Schedulability analysis of limited-preemptive moldable gang tasks

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Real-time systems

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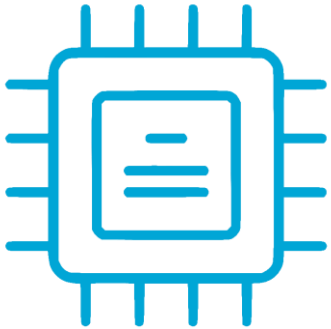

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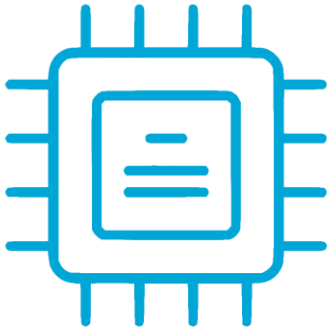

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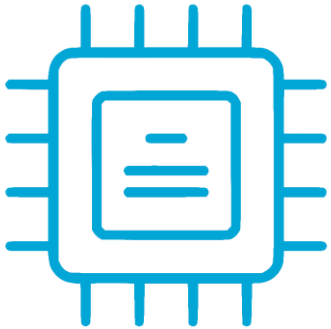

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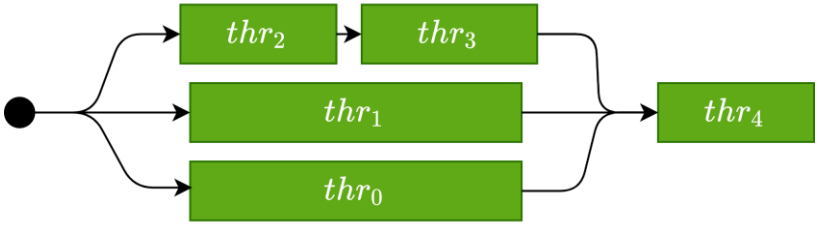

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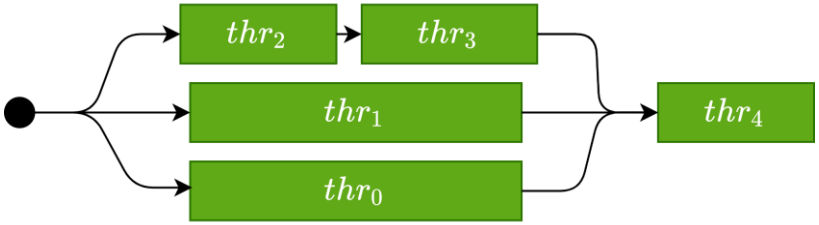
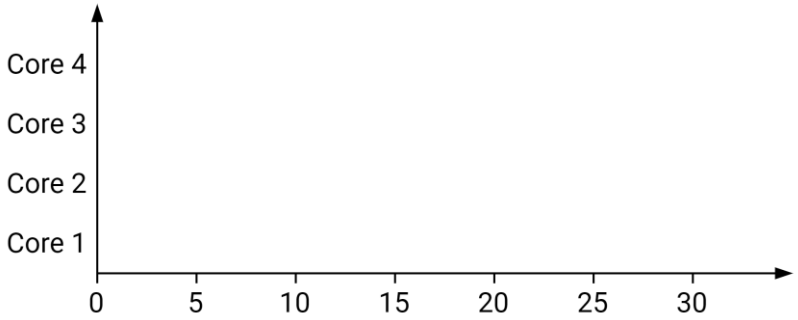


Global scheduling



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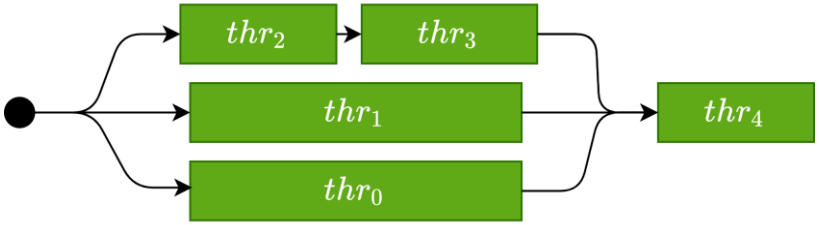
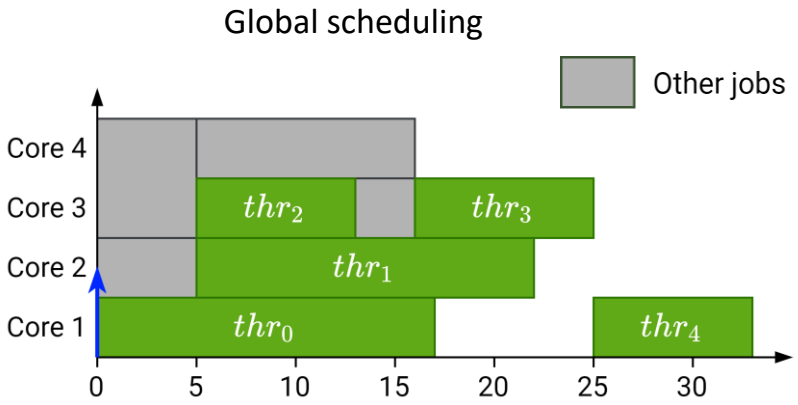
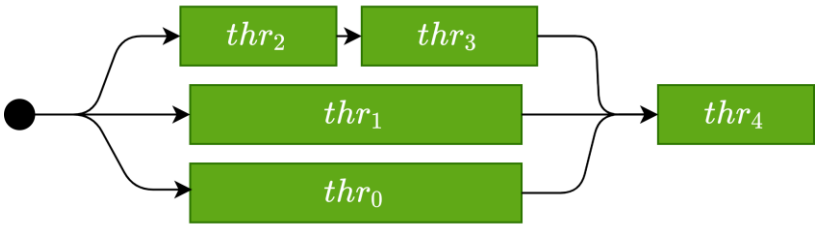

thr_2
thr_3
thr_1
thr_4
thr_0


Global scheduling
Other jobs
Core 4
Core 3
Core 2
Core 1
thr_2
thr_3
thr_1
thr_0
thr_4
0
5
10
15
20
25
30

What is gang?



Parallel threads together as a “gang”

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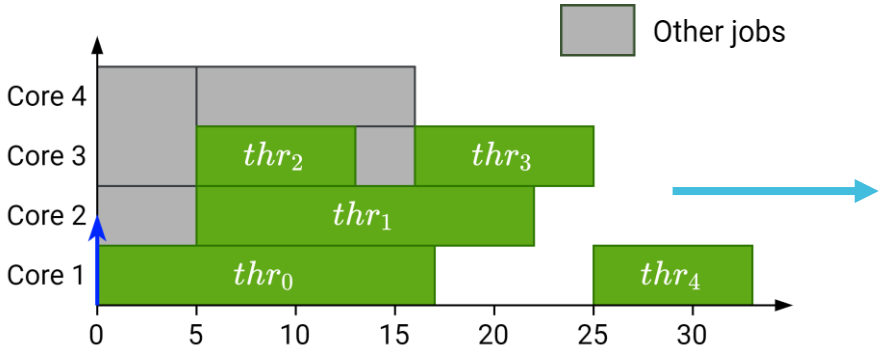

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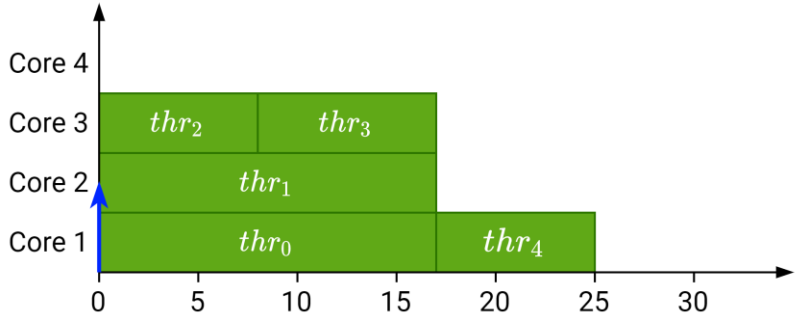

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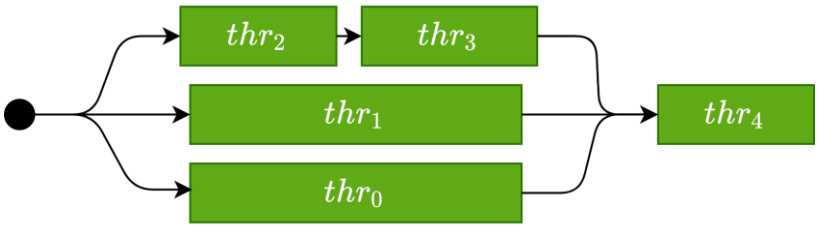

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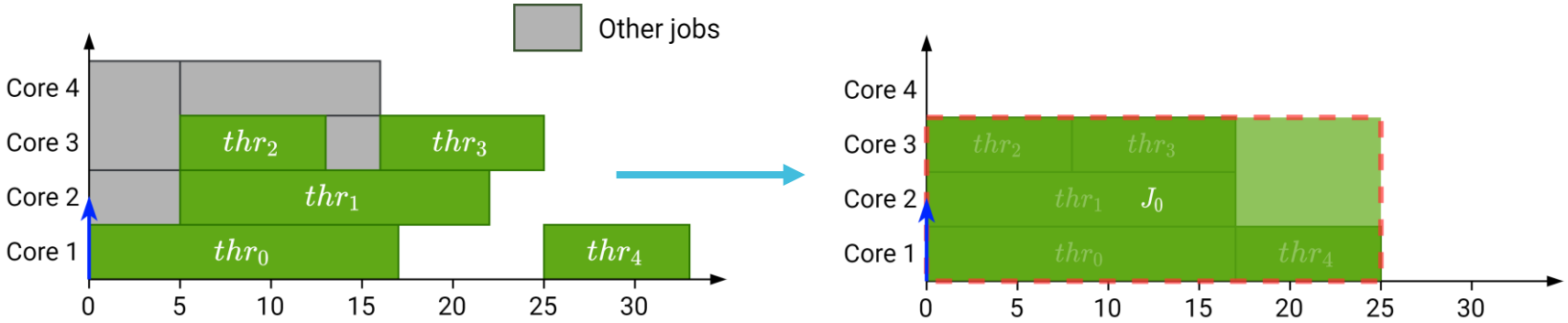

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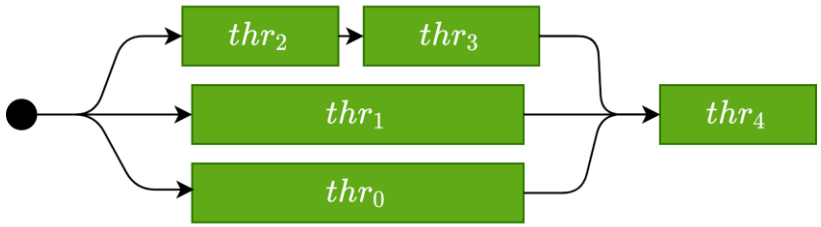

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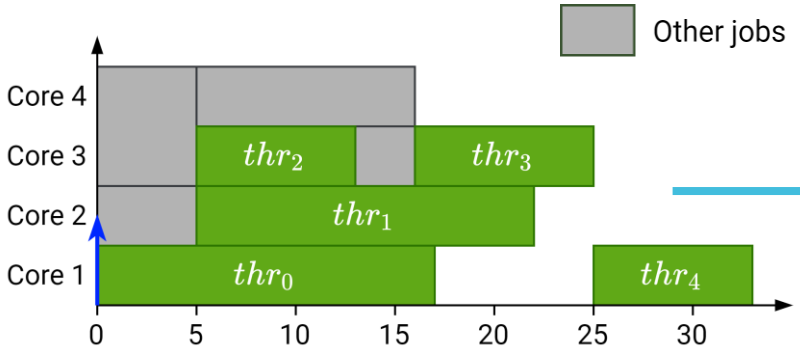

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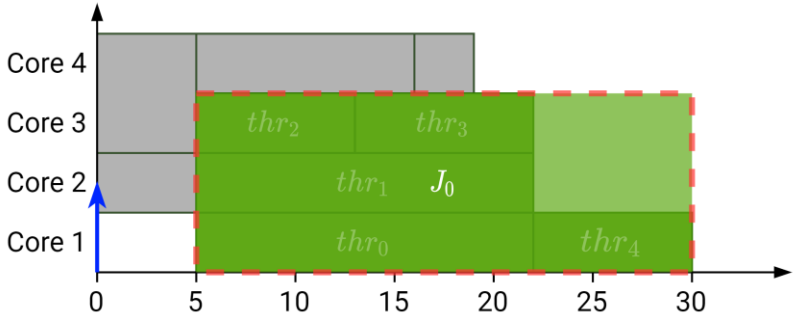

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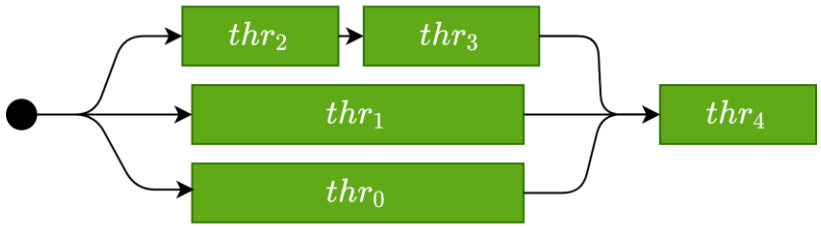

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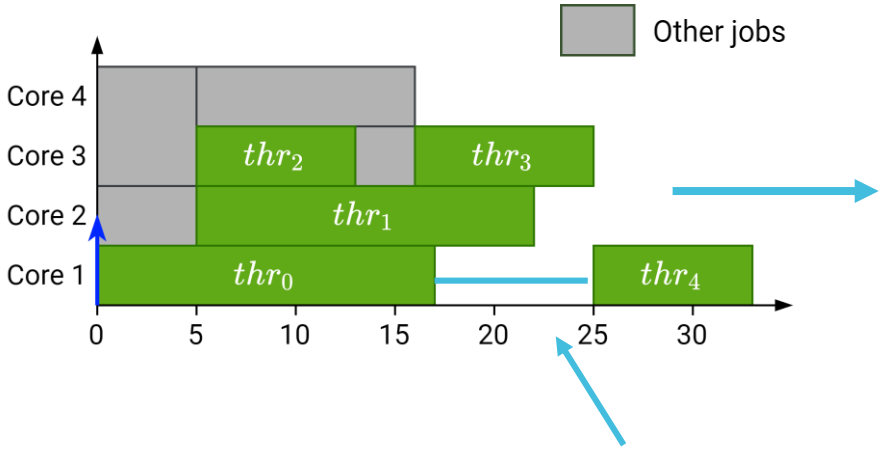

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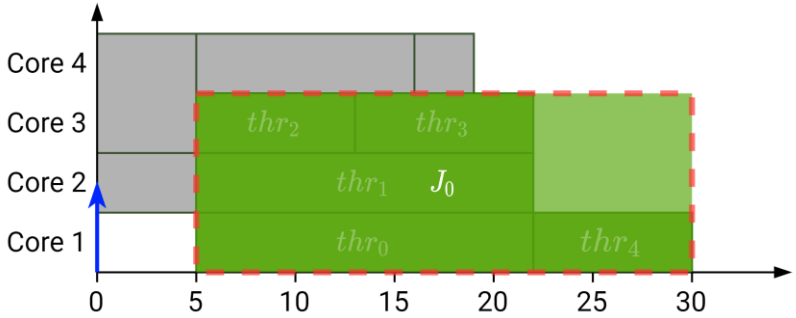

