Semi-Federated Scheduling of Mixed-Criticality System for Sporadic DAG Tasks

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Outline

- Background & Contributions
- Preliminaries
- Semi-Federated Mixed-Criticality Algorithm
- Evaluation

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Mixed-Criticality Systems

Sub-systems with different criticality levels (e.g. avionics):

high

- Monitoring and control sub-system
- Anti-collision sub-system
- Navigation sub-system
- …
- Infotainment sub-system

low

Mixed-Criticality Systems

Characteristics :

- More complex functions of system
- No reduction in system security requirements

Challenges:

- Multicore: no enough analytical techniques
- Task parallelization: dependencies and competitions among tasks

Facing the problem

How to assign computation resources to parallel tasks on a multicore platform while guaranteeing security ?

Our work

Propose a semi-federated mixed-criticality scheduling algorithm

- Propose a mapping algorithm: from mixed-criticality tasks to a middleware layer (mixed-criticality container tasks)
- Prove the schedulablity of our proposed algorithm

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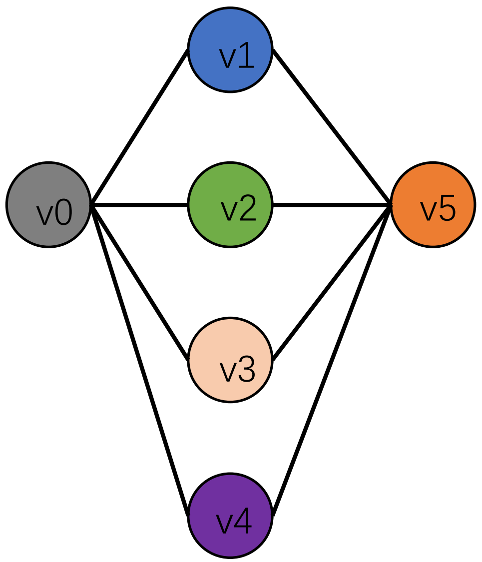
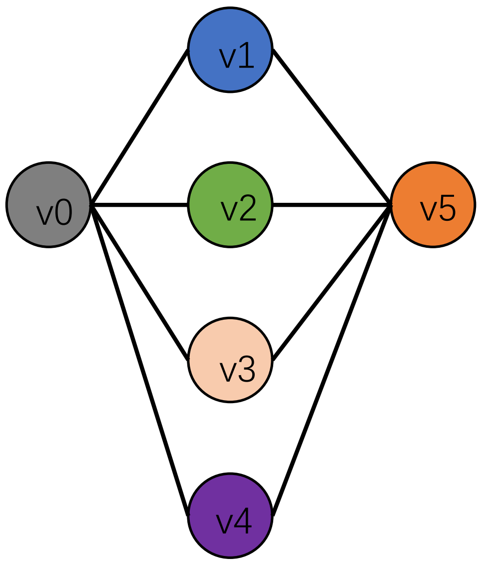
Mixed-Criticality Task Model

- Implicit-deadline sporadic parallel
- Each task is denoted by a directed acyclic graph
  - ✓ Vertices: sequential subtasks
  - ✓ Edges: dependencies
- Two types: low-criticality and high-criticality



Mixed-Criticality Task Model

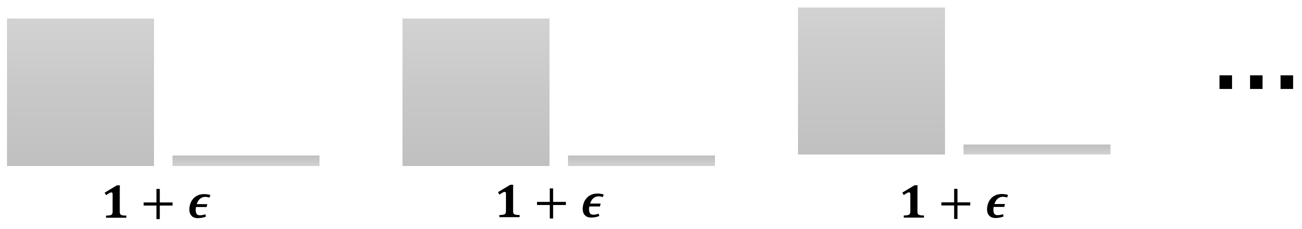
- **WCET** of a vertex (subtask): c^N and c^O
- **WCET** of a task: C^N and C^O
- **The longest chain** of a task: L^N and L^O
- **Deadline** of a task: D
- **Virtual deadline** of a task: D'
- **Task** utilization: $u^N = \frac{C^N}{D'}$ $u^O = \frac{C^O}{D - D'}$



Existing work: Federated Mixed-Criticality Scheduling

- Task types: LH, HVH, HMH
- System states: normal state and critical state
- Assigning strategy: independently usable cores to each task in the normal and critical states.

- **In the worst case, half of the resources are wasted**



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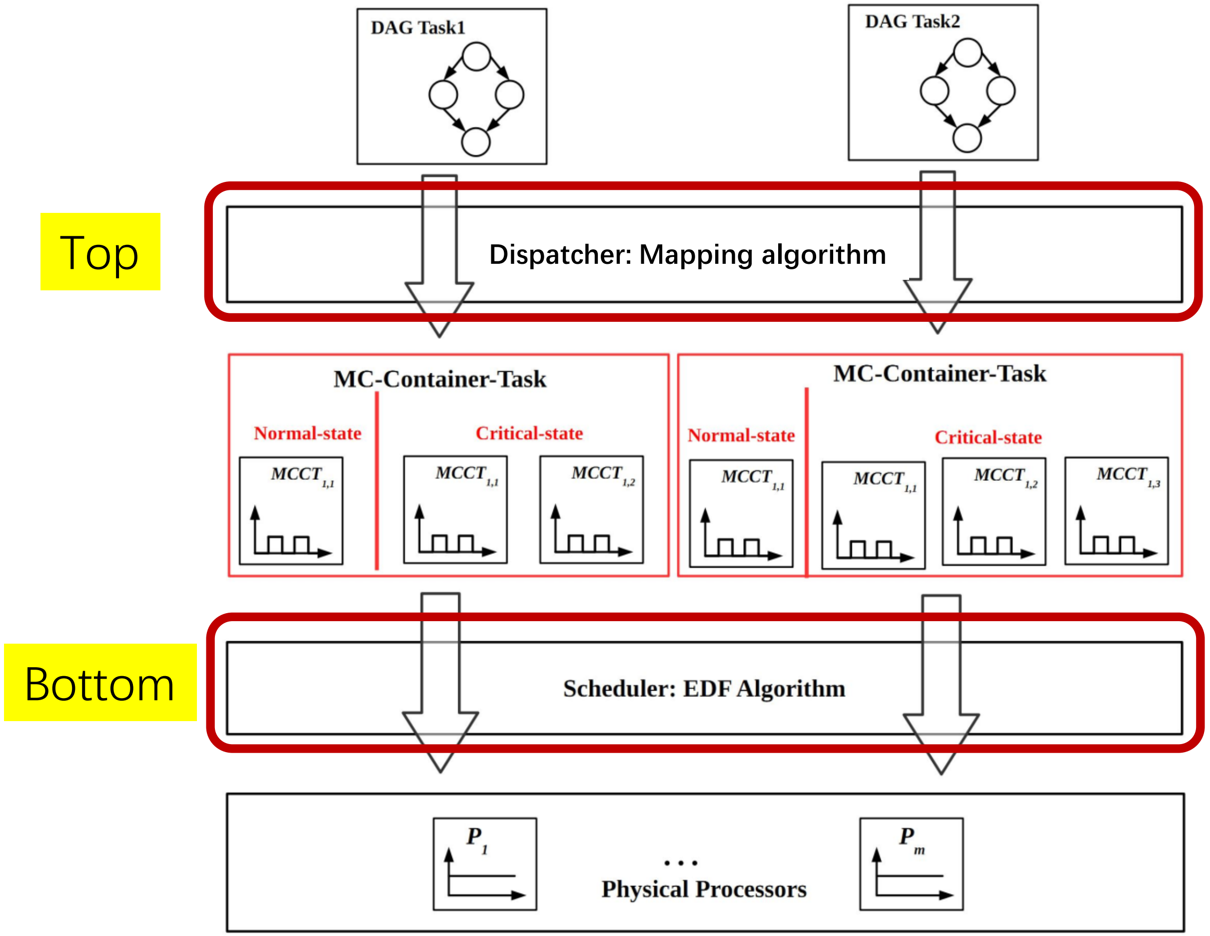
Architecture of Our Algorithm

Semi-Federated Mixed-Criticality Algorithm:

