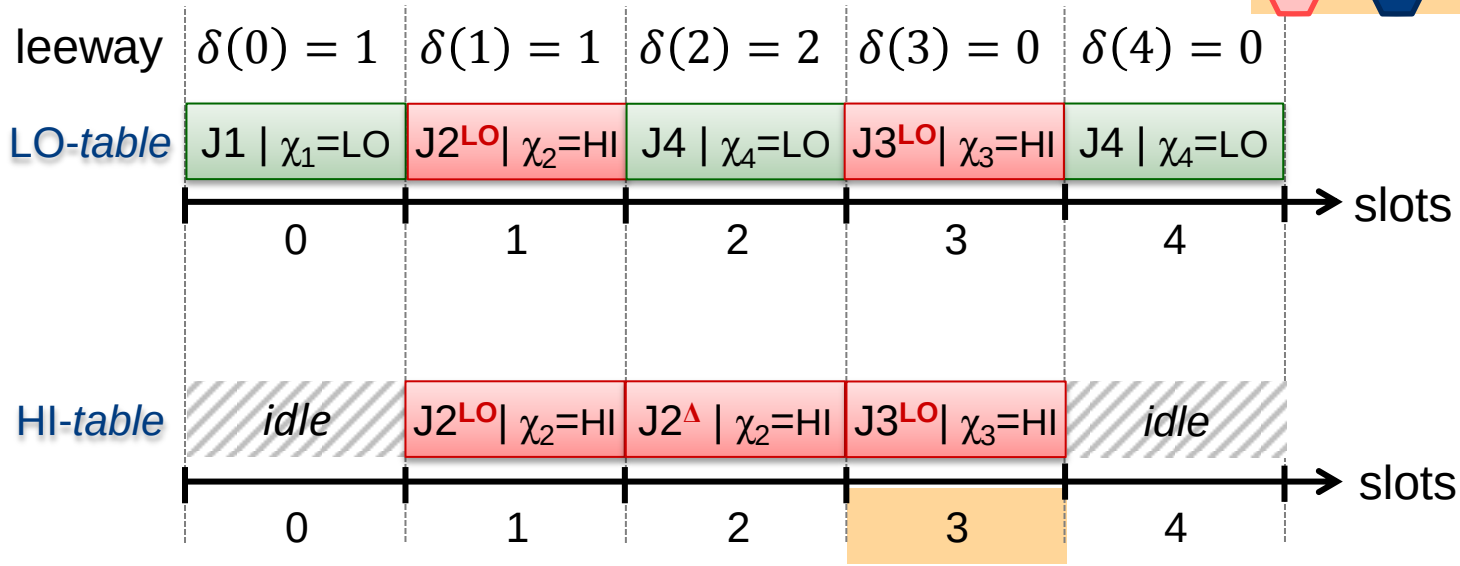
LO-table: select job by EDF

→ $J3^{LO}$

HI-table: schedule same job as in LO-table

→ $J3^{LO}$



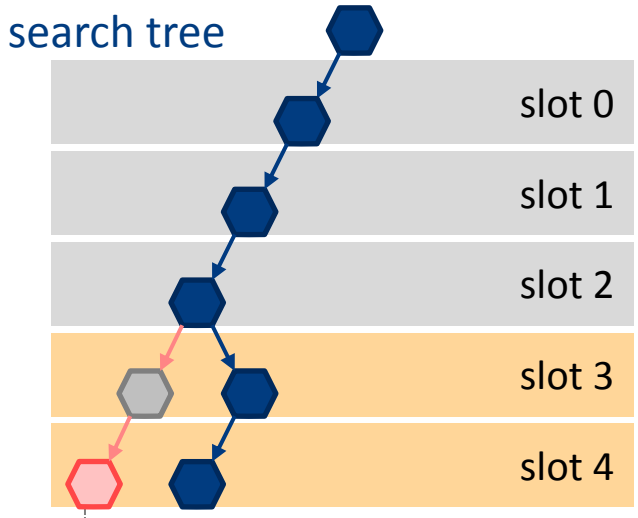


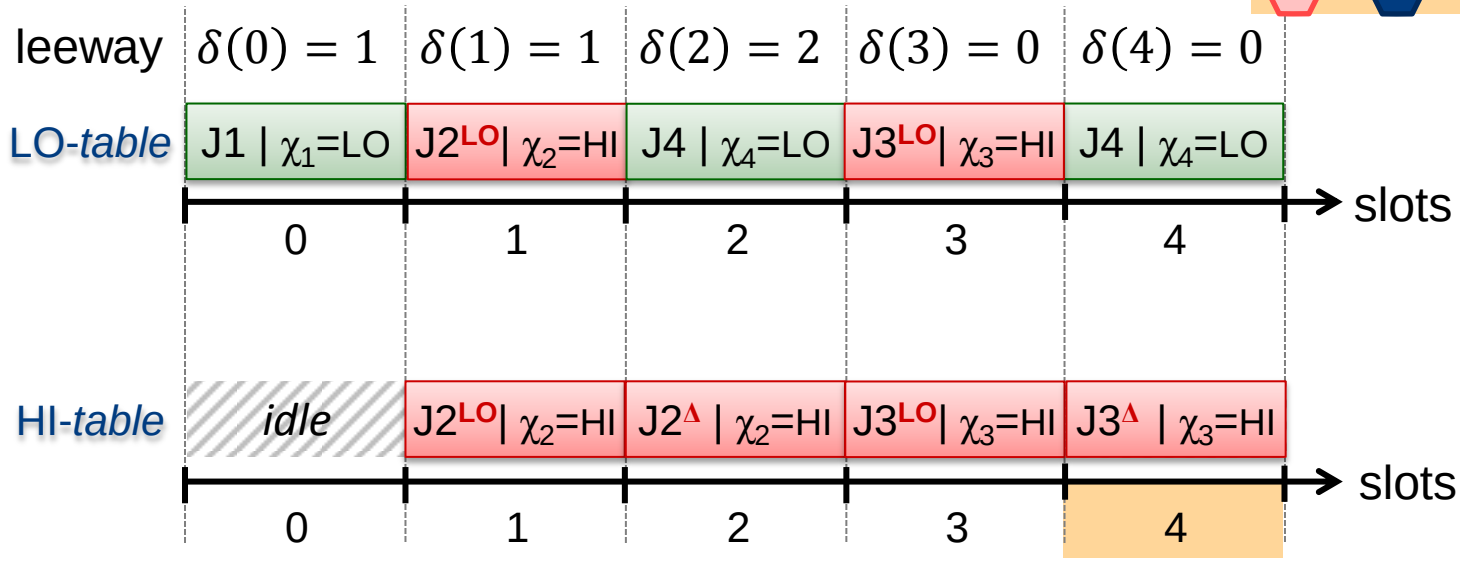
Schedule Tables Generation

LO-table: swapped job has LO-criticality

HI-table: select Δ-fraction job by EDF

→ $J3^{\Delta}$





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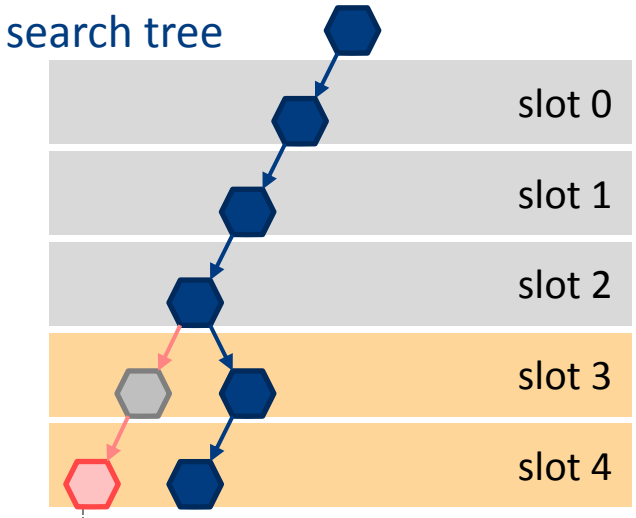

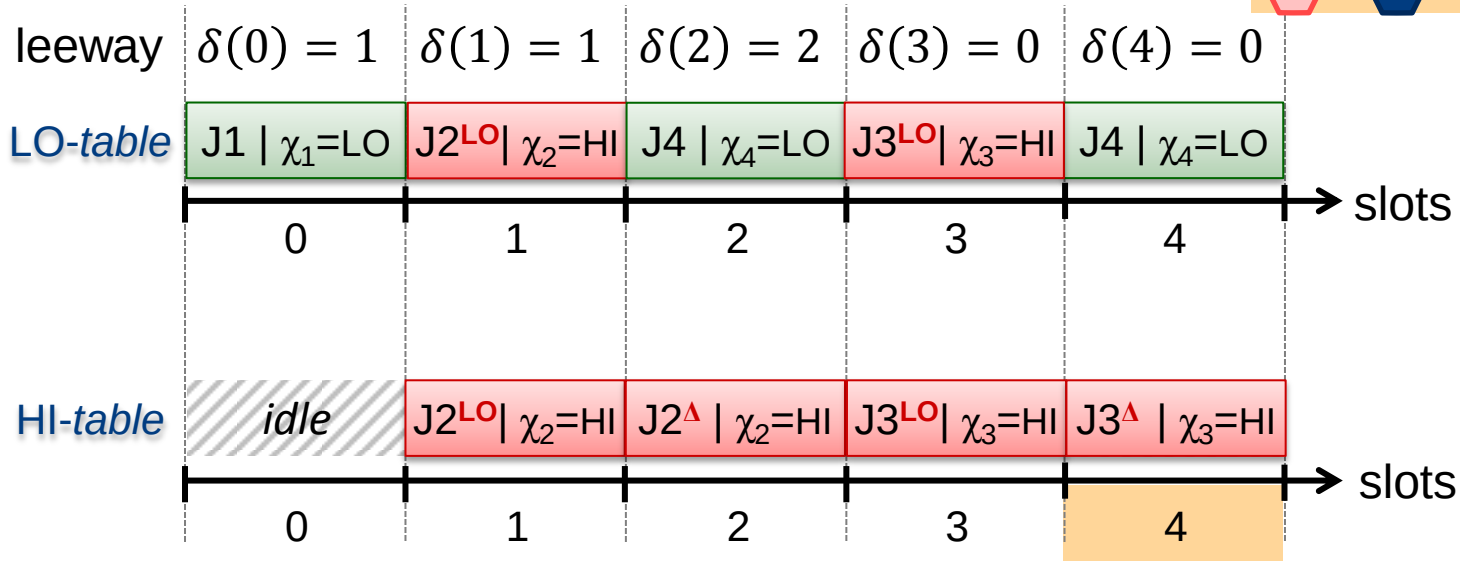

Conclusion

- System
  - mixed criticality
  - safety critical
  - certification

Conclusion

- created two TT schedule tables *(one for each criticality level)*
- constructive proof by TT execution
- job splitting separates designer and CAs assumptions
- added precedence constraints
- pessimistic CAs assumptions excluded from LO-criticality system behavior
- *leeway* and *swapping* used for backtracking

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Thank You.

Jens Theis and Gerhard Fohler

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