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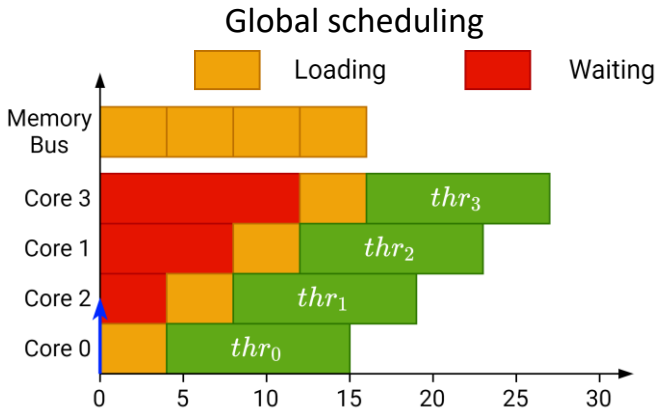

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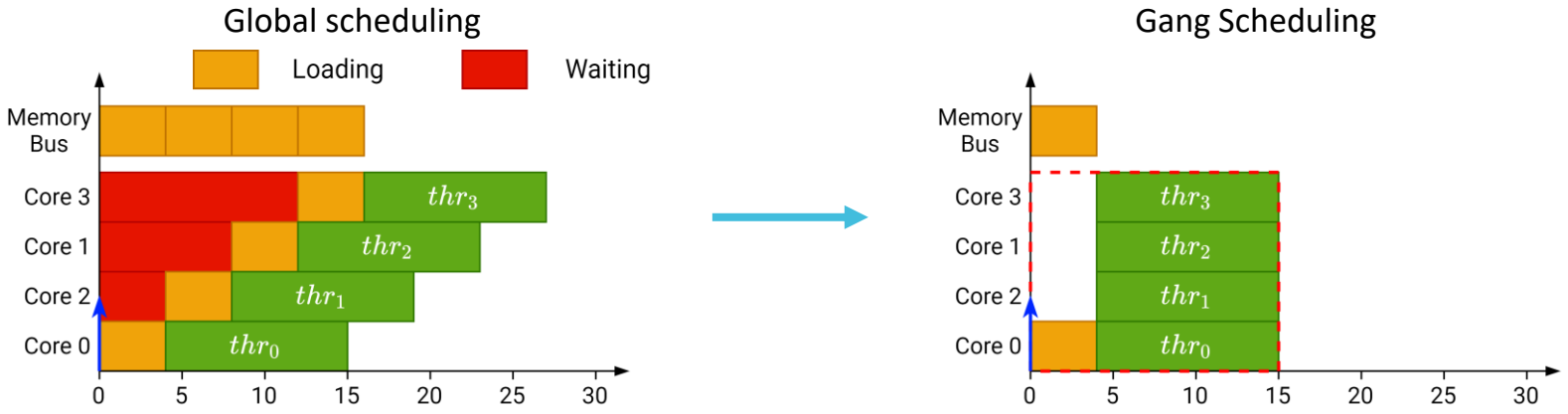
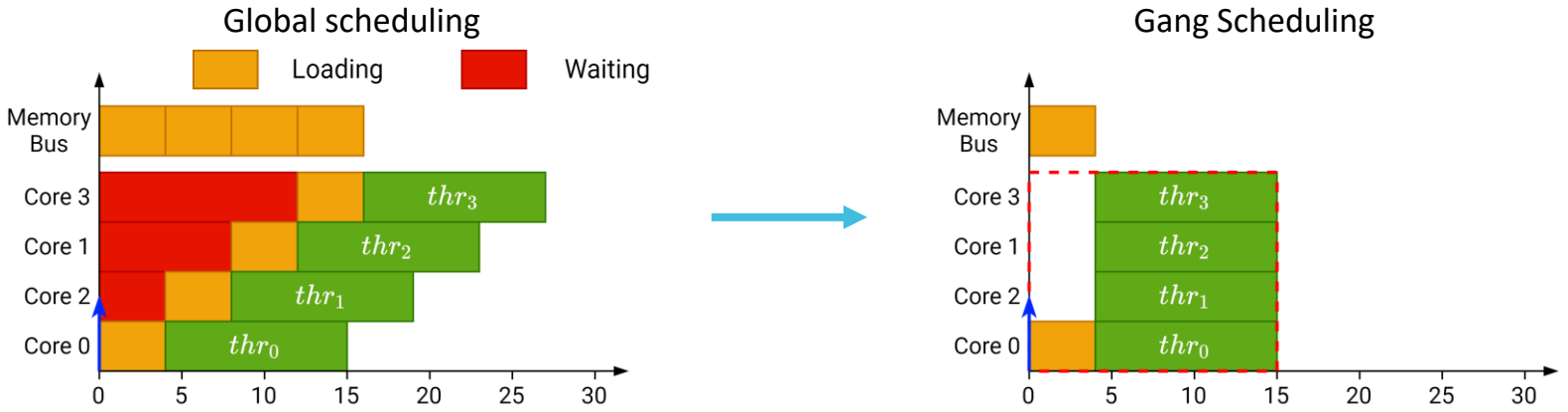


Why gang?

- More efficient synchronization
- Reduces variability in the execution
- Avoids overhead when loading initial data
- Shows its full potential when executed non-preemptively



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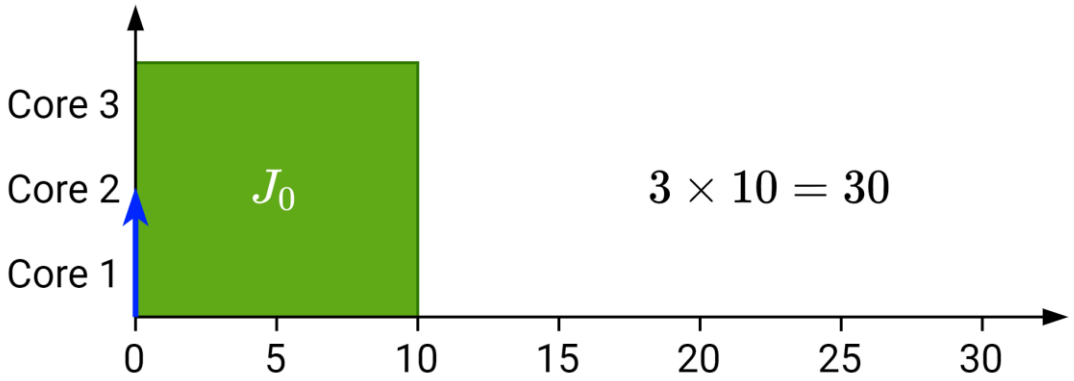

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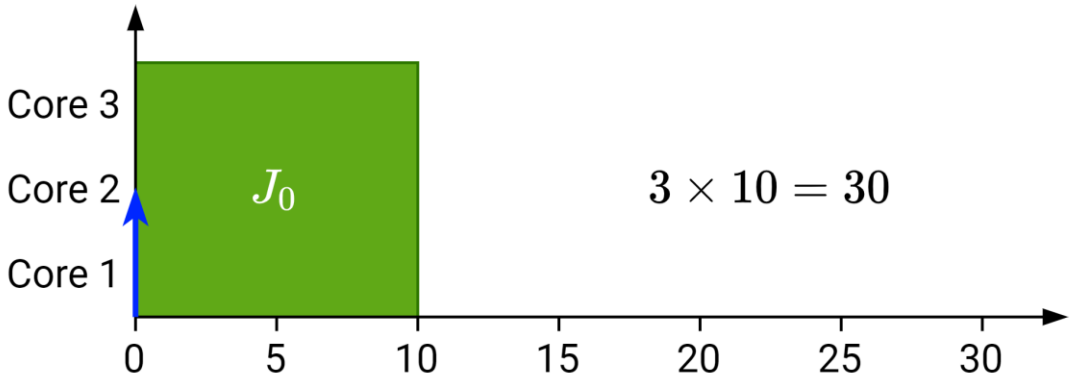

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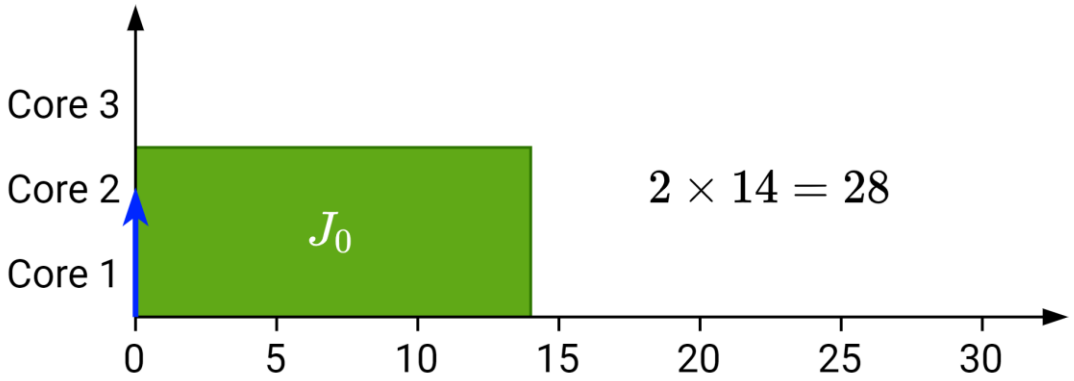

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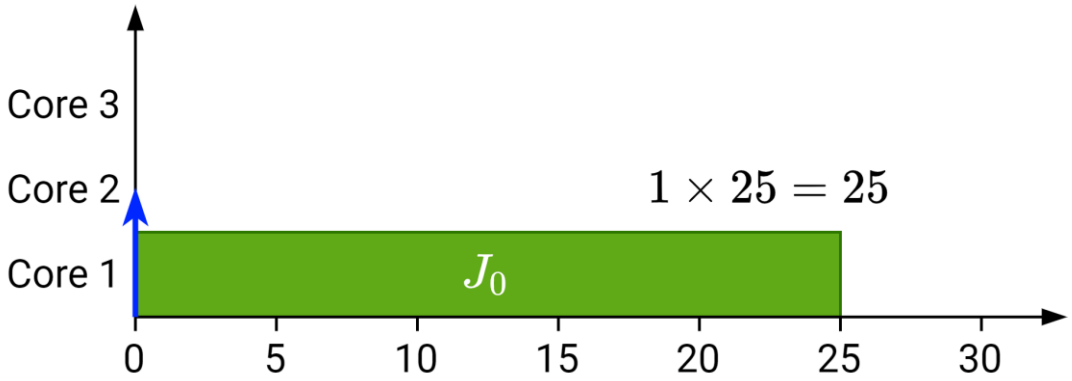

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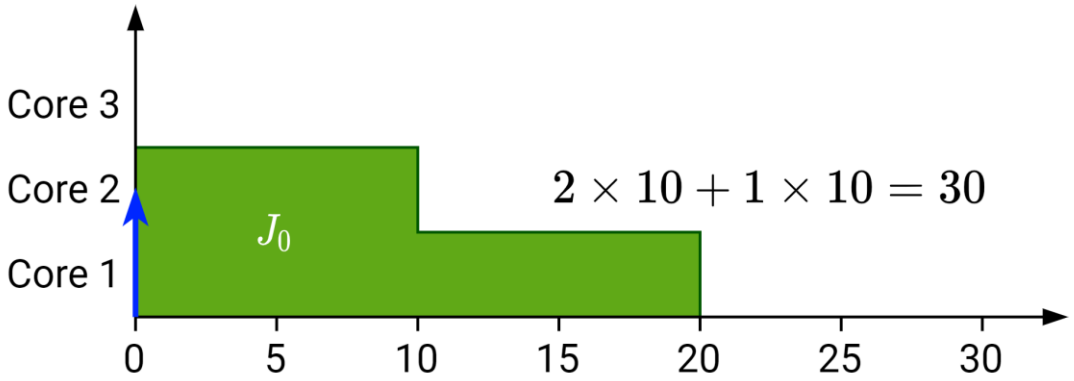

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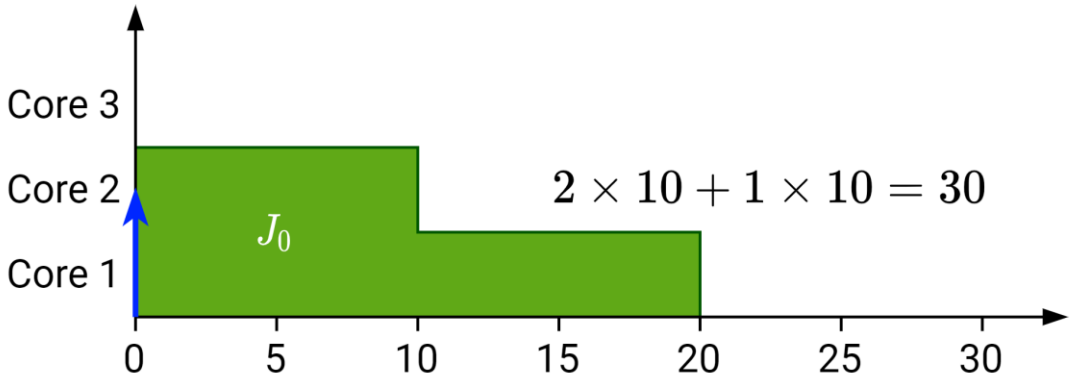

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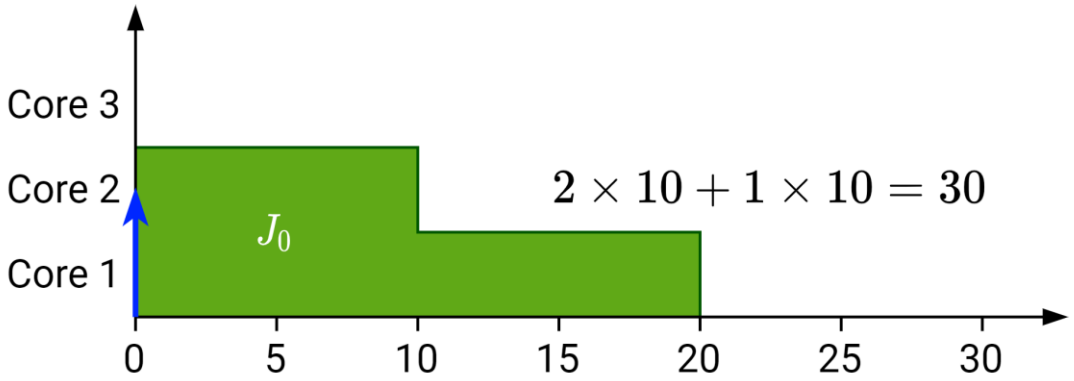

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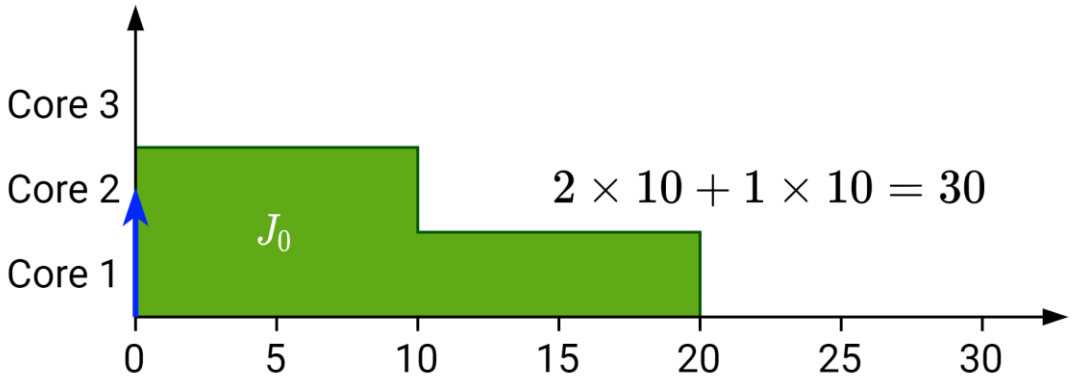