- Two-level hierarchical scheduling framework



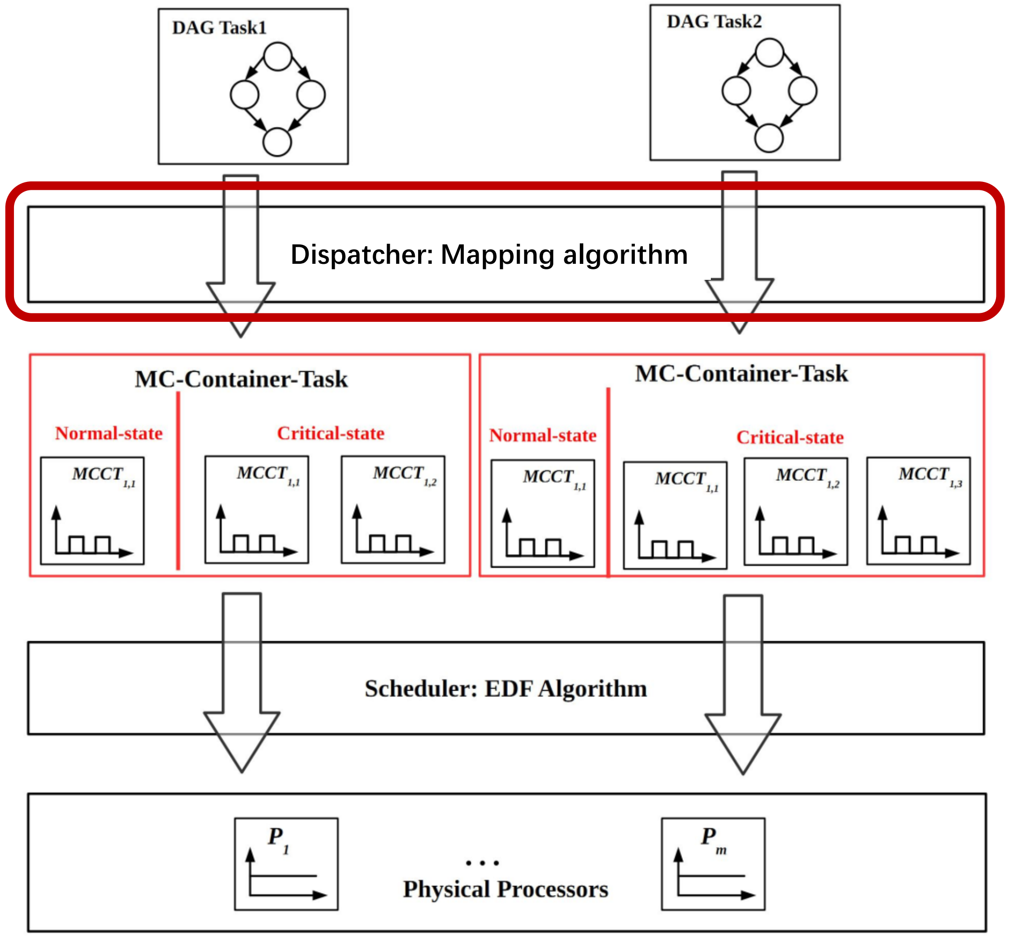
Architecture of Our Algorithm

Semi-Federated Mixed-Criticality Algorithm:

- Two-level hierarchical scheduling framework

- **Top-level** calculates the mapping from mixed-criticality tasks to mixed-criticality container-tasks.