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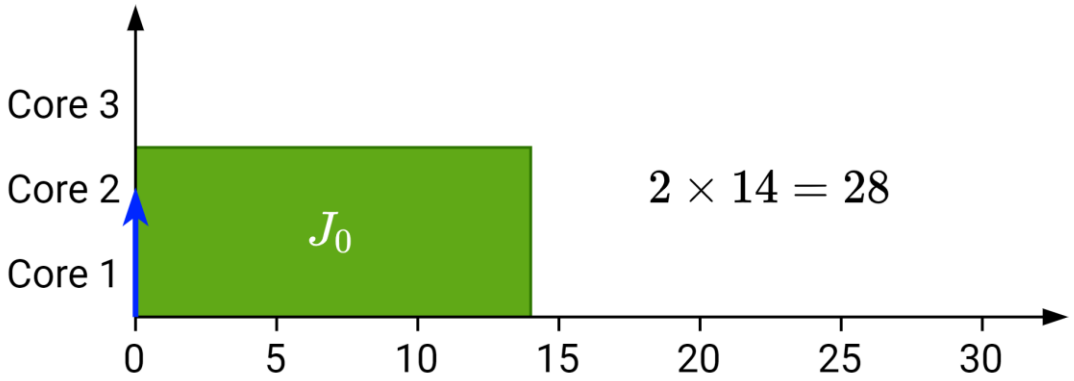
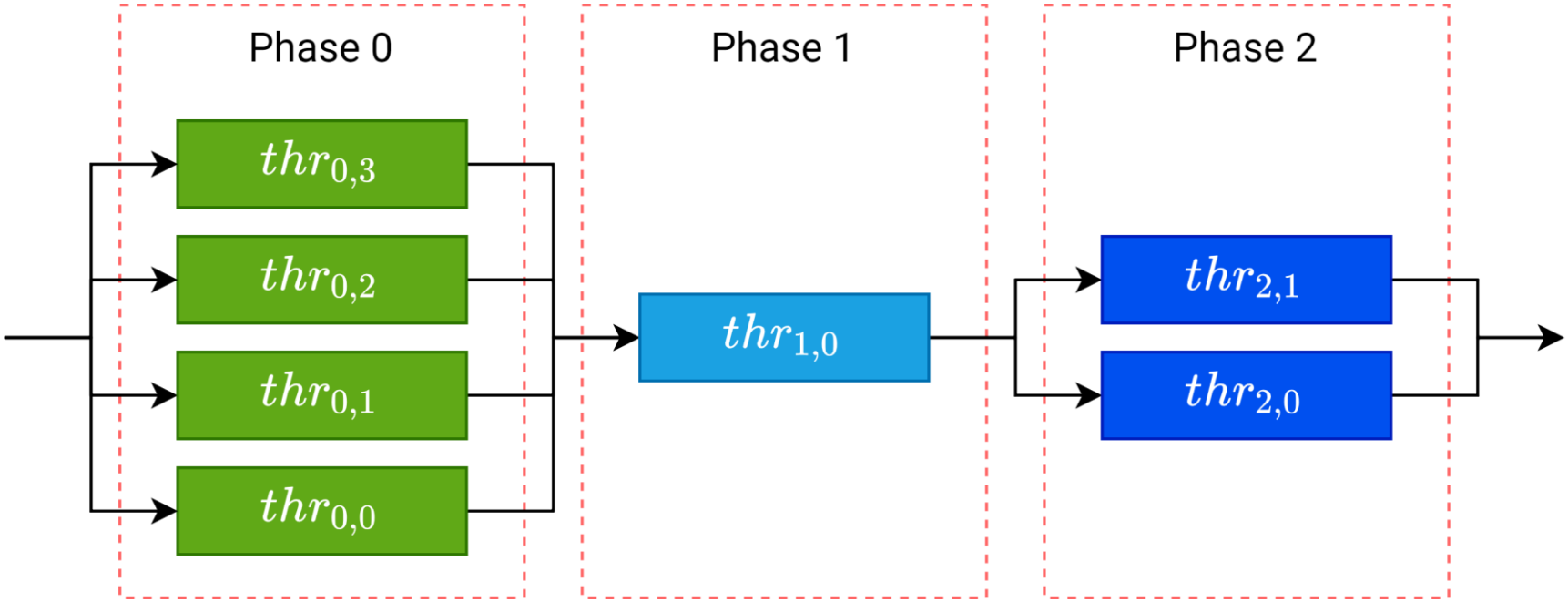


Bundled scheduling[1] vs limited-preemptive



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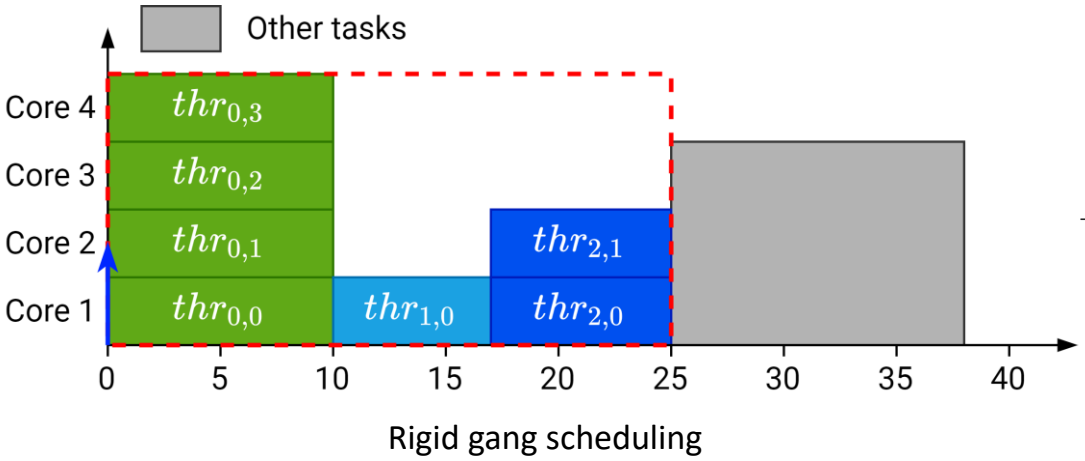

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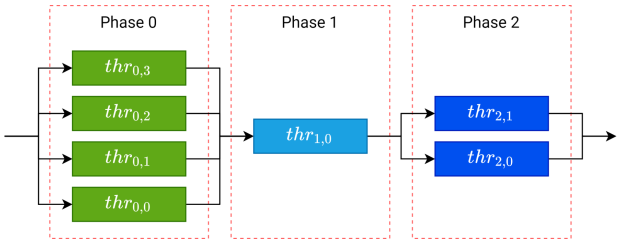

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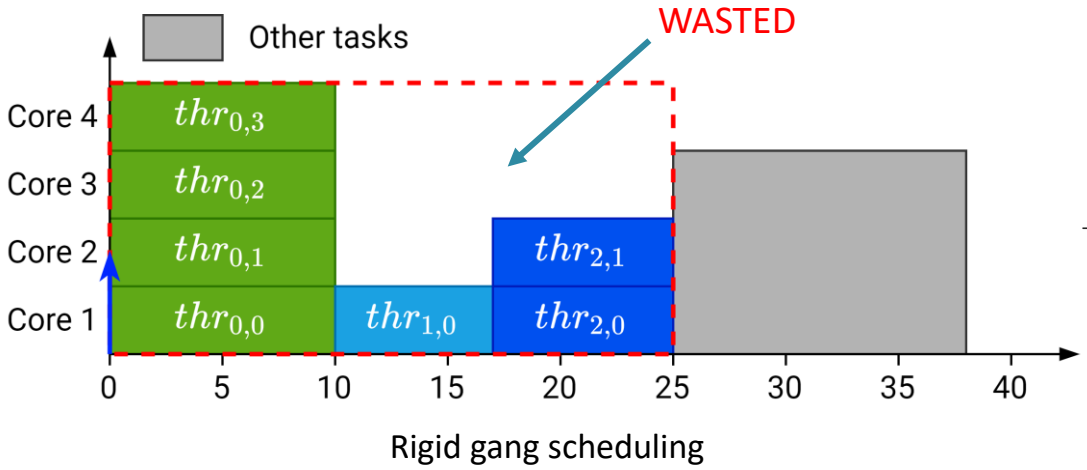

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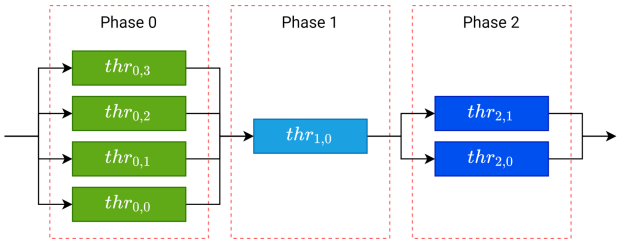

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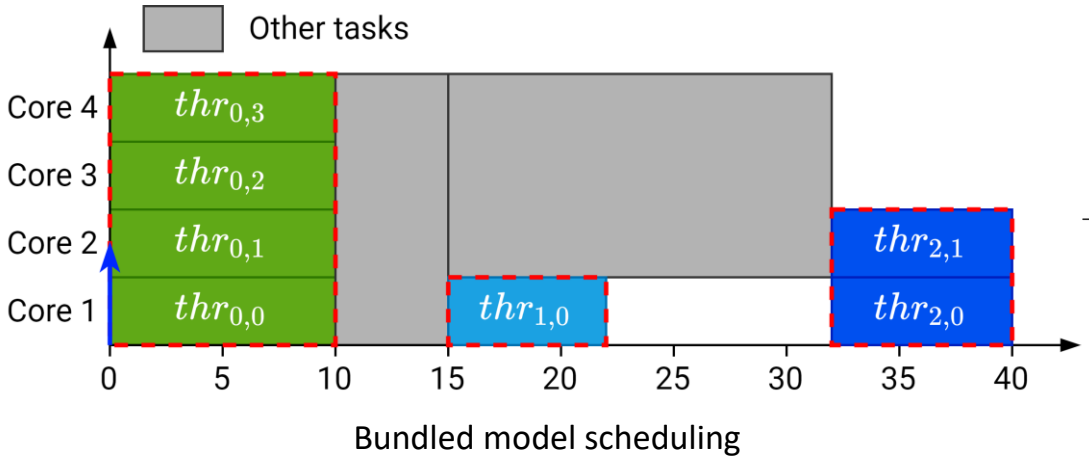
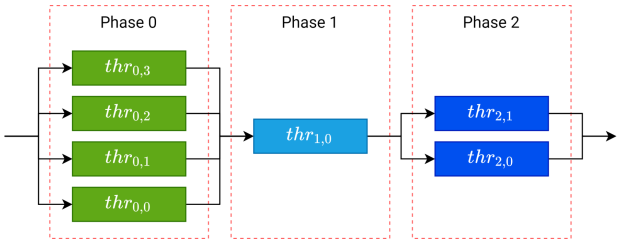


Bundled model scheduling



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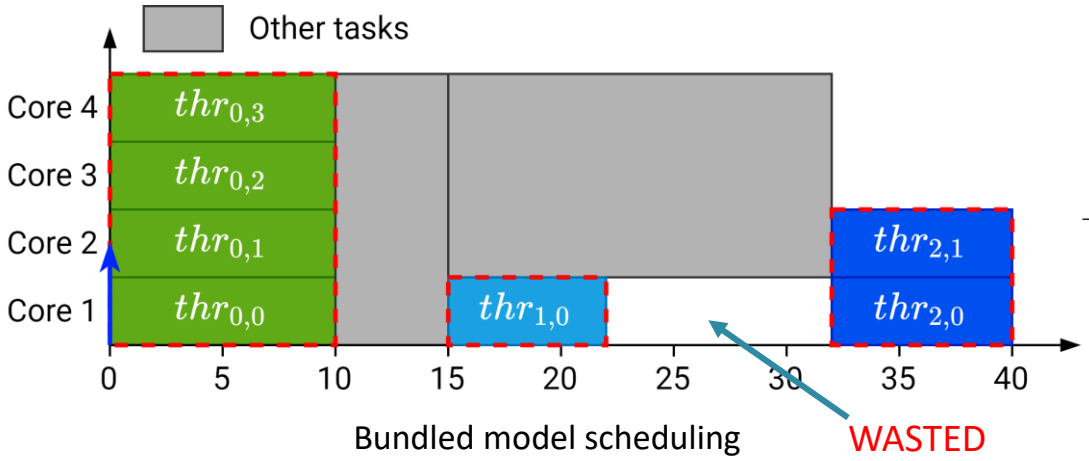

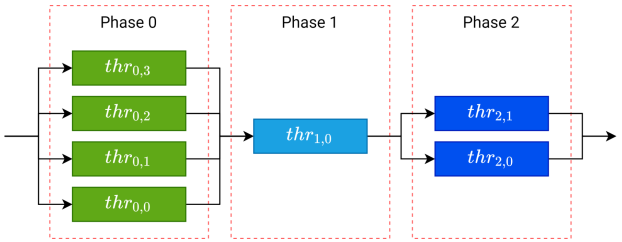

Bundled scheduling[1] vs limited-preemptive

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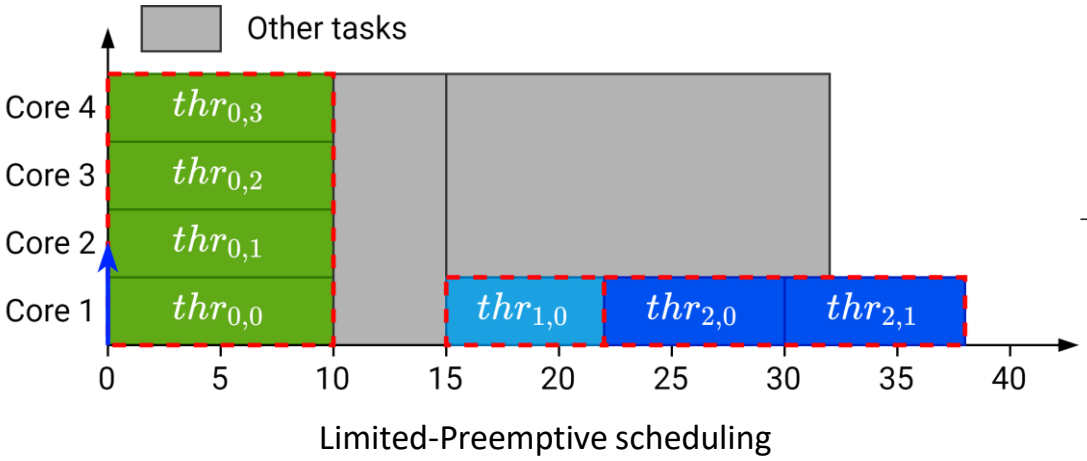
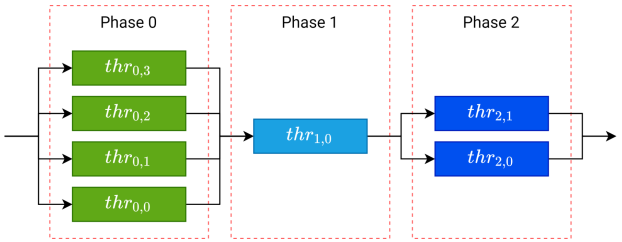
- Bundled creates rigid blocks with dependencies
- Limited-Preemptive creates moldable blocks with dependencies



Limited-Preemptive scheduling



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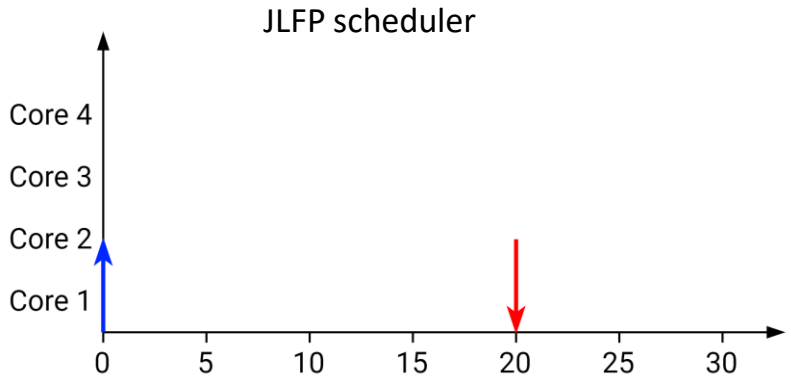

	Priority	Min cores	Max cores	Deadline	Execution time
J_0	High	1	3	20	30, 15, 10
J_1	Low	2	2	20	15

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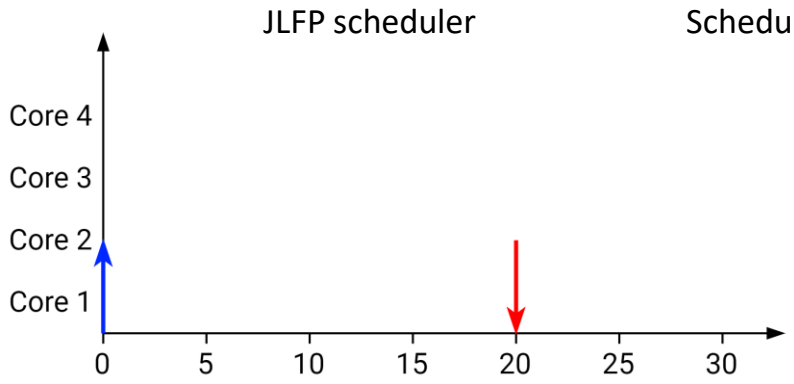
- Based on global JLFP scheduler
- Assigns maximum possible cores to a job

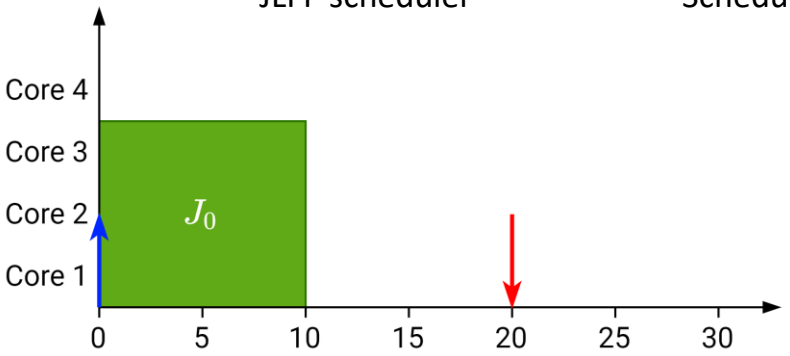


	Priority	Min cores	Max cores	Deadline	Execution time
J_0	High	1	3	20	30, 15, 10
J_1	Low	2	2	20	15

Job-level fixed-priority scheduling (JLFP) for gang

- Based on global JLFP scheduler
- Assigns maximum possible cores to a job

JLFP scheduler



Scheduling: J_0

	Priority	Min cores	Max cores	Deadline	Execution time
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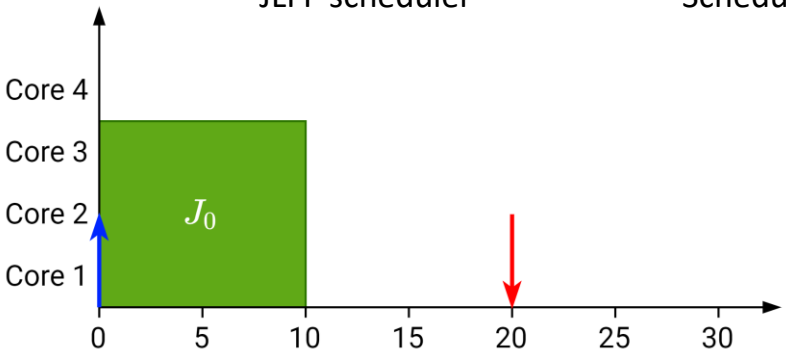

Scheduling: J_1

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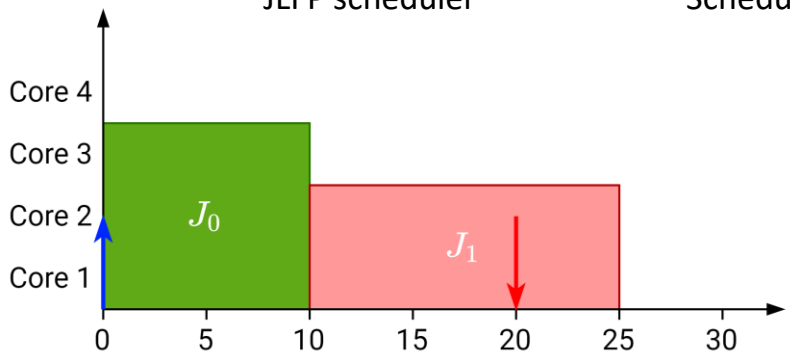

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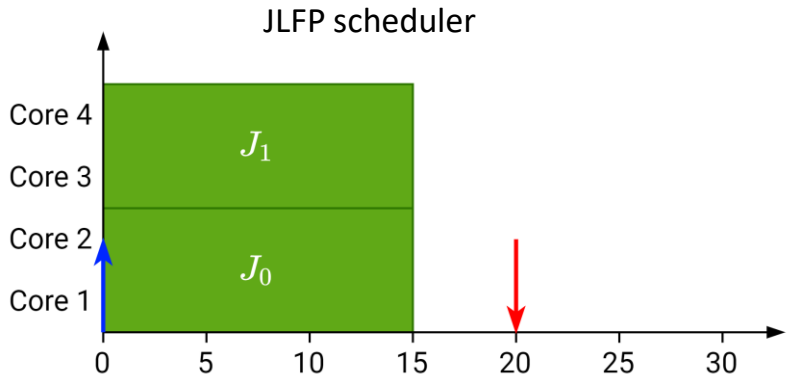

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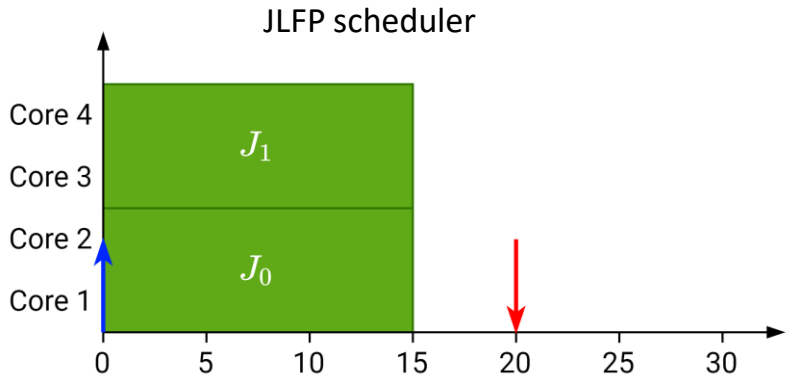
Job-level fixed-priority scheduling (JLFP) for gang

- Based on global JLFP scheduler
- Assigns maximum possible cores to a job
- We will solve this issue



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Previous work

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Introduced in high-performance computing in 1982[1]

[1]Ousterhout, 1982

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Preemptive solutions

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Schedulability tests

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- Job-level fixed-priority[2]

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- Job-level fixed-priority[2]
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Non-preemptive solutions

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Non-preemptive solutions

Schedulability tests

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Non-preemptive solutions

Schedulability tests

- Earliest deadline first for rigid gang[6]

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[3]Kato et al., 2009
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[6]Dong et al. 2019

Our work

Project goals

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1. Design an accurate schedulability analysis for limited-preemptive moldable gang tasks

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2. Evaluate the impact of the level of parallelism assigned to a job

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1. Design an accurate schedulability analysis for limited-preemptive moldable gang tasks

2. Evaluate the impact of the level of parallelism assigned to a job

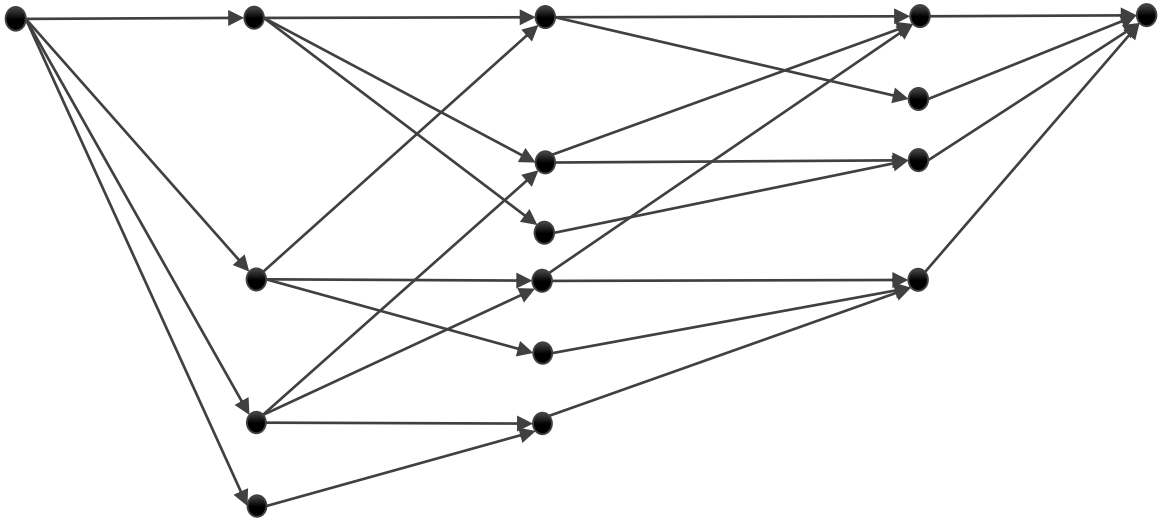
3. Propose a new scheduling algorithm to improve the schedulability of limited-preemptive moldable gang tasks

Agenda

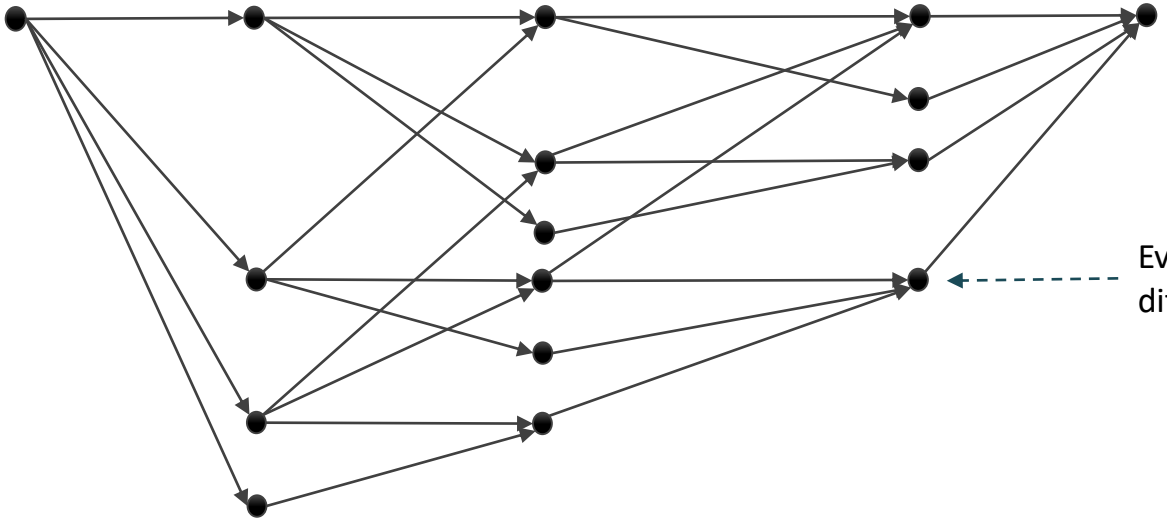
- Gang schedulability analysis
- New scheduling policy

Schedule abstraction graph

Schedule abstraction graph



Schedule abstraction graph



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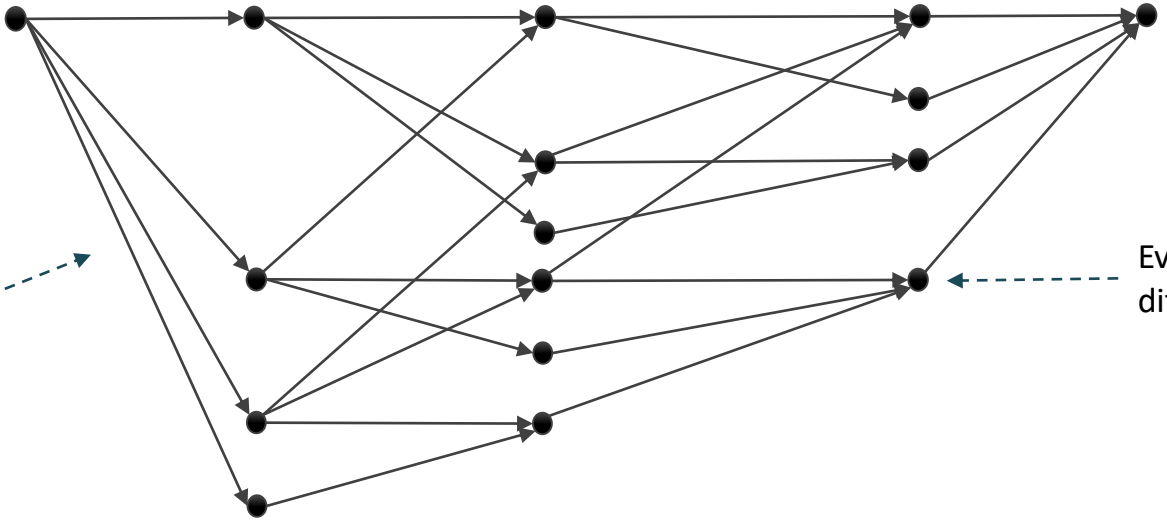
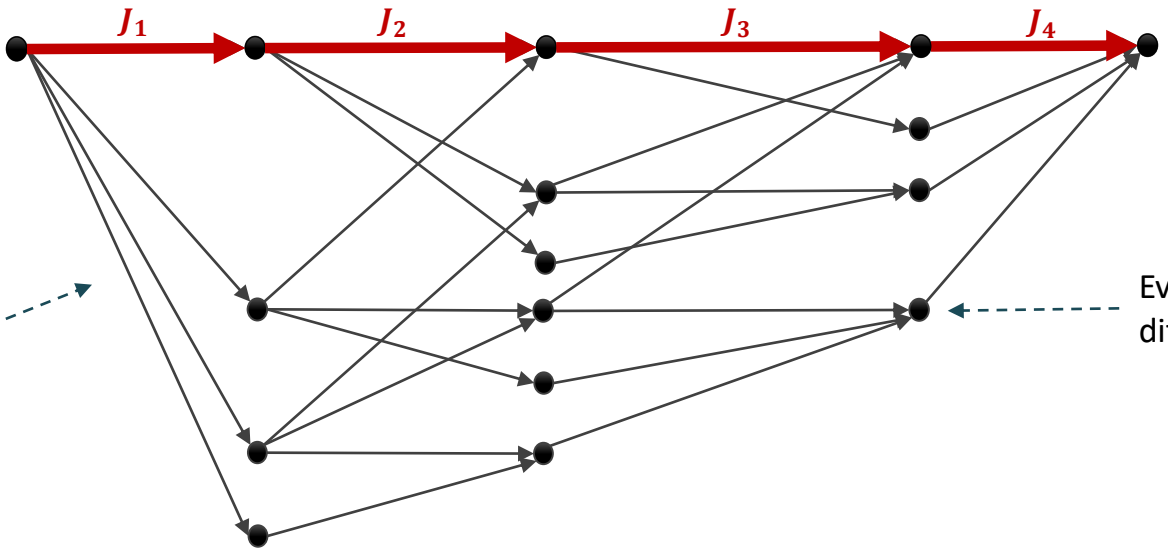