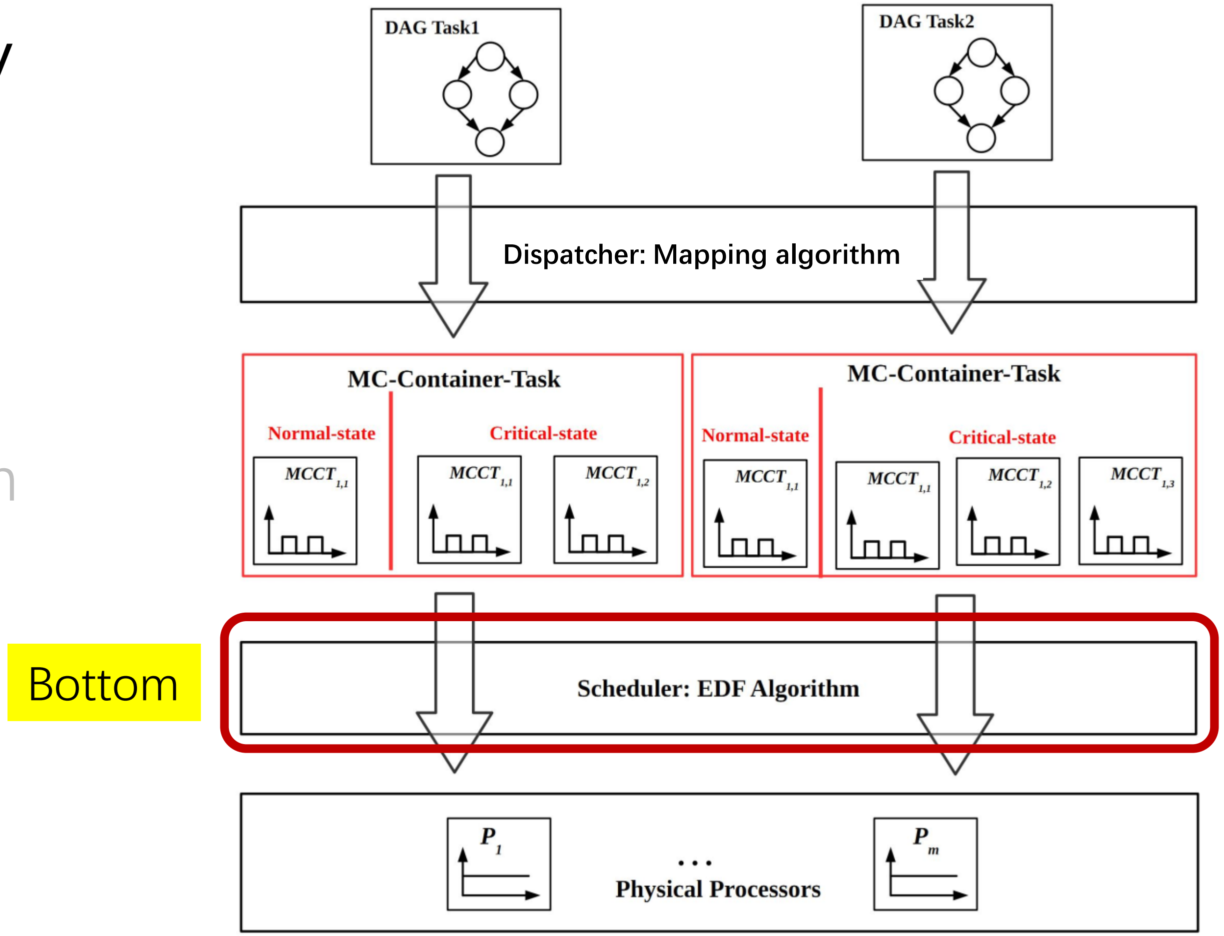
Top



Architecture of Our Algorithm

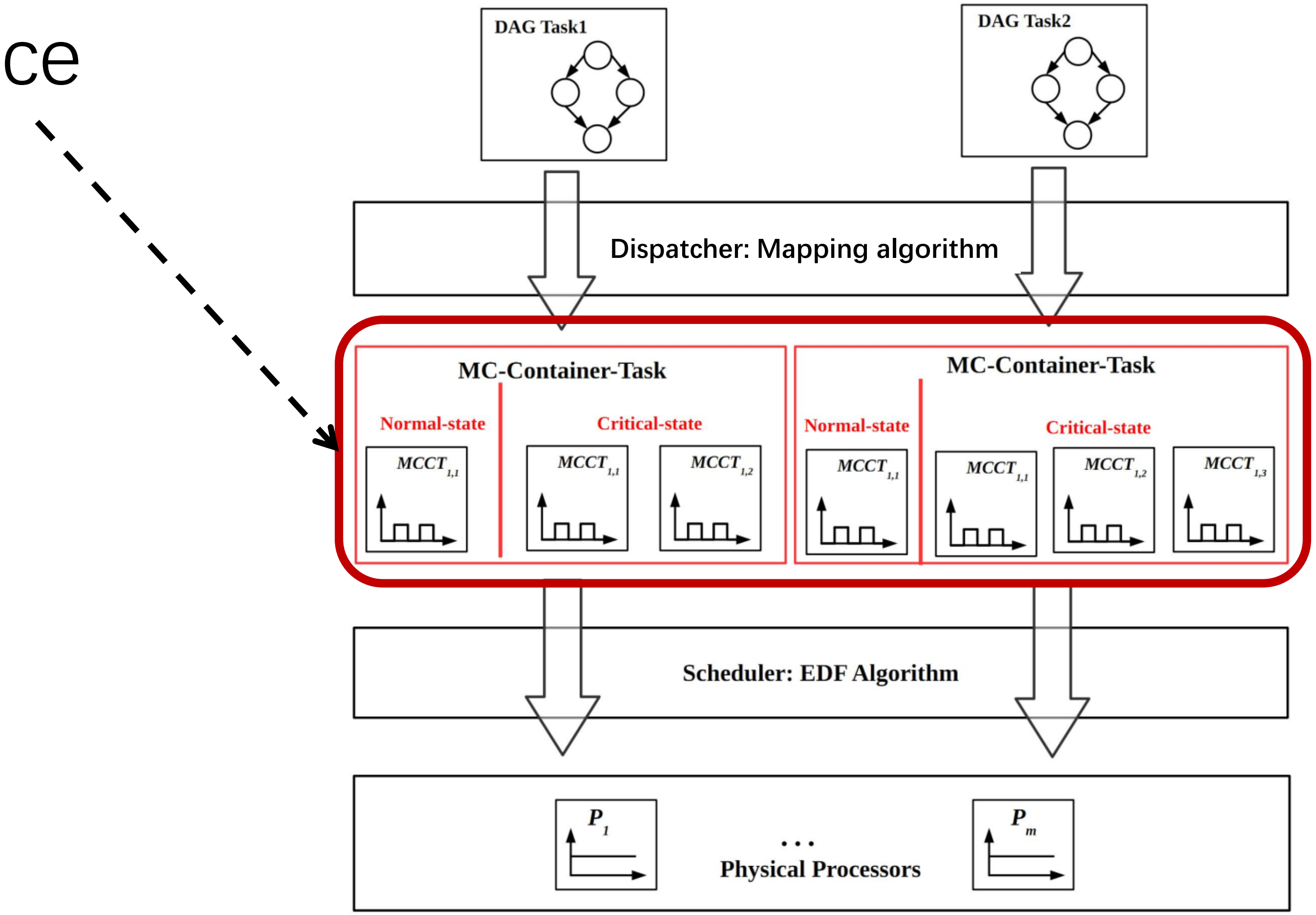
Semi-Federated Mixed-Criticality Algorithm:

- Two-level hierarchical scheduling framework
- Top-level calculates the mapping from mixed-criticality tasks to mixed-criticality container-tasks.
- **Bottom-level** schedules mixed-criticality container-tasks on physical processors.



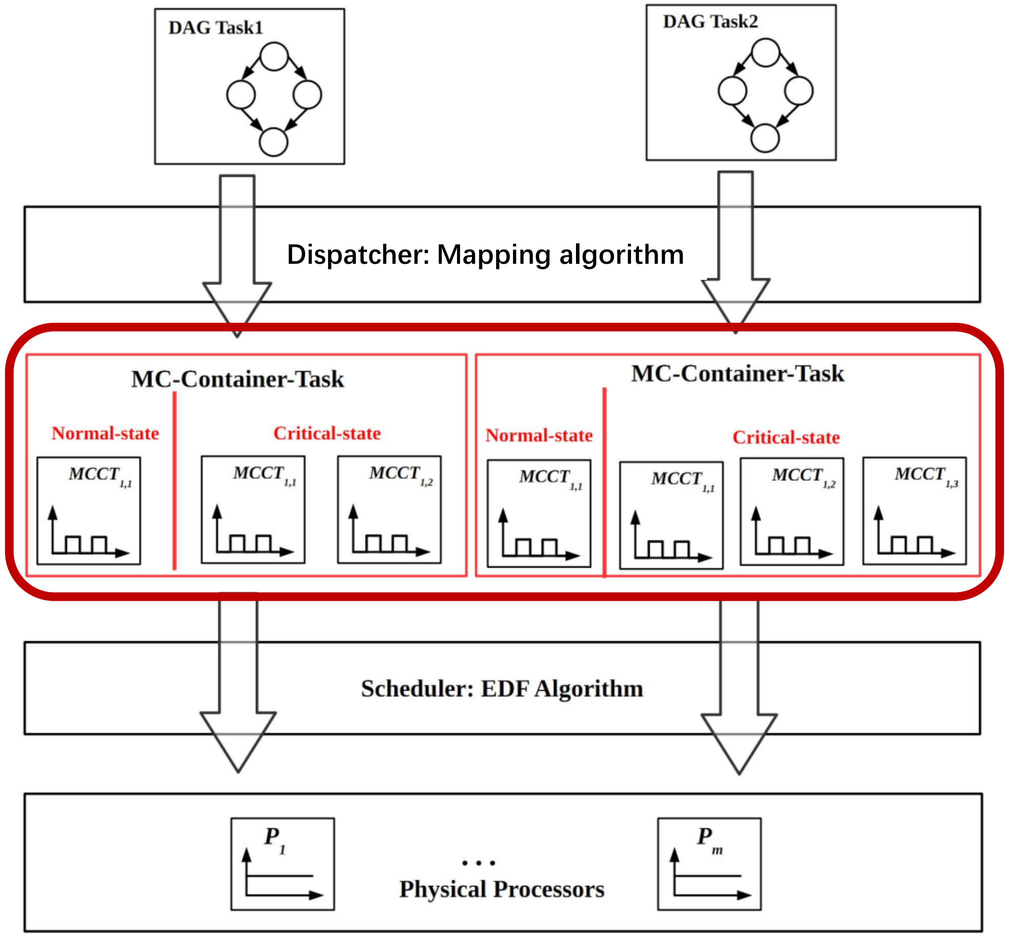
Mixed-Criticality Container Task

- Processor resources interface



Mixed-Criticality Container Task

- Processor resources interface
- Calculate number of mixed-criticality container tasks in both normal states and critical states

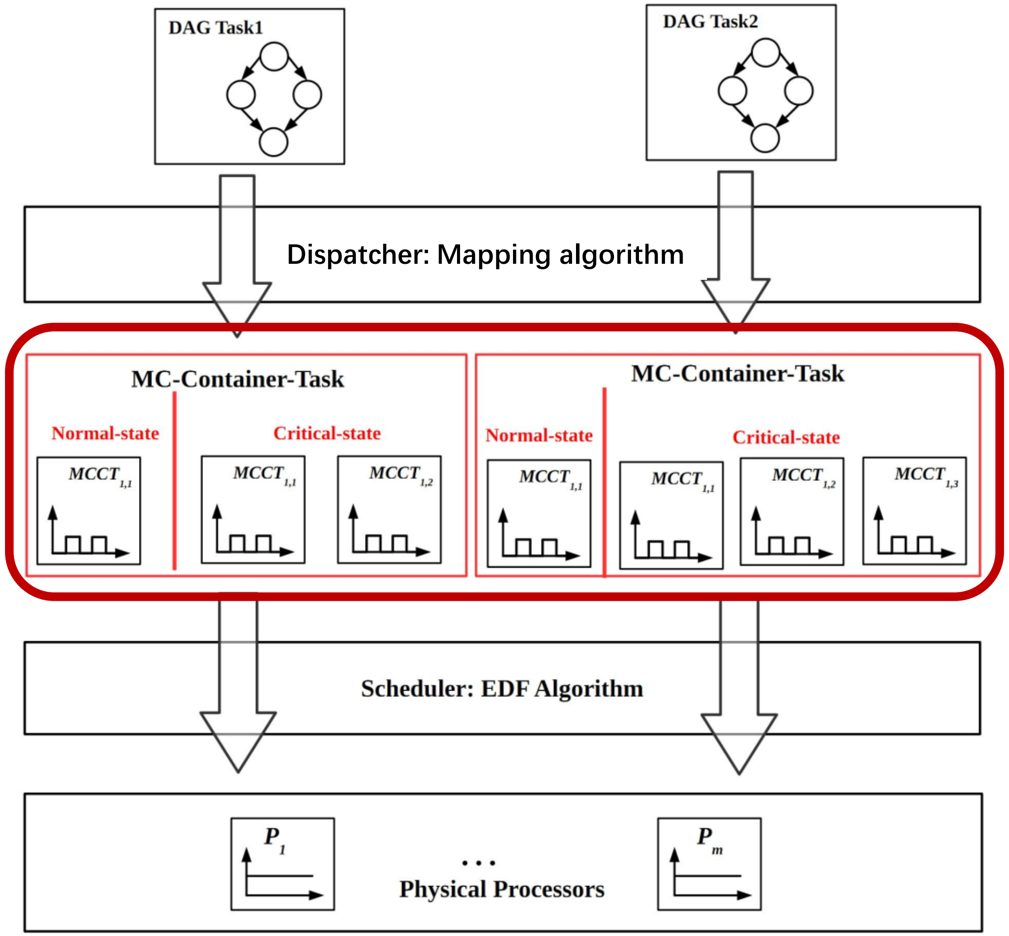


Mixed-Criticality Container Task

- Processor resources interface

- Semi-federated:

Mixed-criticality container tasks provide virtual resources, so the number of mixed-criticality task can be decimal, avoiding resource waste

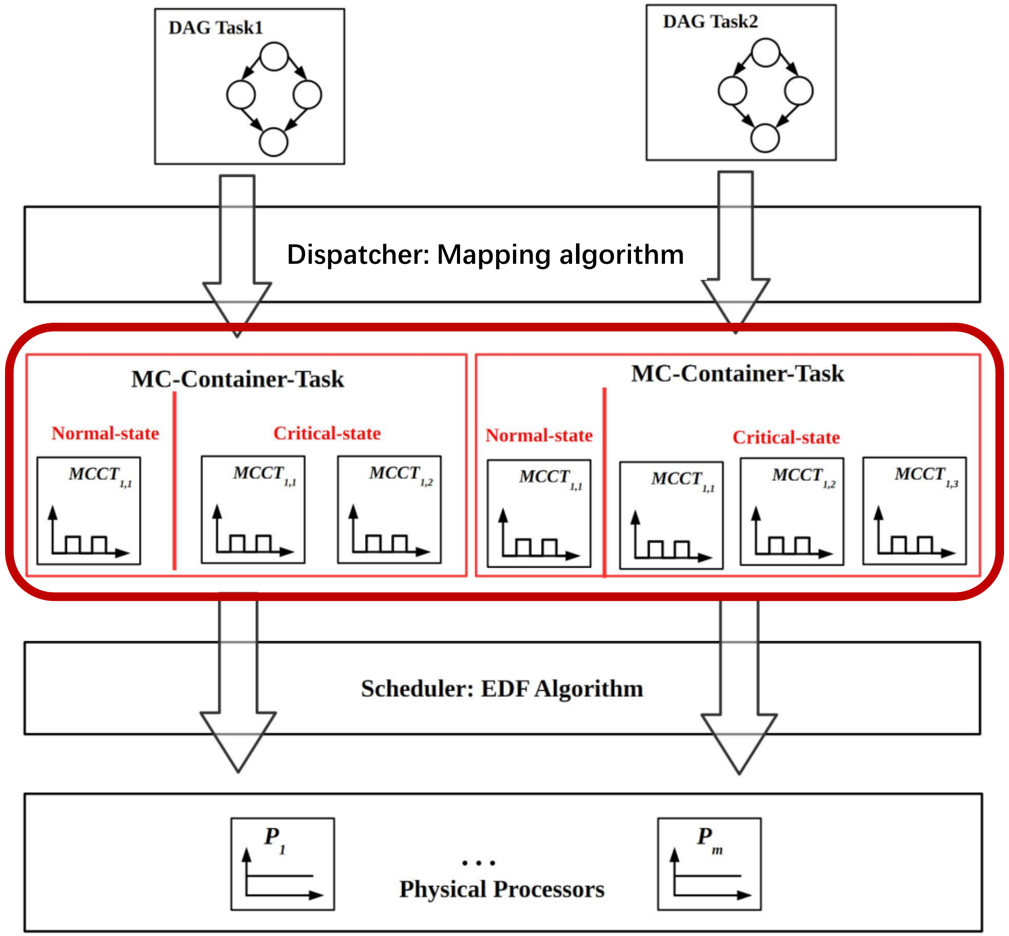


Mixed-Criticality Container Task

- Processor resources interface

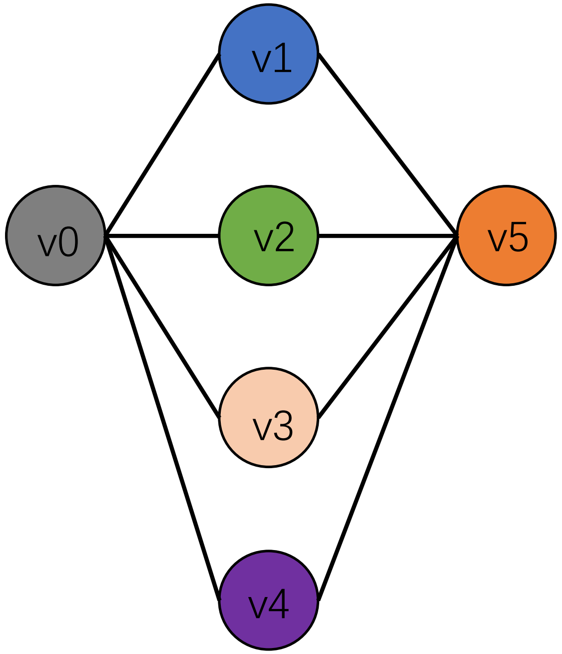
- If the WCET of a task equals **c** when it executes on a unit speed processor, then its WCET on a container-task with speed σ is:

$$t = \frac{c}{\sigma}$$



Mapping Algorithm

A mixed-criticality task



$c_{v0}^{N} = 1\ c_{v0}^{O} = 2,$ $c_{v1}^{N} = 1\ c_{v1}^{O} = 3$

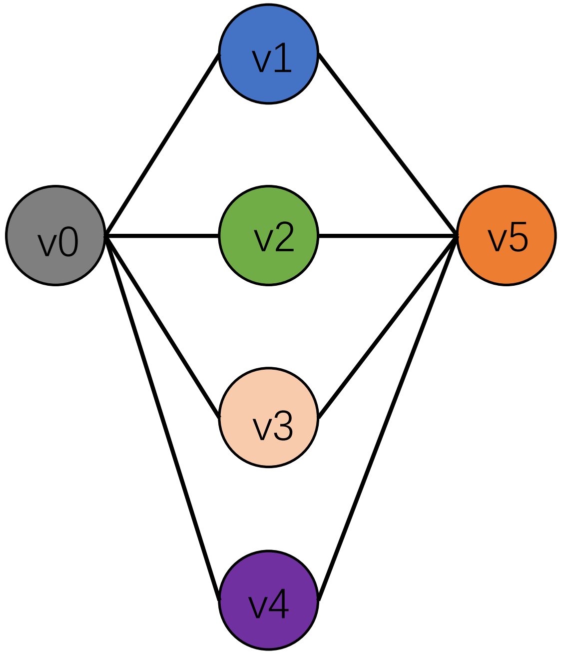
$c_{v2}^{N} = 1\ c_{v2}^{O} = 3,$ $c_{v3}^{N} = 1\ c_{v3}^{O} = 3$

$c_{v4}^{N} = 1\ c_{v4}^{O} = 3,$ $c_{v5}^{N} = 1\ c_{v5}^{O} = 2$

$D = 13,\ D' = 5$

Mapping Algorithm

A mixed-criticality task



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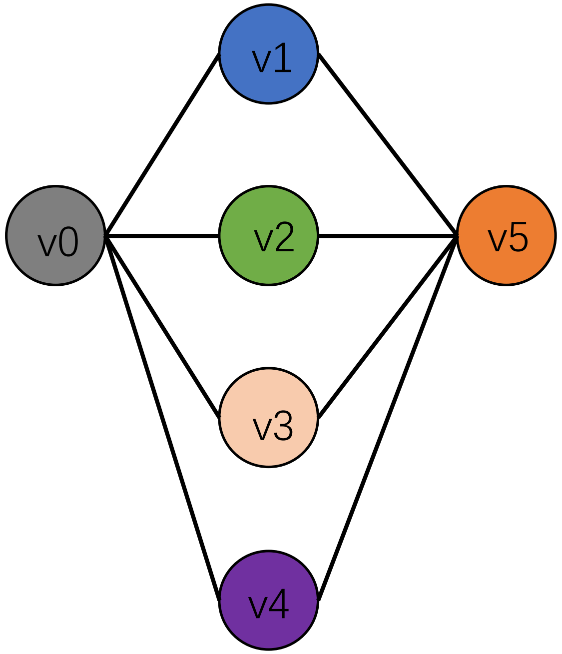
$D = 13,\ D' = 5$

$C^{N} = 6,\ C^{O} = 16,\ L^{N} = 3,\ L^{O} = 7$

Mapping Algorithm

A mixed-criticality task



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$c_{v4}^{N} = 1\ c_{v4}^{O} = 3,$ $\quad c_{v5}^{N} = 1\ c_{v5}^{O} = 2$