Every edge is a different scheduler decision

Every node is a different system state

Schedule abstraction graph



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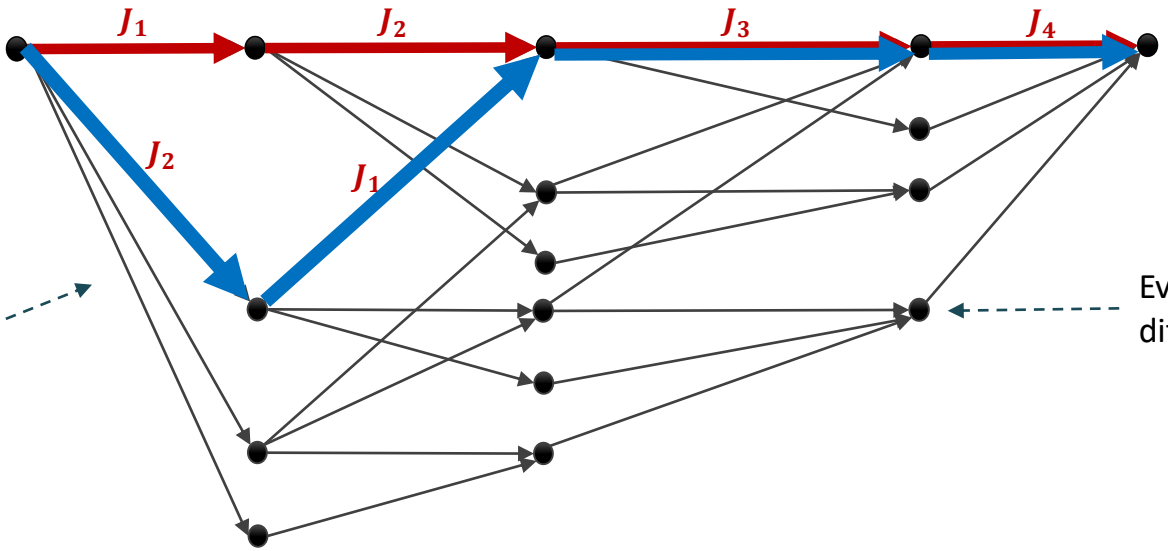

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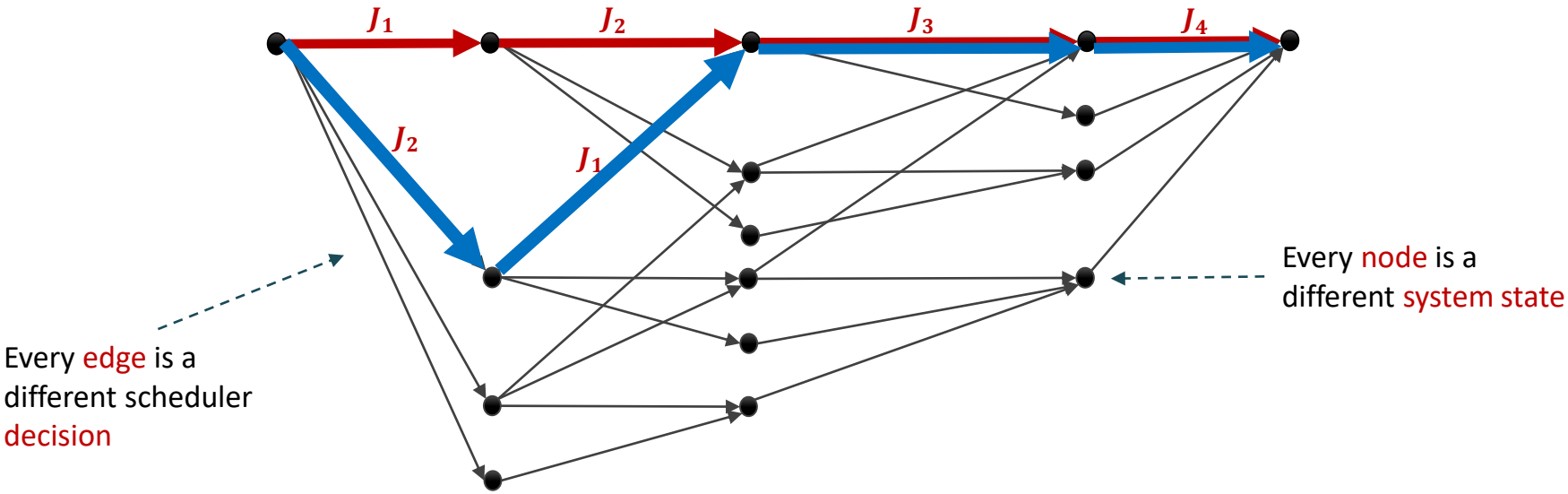
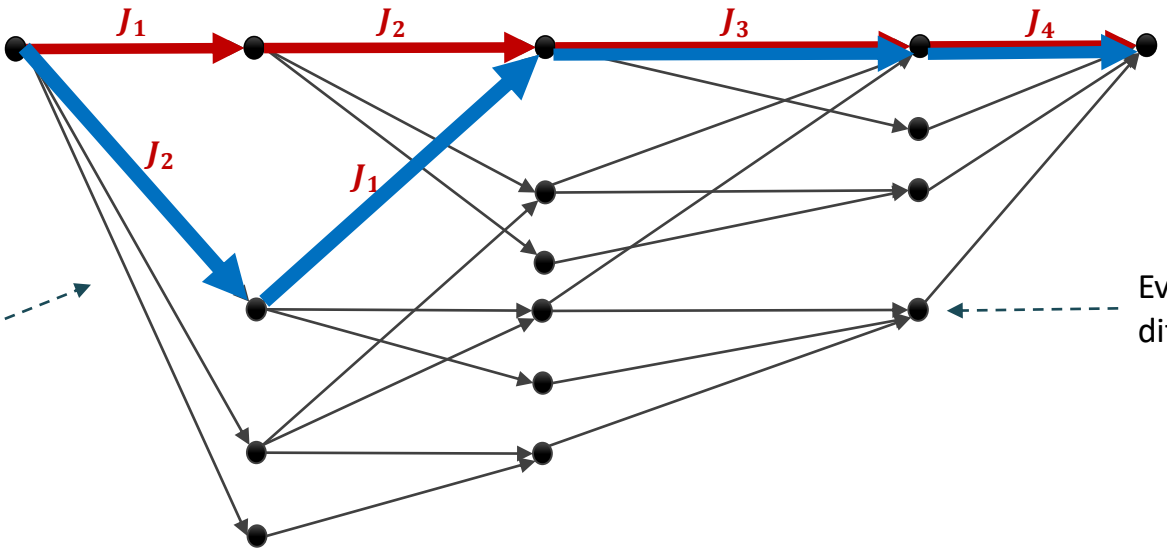
Schedule abstraction graph

- It is a technique that allows:



Schedule abstraction graph

- It is a technique that allows:
  - Search for all possible schedules



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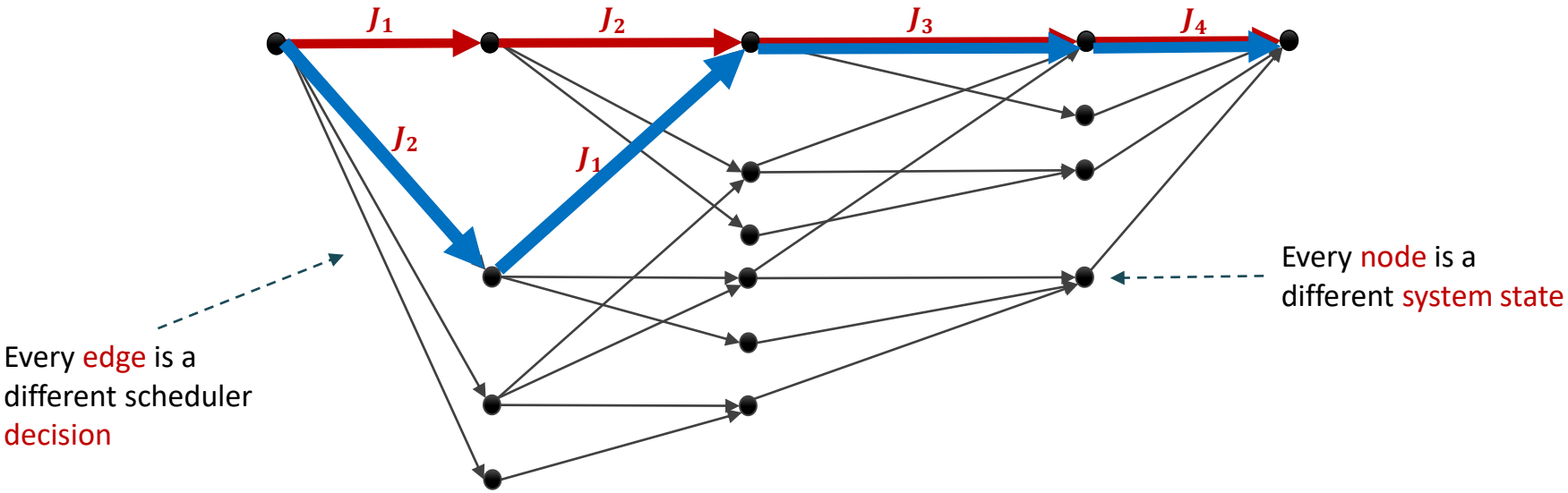
  - Aggregate “similar” schedules



Schedule abstraction graph

- It is a technique that allows:
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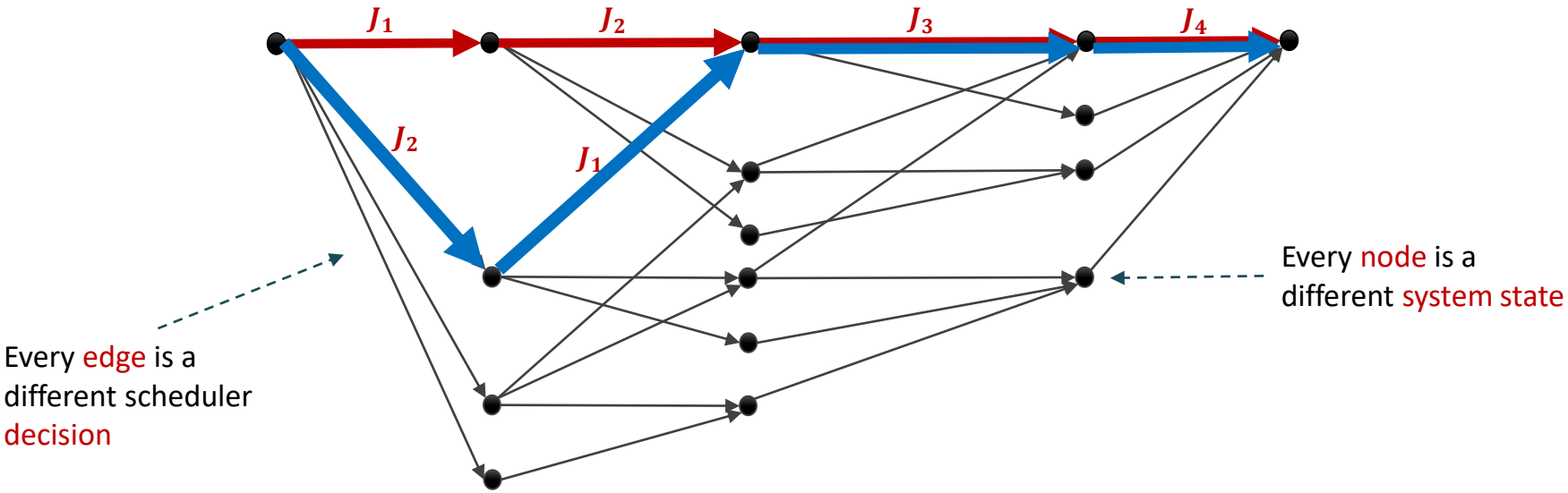
  - Aggregate “similar” schedules
  - Model timing uncertainties



Using SAG for gang scheduling

Using SAG for gang scheduling

- Introduce new system state representation

Using SAG for gang scheduling

- Introduce new system state representation
- Introduce new expansion rules

Using SAG for gang scheduling

- Introduce new system state representation
- Introduce new expansion rules
- Introduce new merge rules

New system state representation

New system state representation

- Availabilities of cores

New system state representation

- Availabilities of cores → Know how many cores we have at time *t*

New system state representation

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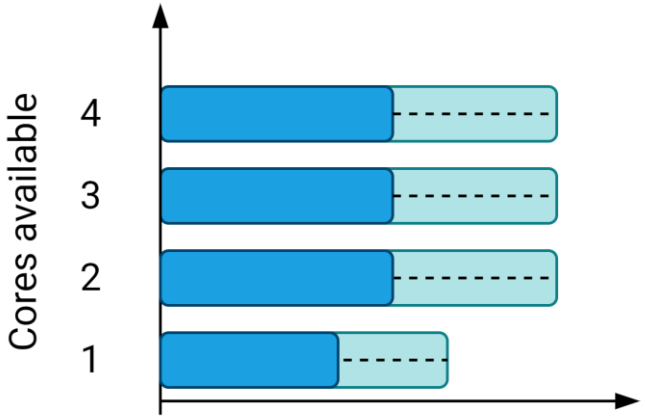
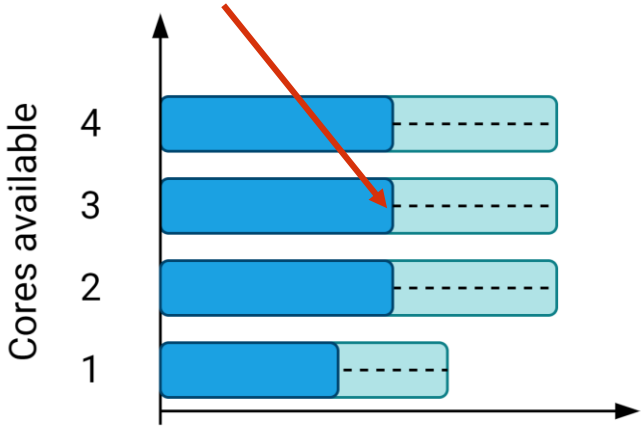