$D = 13,\ D' = 5$

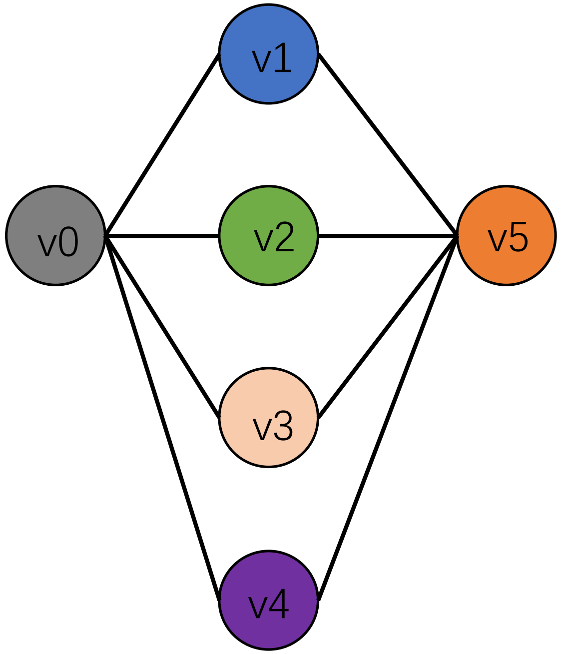
$C^{N} = 6, C^{O} = 16, L^{N} = 3, L^{O} = 7$

$$u^{N} = \frac{C^{N}}{D'} = \frac{6}{5} > 1$$

Mapping Algorithm

A mixed-criticality task

- **Calculating the mapping**



$$C^N = 6,\ C^O = 16,\ L^N = 3,\ \ L^O = 7, D = 13,\ D' = 5$$

Using our mapping equation:

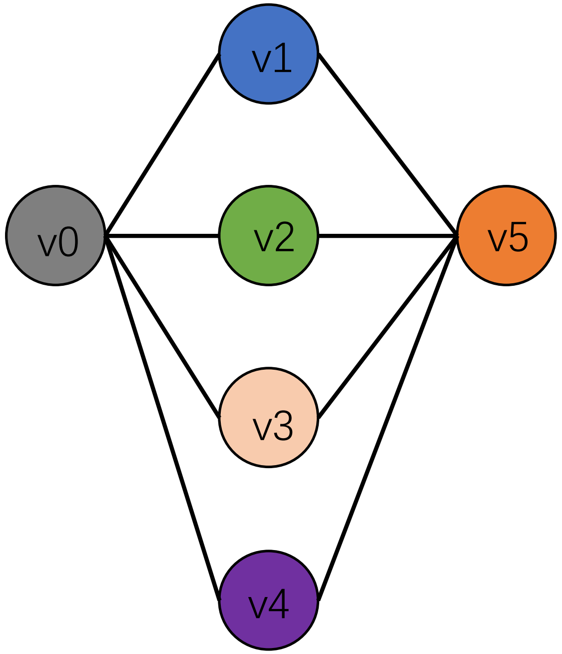
$$S_i^N = \begin{cases} u_i^N & \text{when } u_i^N < 1 \\ \dfrac{C_i^N - L_i^N}{D_i' - L_i^N} & \text{when } u_i^N \geq 1 \end{cases}$$

$$S_i^O = \begin{cases} 0 & if\ task\ is\ LO \\ \dfrac{C_i^O - S_i^N D_i' - L_i^O}{D_i - D_i' - L_i^O} & if\ task\ is\ HI \end{cases}$$

Mapping Algorithm

A mixed-criticality task

- **Calculating the mapping**



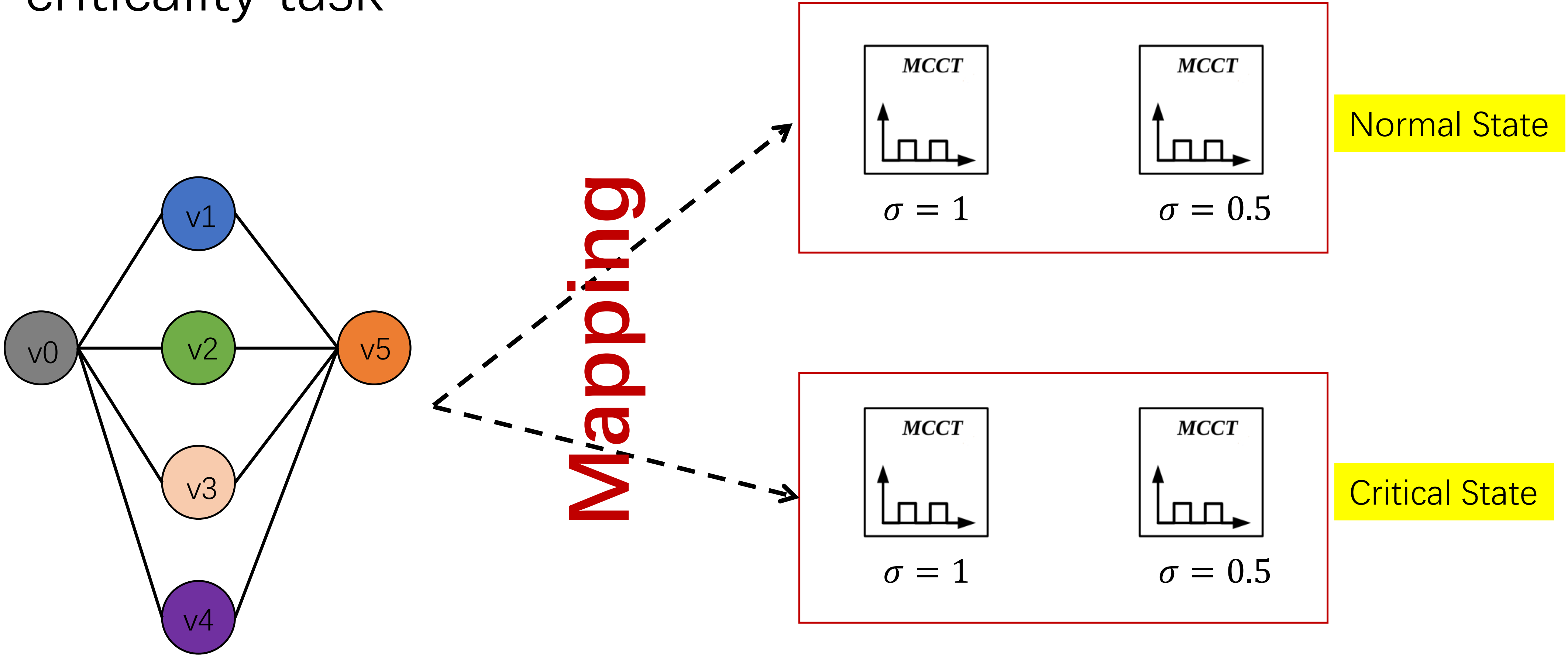
$$C^N = 6, C^O = 16, L^N = 3, \ L^O = 7, D = 13, D' = 5$$

$$S^N = \frac{C^N - L^N}{D' - L^N} = \frac{6-3}{5-3} = \mathbf{1.5}$$

$$S^O = \frac{C^O - S^N D' - L^O}{D - D' - L^O} = \frac{16 - 1.5 * 5 - 7}{13 - 5 - 7} = \mathbf{1.5}$$

Mapping Algorithm

A mixed-criticality task



Runtime of a Mixed-Criticality Task

- Mixed-Criticality tasks are encapsulated into mixed-criticality container-tasks
- Scheduling these mixed-criticality container-tasks to physical processors with a partitioned or global algorithm

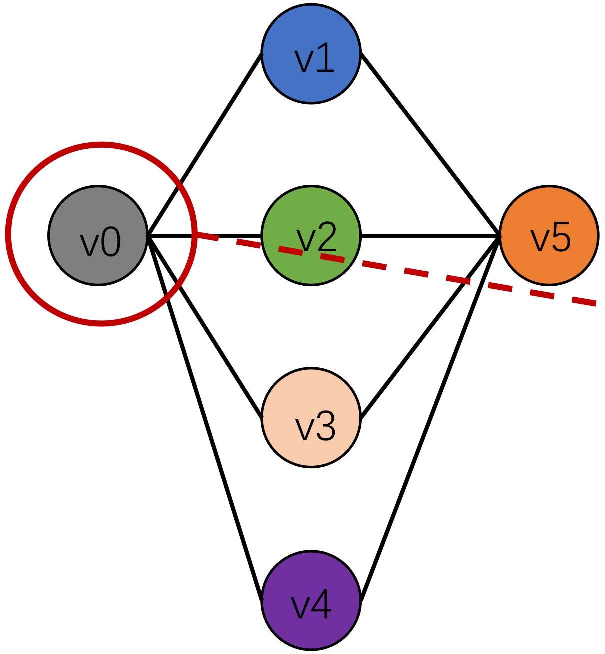
Runtime of a Mixed-Criticality Task

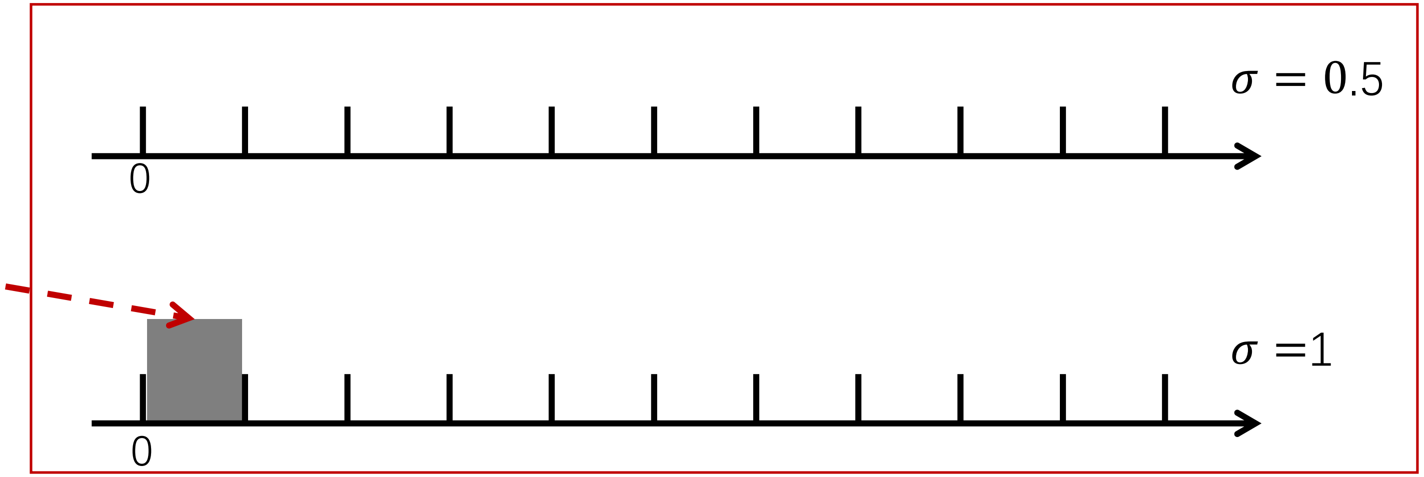
$c_{v0}^{N} = 1\ c_{v0}^{O} = 2,\quad c_{v1}^{N} = 1\ c_{v1}^{O} = 3$

$c_{v2}^{N} = 1\ c_{v2}^{O} = 3,\quad c_{v3}^{N} = 1\ c_{v3}^{O} = 3$

$c_{v4}^{N} = 1\ c_{v4}^{O} = 3,\quad c_{v5}^{N} = 1\ c_{v5}^{O} = 2$

- Mixed-Criticality tasks are encapsulated into mixed-criticality container-tasks
  - **Encapsulating the vertex v0**





Normal State

Runtime of a Mixed-Criticality Task

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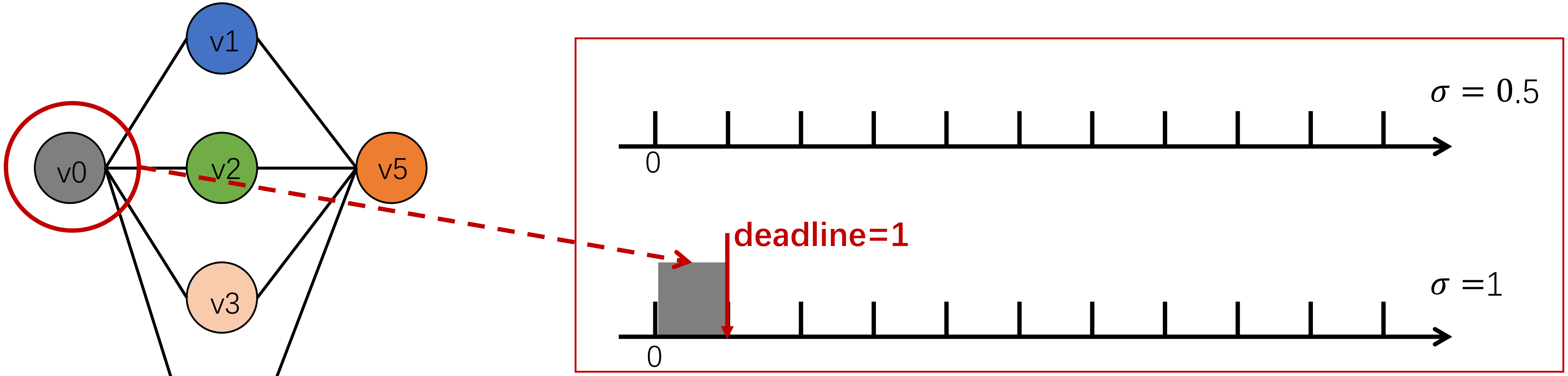
$c_{v4}^{N} = 1\ c_{v4}^{O} = 3,$ $c_{v5}^{N} = 1\ c_{v5}^{O} = 2$

- Mixed-Criticality tasks are encapsulated into mixed-criticality container-tasks
  - ➢ **Setting the deadline of the mixed-criticality container-task**



Normal State

Runtime of a Mixed-Criticality Task

$c_{v0}^N = 1\ c_{v0}^O = 2,\quad c_{v1}^N = 1\ c_{v1}^O = 3$

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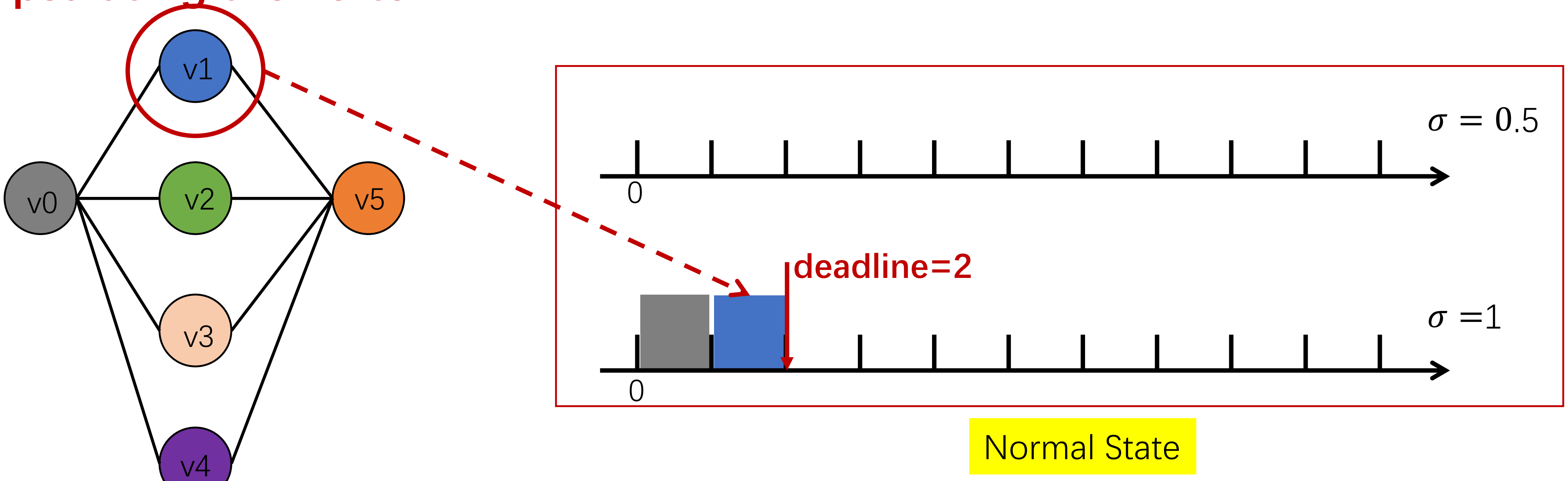
$c_{v4}^N = 1\ c_{v4}^O = 3,\quad c_{v5}^N = 1\ c_{v5}^O = 2$

- Mixed-Criticality tasks are encapsulated into mixed-criticality container-tasks
  - **Encapsulating the vertex v1**