New system state representation

- Availabilities of cores ⟶ Know how many cores we have at time *t*

Time at which 3 cores are **possibly** available



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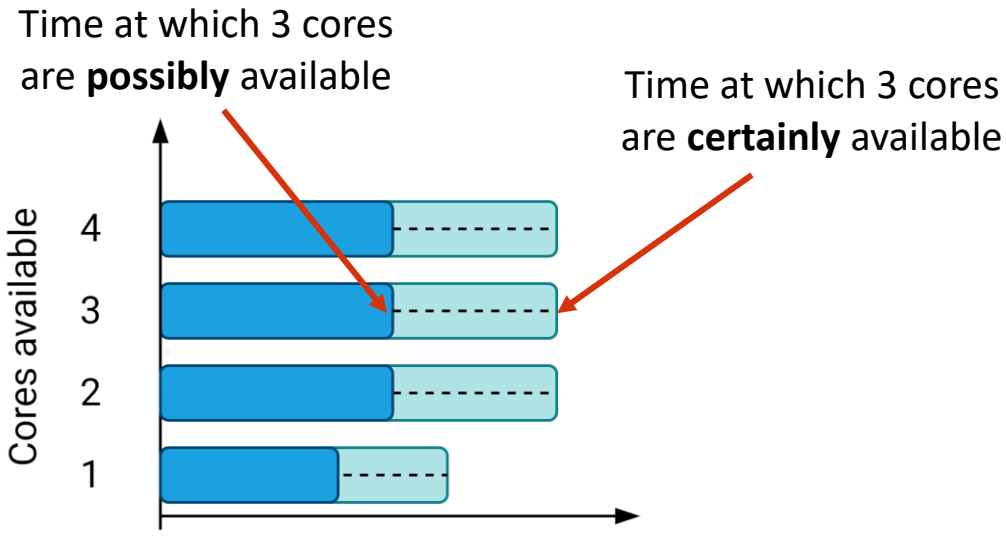
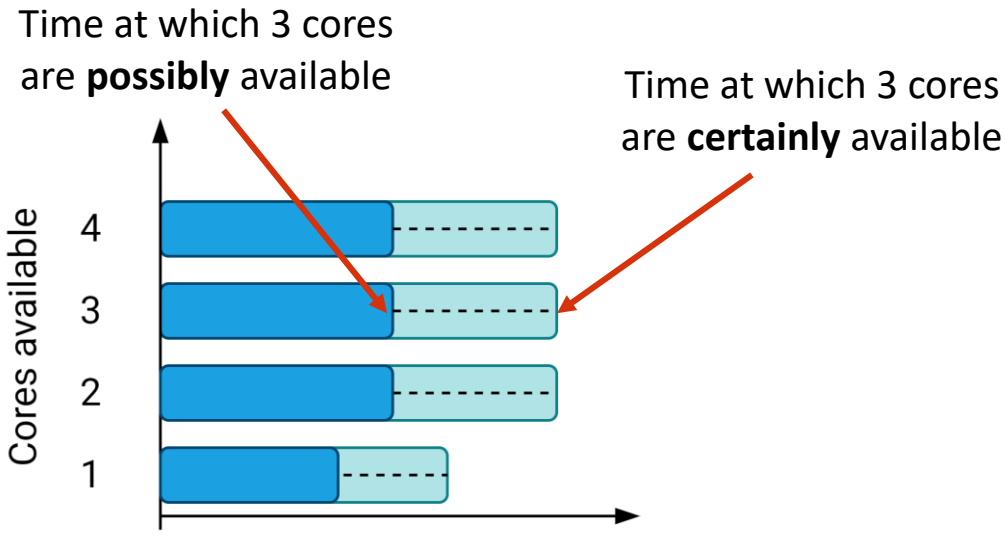


New system state representation

- Availabilities of cores → Know how many cores we have at time t
- Simultaneous groups of cores



New system state representation

- Availabilities of cores → Know how many cores we have at time t
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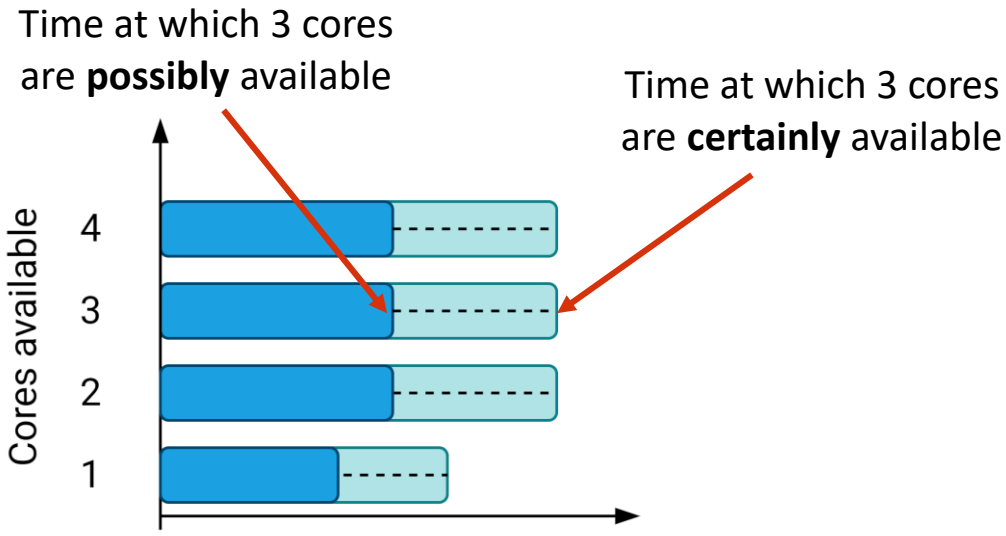

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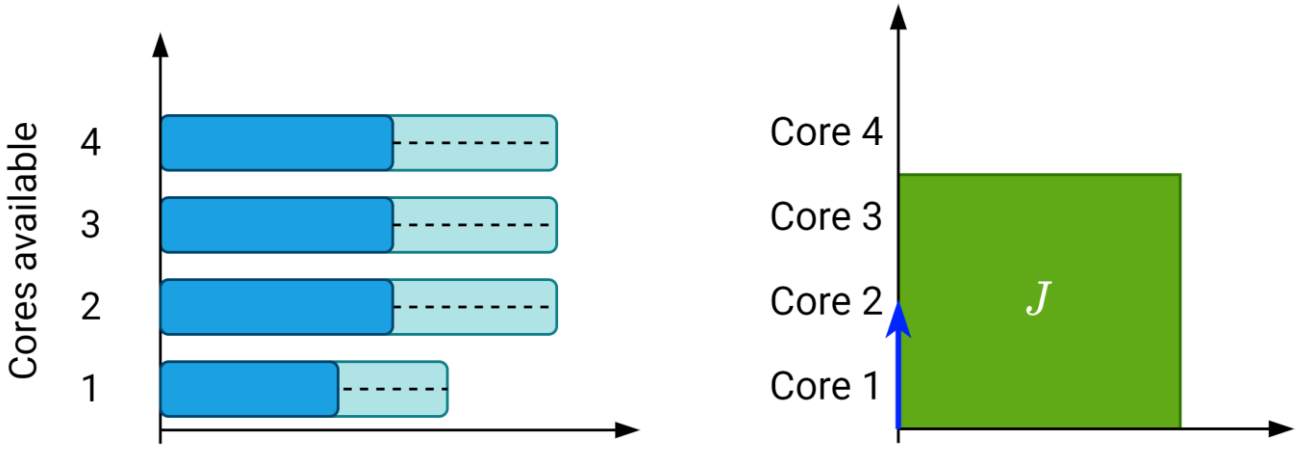

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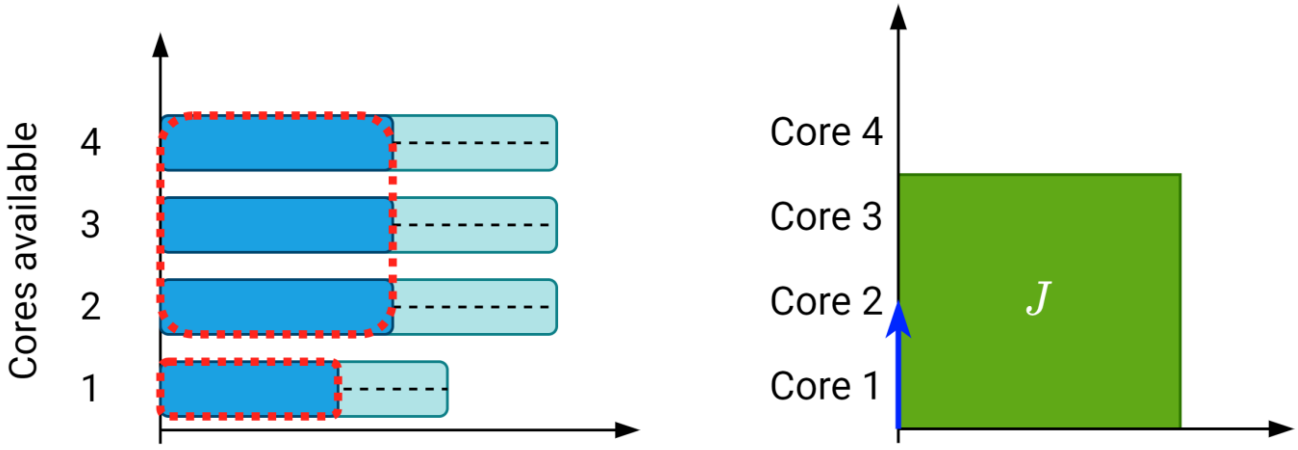

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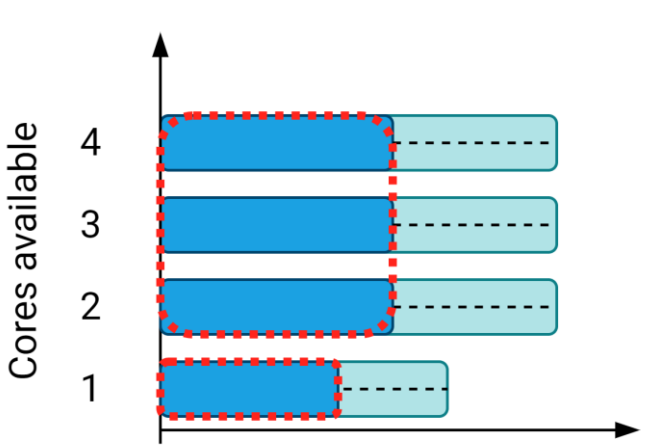

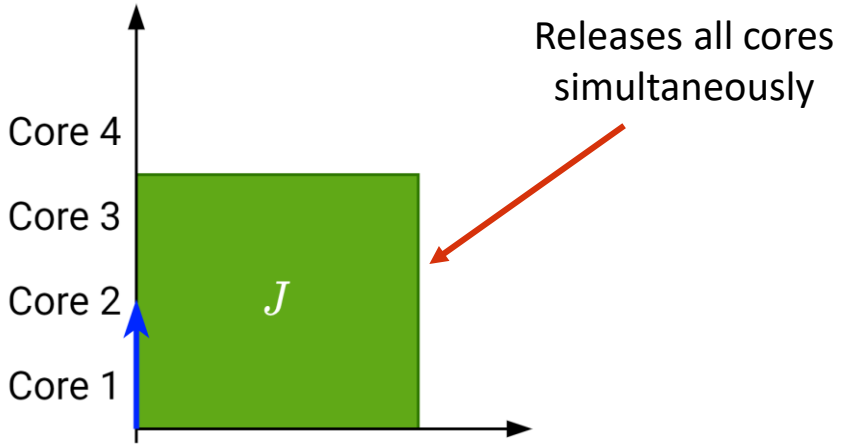

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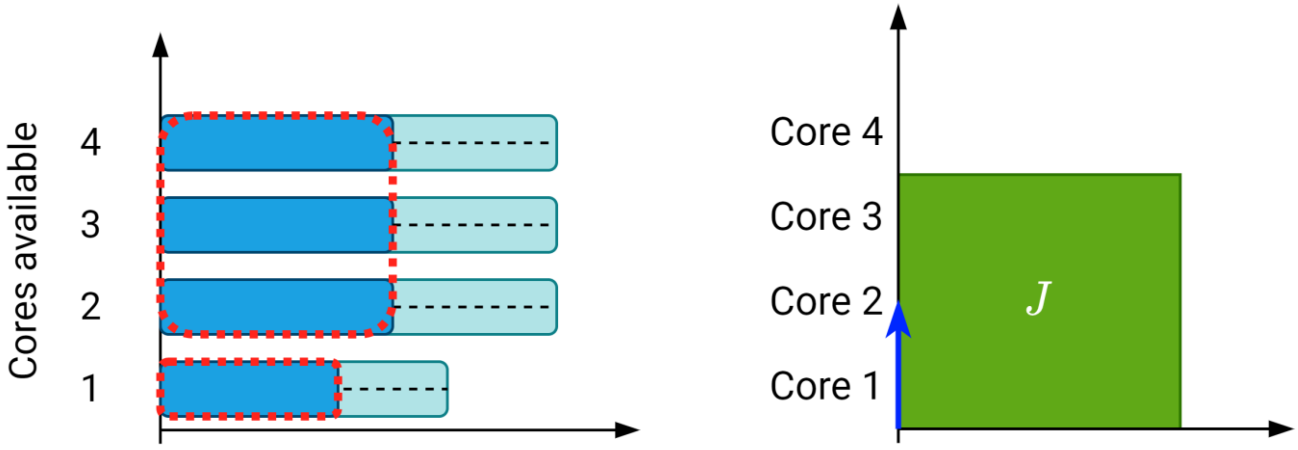

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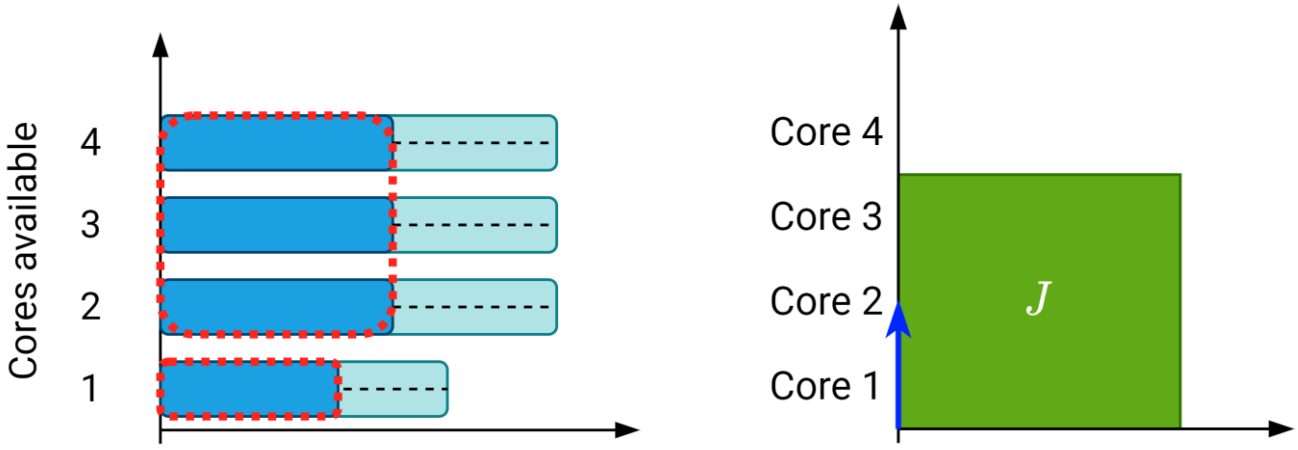

New SAG expansion rules

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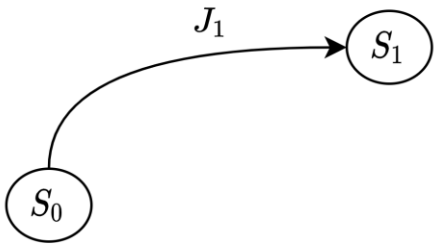

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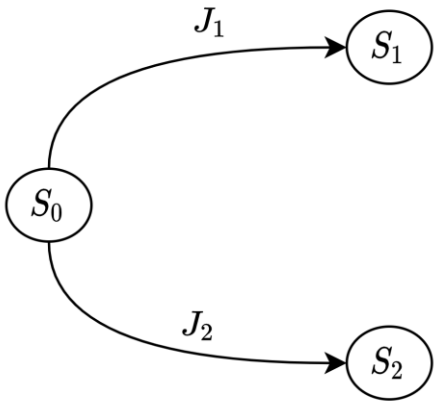
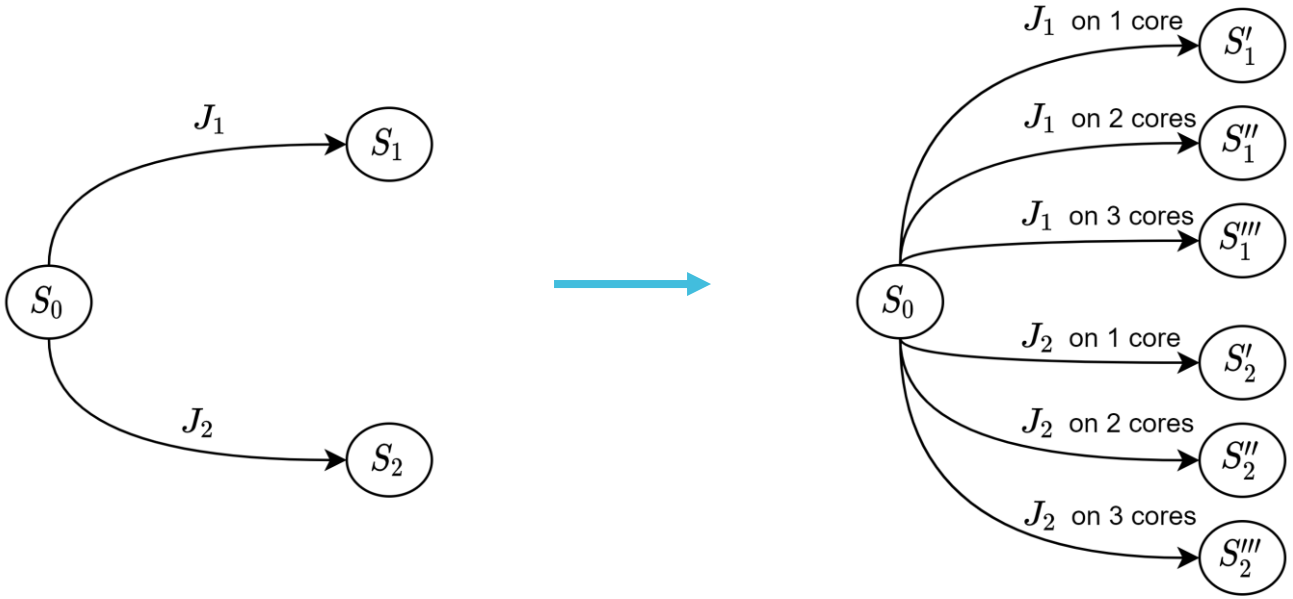


New SAG expansion rules

- Previously a state was created for every dispatchable job
- Now a state is created for every job and possible number of cores



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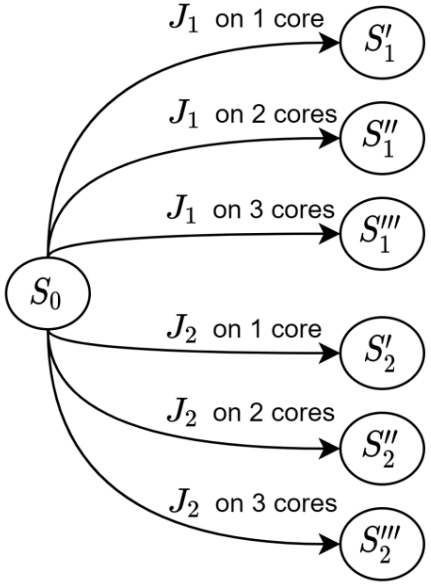

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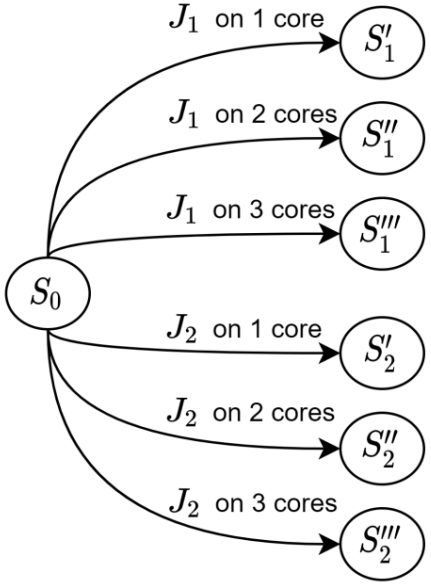
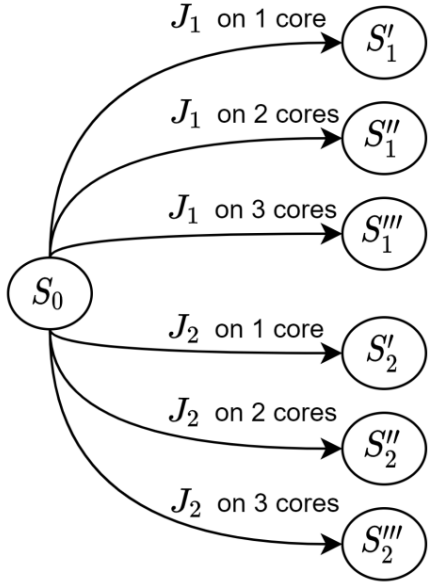
- Exploring more states is



New SAG expansion rules

- Exploring more states is
  - 👍 Sound (does not accept unschedulable task sets)



New SAG expansion rules

- Exploring more states is
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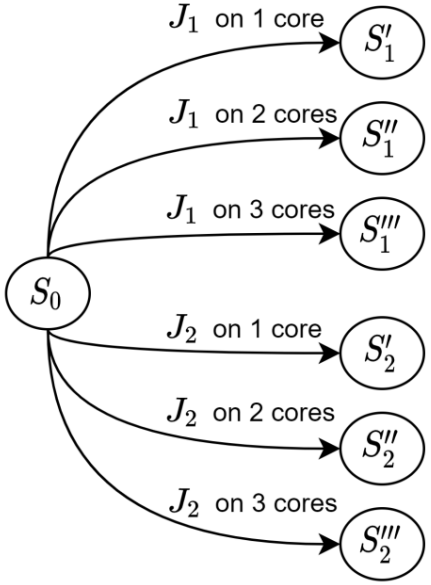
  - 👎 Slower and more pessimistic



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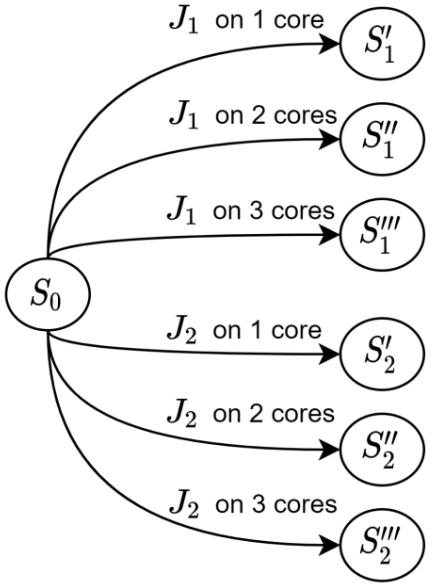
  - Slower and more pessimistic

Try to minimize number of states that represent an impossible scenario



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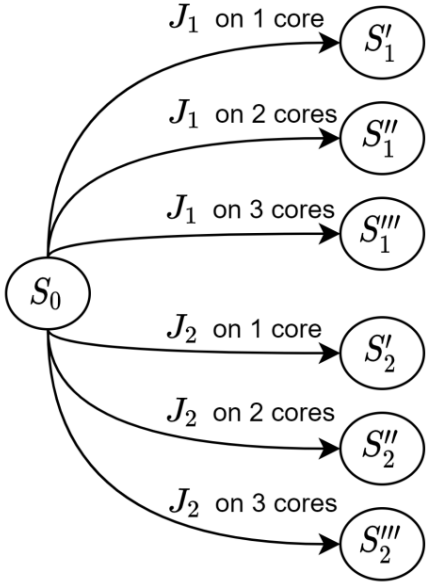

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- Purge states by checking that
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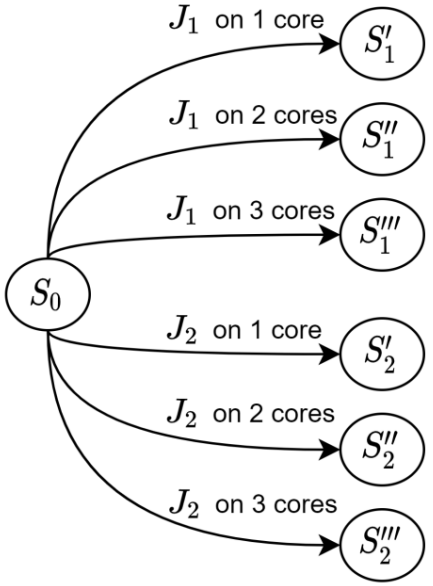

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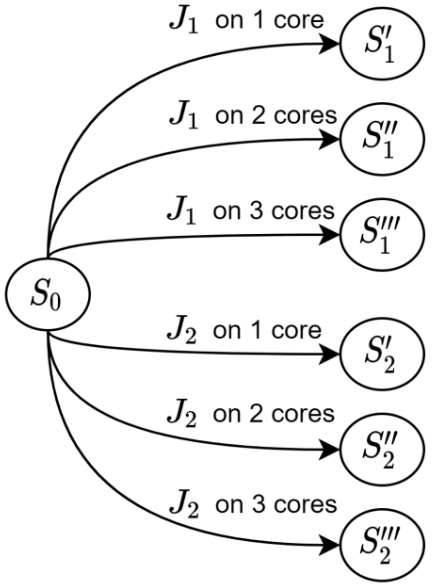

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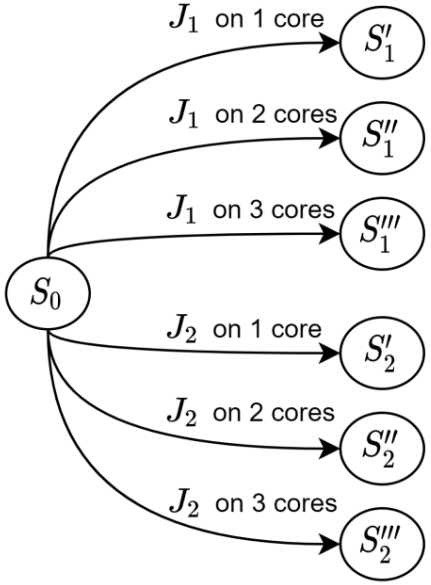

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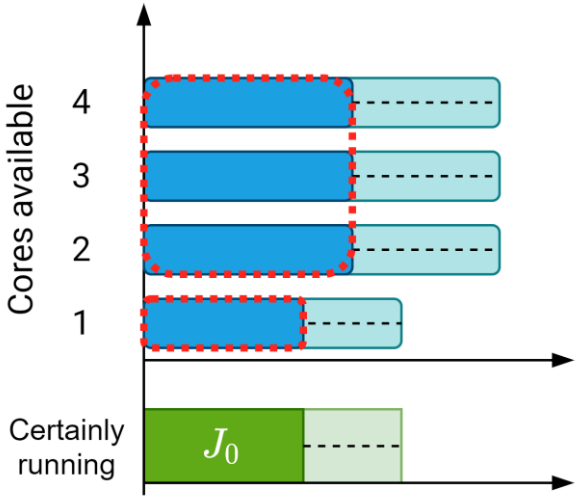

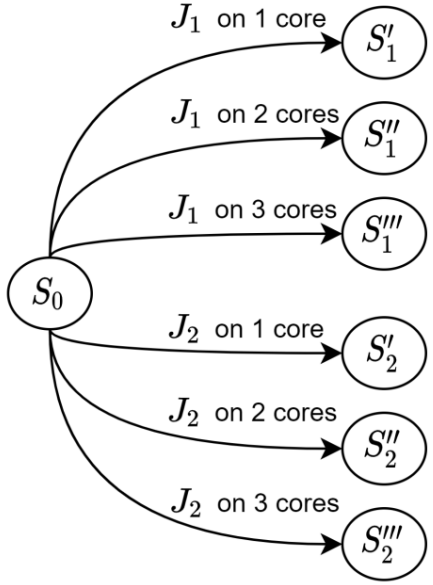

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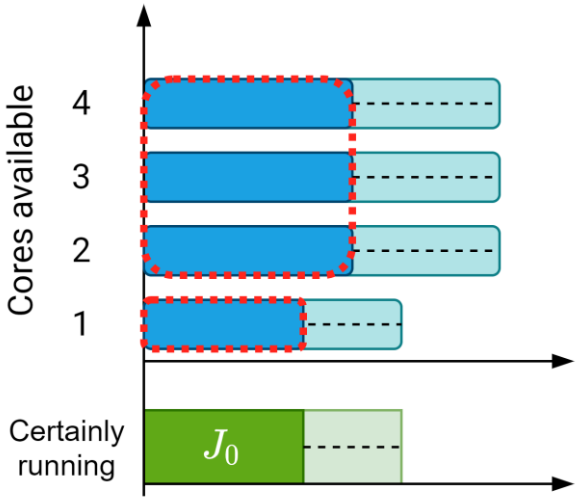

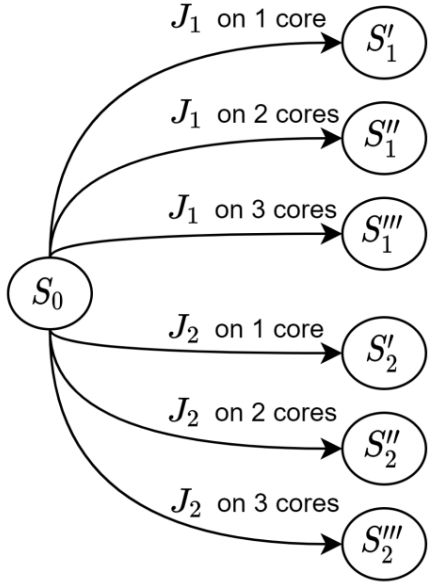

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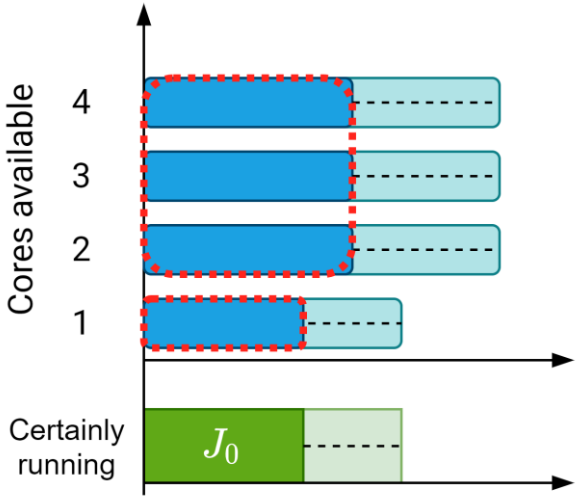

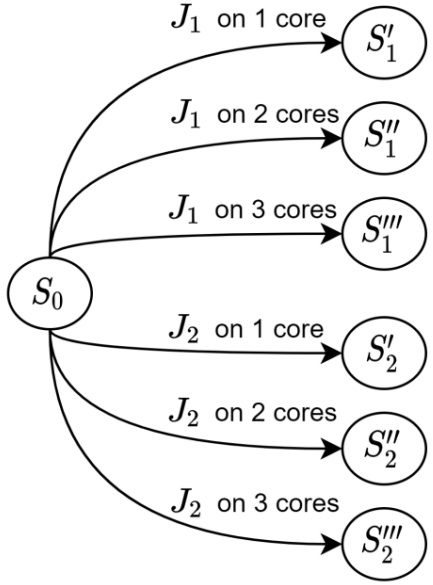

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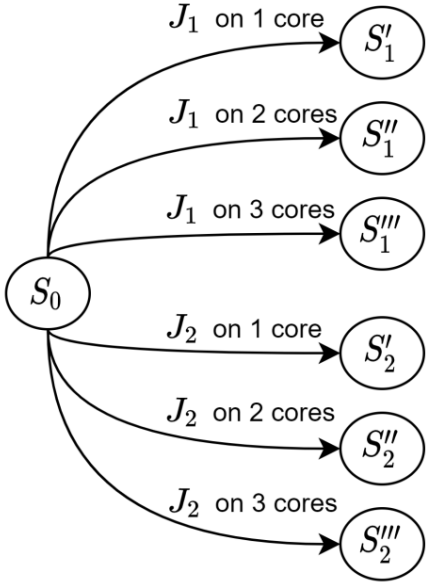