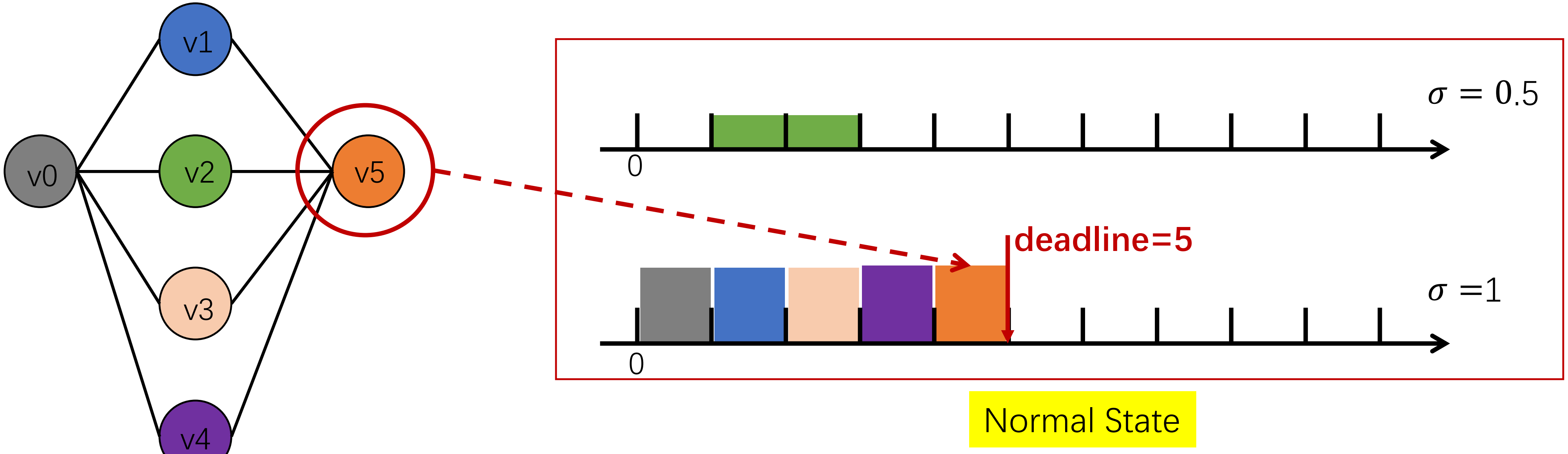
Runtime of a Mixed-Criticality Task

$c_{v0}^{N}=1\ c_{v0}^{O}=2,\quad c_{v1}^{N}=1\ c_{v1}^{O}=3$

$c_{v2}^{N}=1\ c_{v2}^{O}=3,\quad c_{v3}^{N}=1\ c_{v3}^{O}=3$

$c_{v4}^{N}=1\ c_{v4}^{O}=3,\quad c_{v5}^{N}=1\ c_{v5}^{O}=2$

- Mixed-Criticality tasks are encapsulated into mixed-criticality container-tasks
  - **Encapsulating the vertex v5**



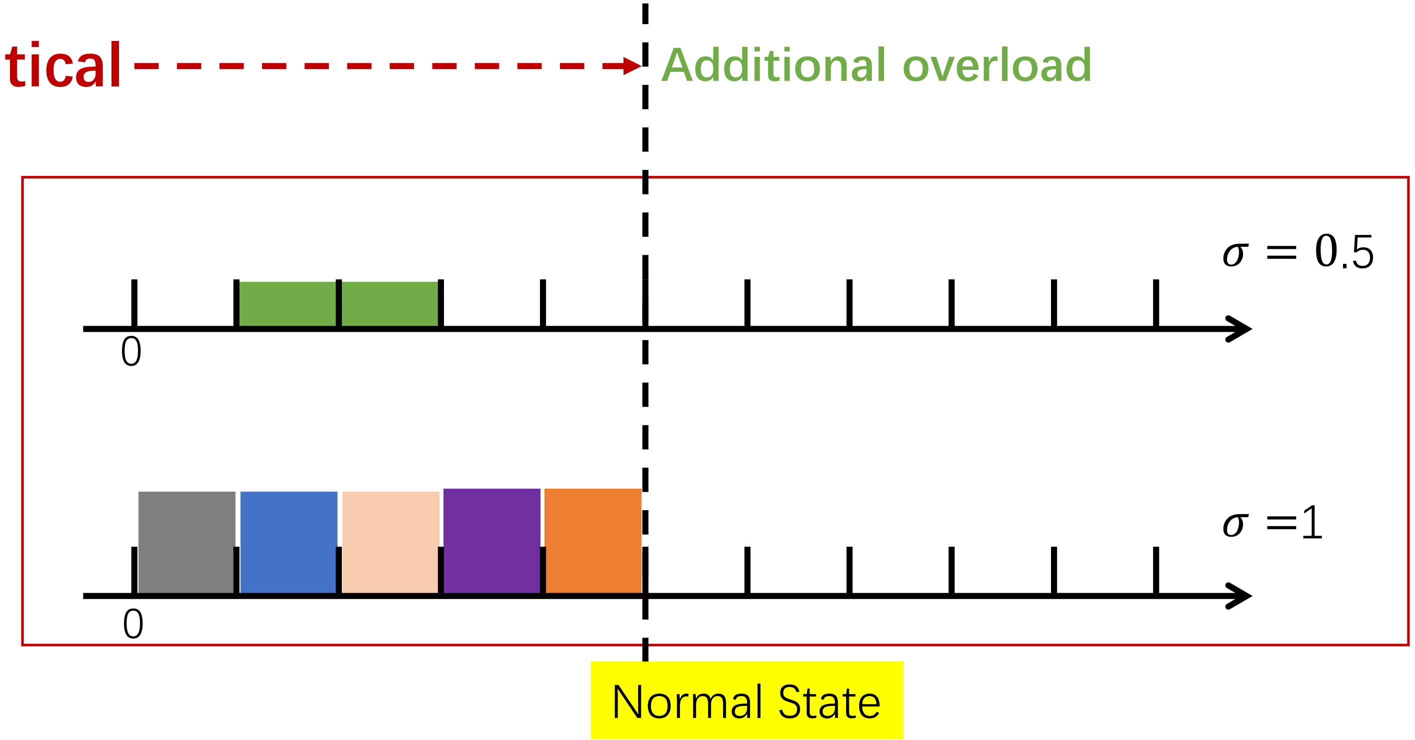
Runtime of a Mixed-Criticality Task

$c_{v0}^{N} = 1\ c_{v0}^{O} = 2,\quad c_{v1}^{N} = 1\ c_{v1}^{O} = 3$

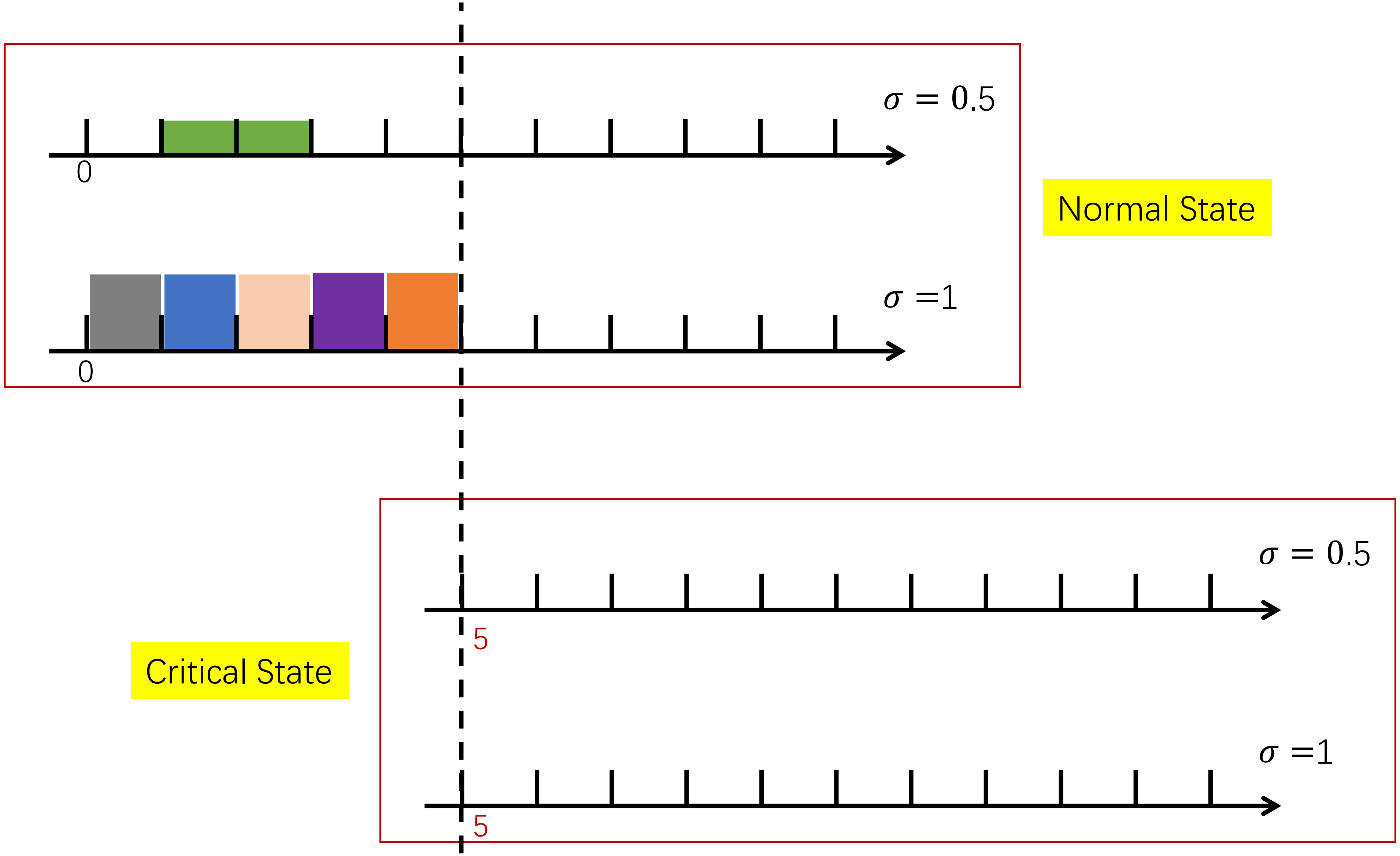
$c_{v2}^{N} = 1\ c_{v2}^{O} = 3,\quad c_{v3}^{N} = 1\ c_{v3}^{O} = 3$

$c_{v4}^{N} = 1\ c_{v4}^{O} = 3,\quad c_{v5}^{N} = 1\ c_{v5}^{O} = 2$

- Mixed-Criticality tasks are encapsulated into mixed-criticality container-tasks
  - **State transition: normal -> critical**



Runtime of a Mixed-Criticality Task



Runtime of a Mixed-Criticality Task

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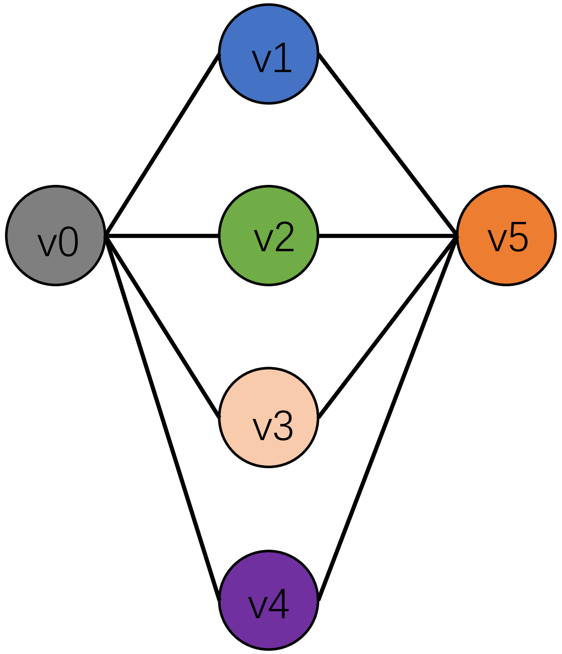
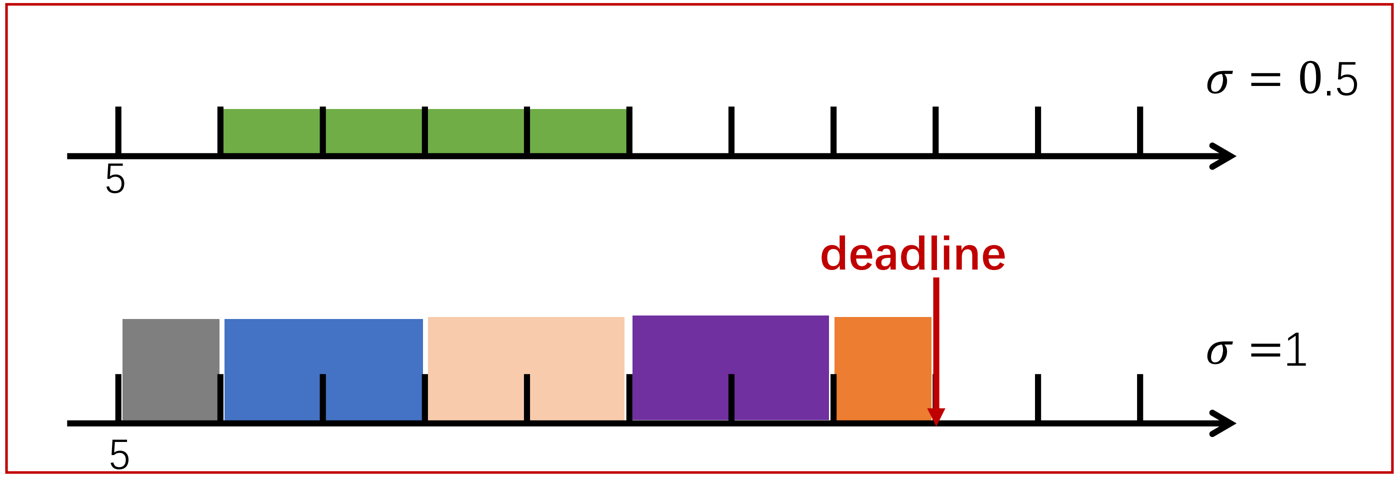
$c_{v4}^N = 1\ c_{v4}^O = 3,\quad c_{v5}^N = 1\ c_{v5}^O = 2$

- Mixed-Criticality tasks are encapsulated into mixed-criticality container-task
  - **In critical states**





Critical State

Runtime of a Mixed-Criticality Task

- Mixed-Criticality tasks are encapsulated into mixed-criticality container-tasks

- Scheduling these mixed-criticality container-task to physical processor with a partitioned or global algorithm
  - ➢ First, system is in normal state and only normal mixed-criticality container-tasks are scheduled
  - ➢ When the system experiences state transition, all normal mixed-criticality container-tasks are banned from scheduling and only critical mixed-criticality container-tasks can run

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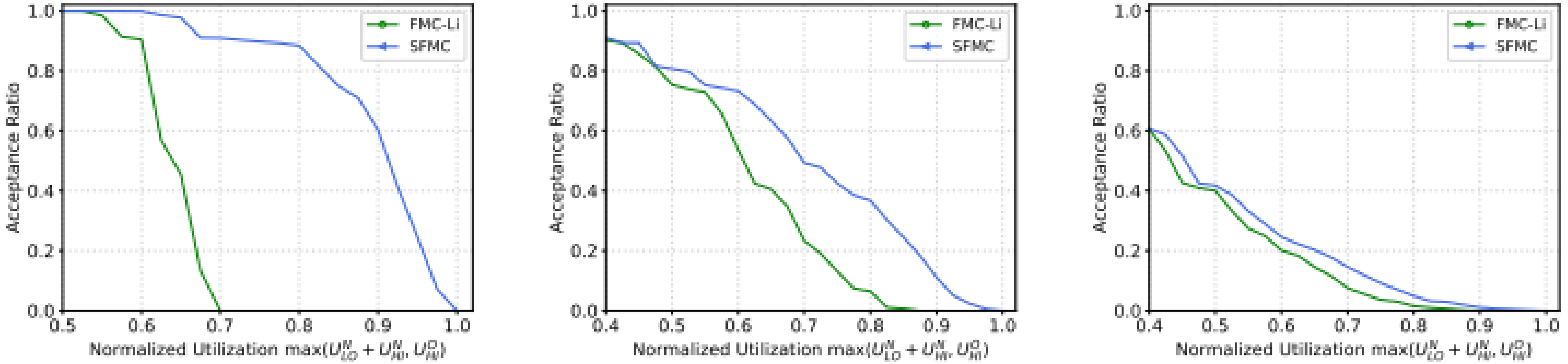
Evaluation

- Our task sets are generated based on OpenMP benchmarks and ompTG tool.
- Evaluate the acceptance ratio of task sets with different normalized utilizations.
- We compare our results with those in existing work for federated mixed-criticality scheduling.

Evaluation



(a) m=8 (b) m=16 (c) m=32

Comparison of FMC-Li and SFMC

Semi-federated mixed-criticality algorithm has better schedulability performance

Q&A

Thanks for your attention !