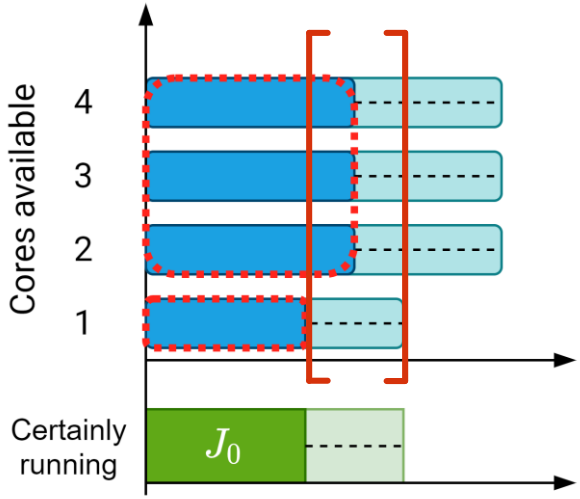

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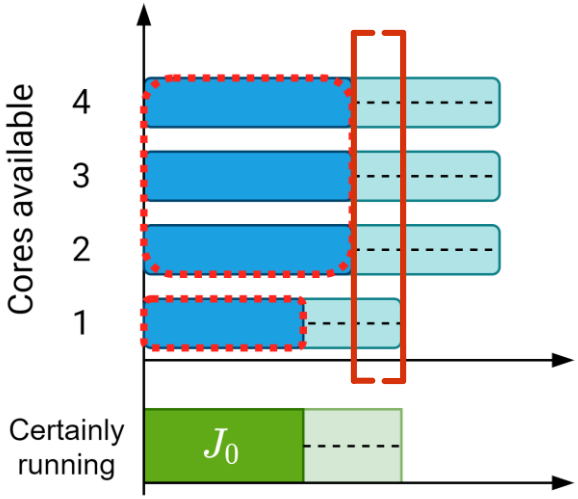

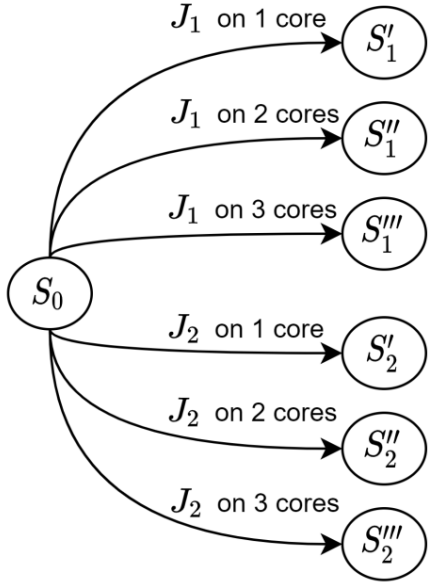

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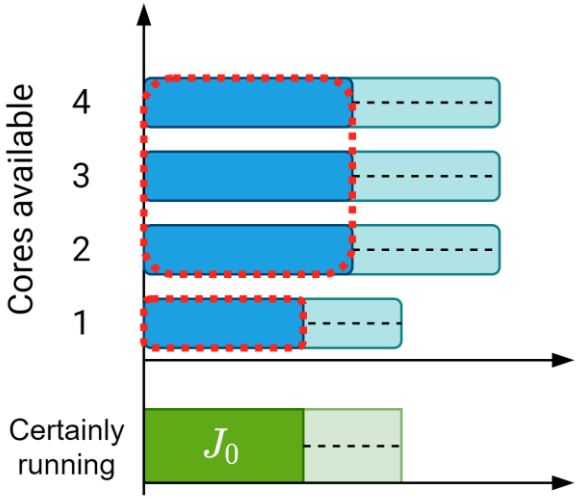

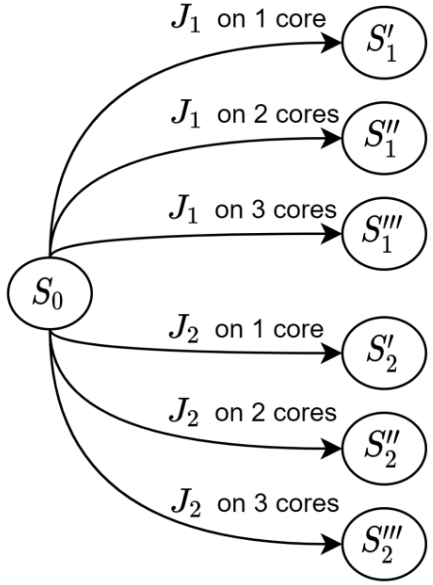

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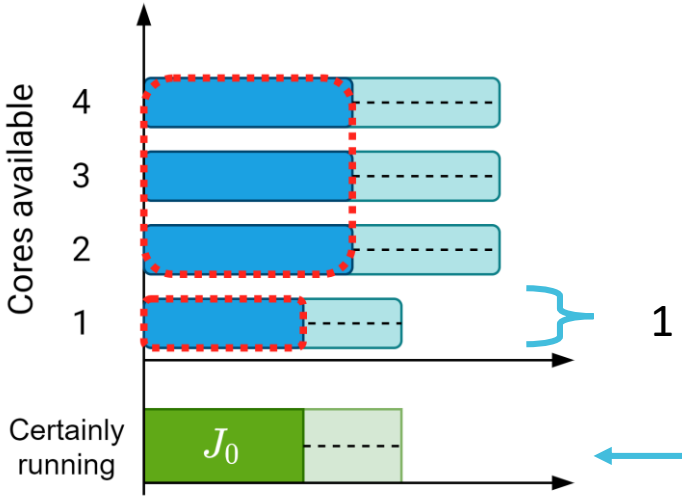

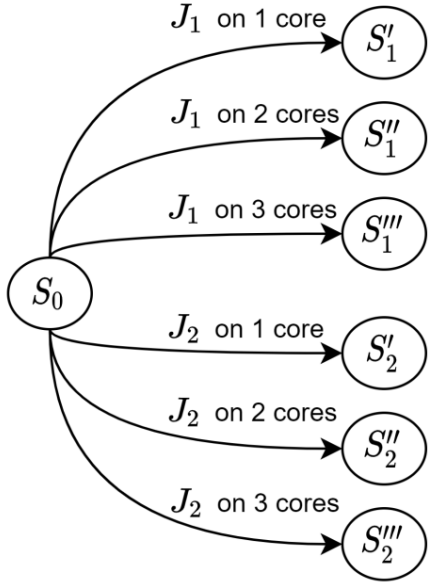

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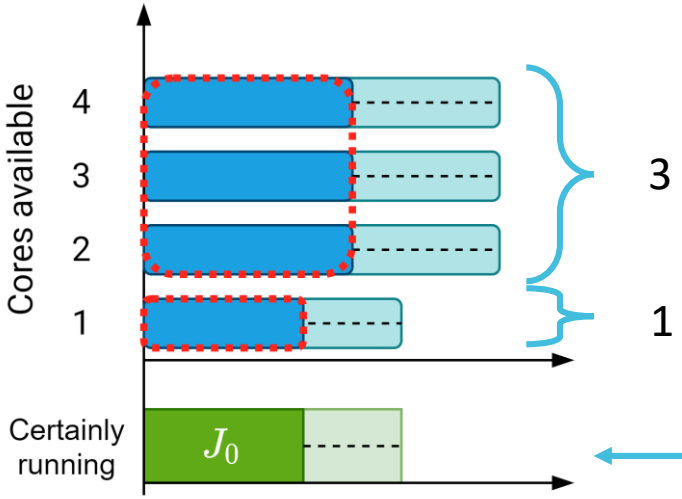

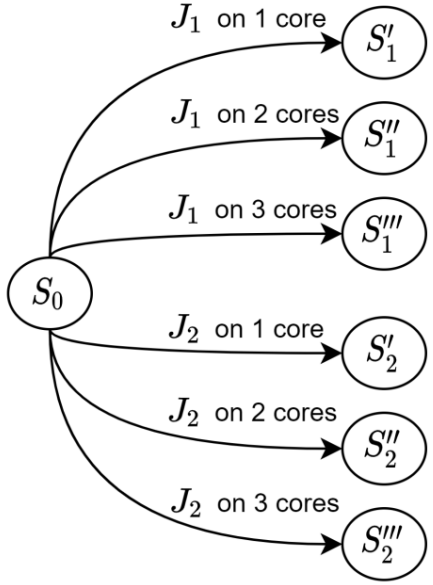

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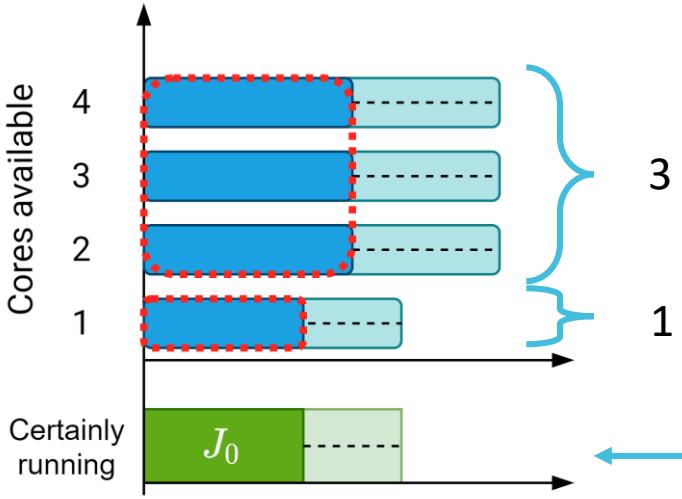

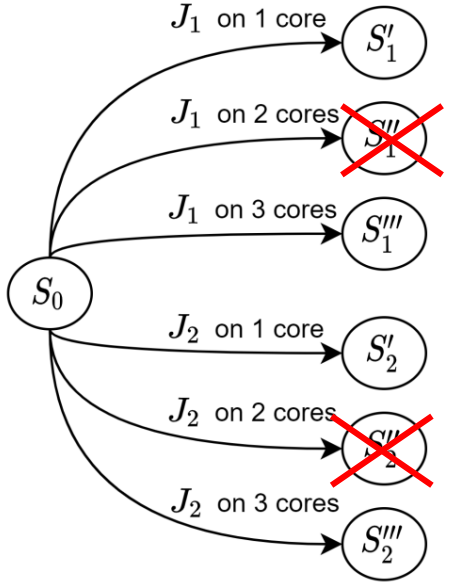

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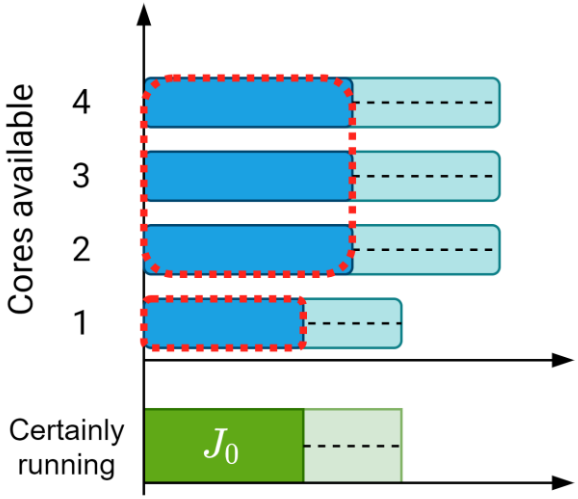

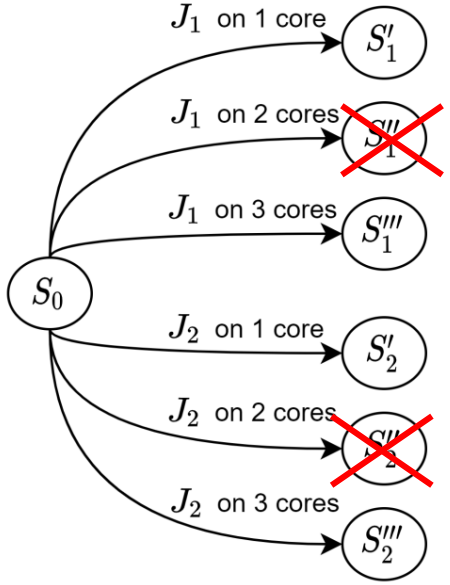

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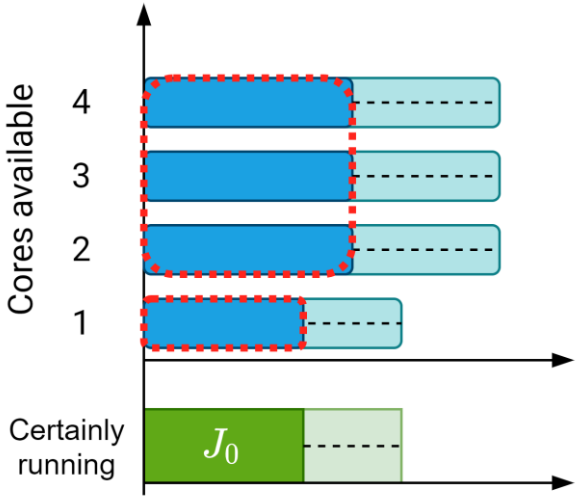

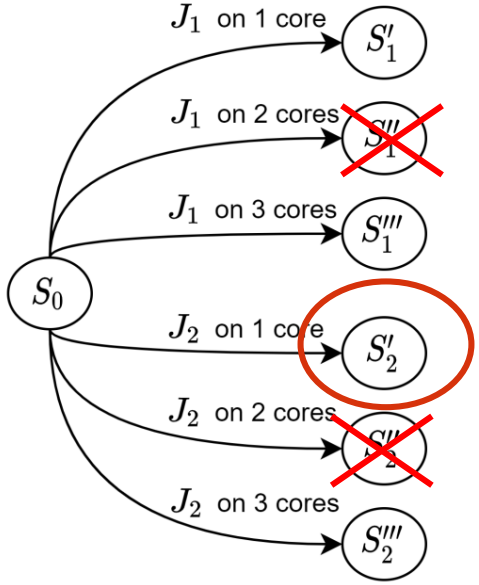

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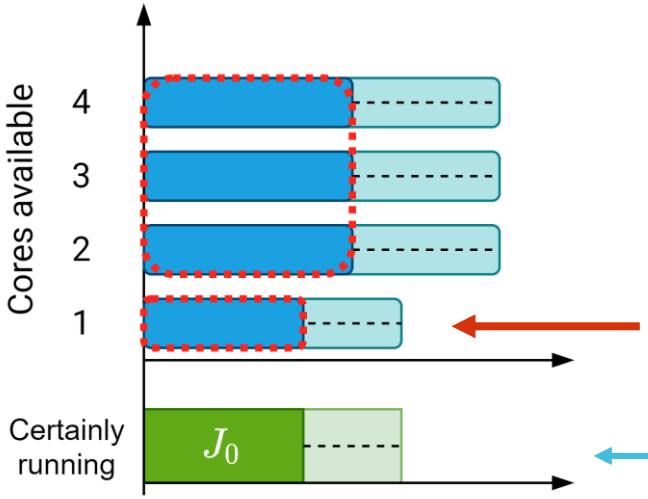

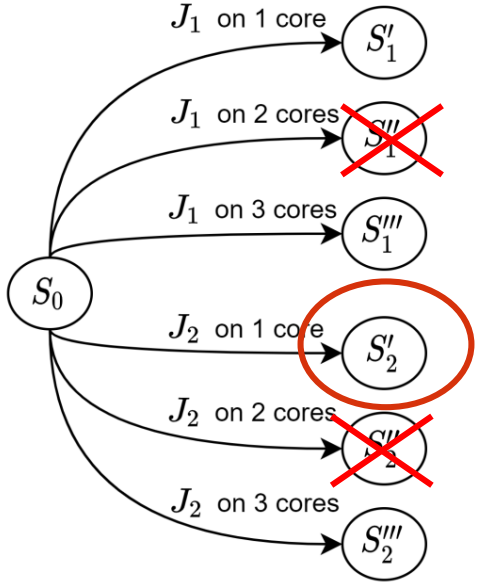

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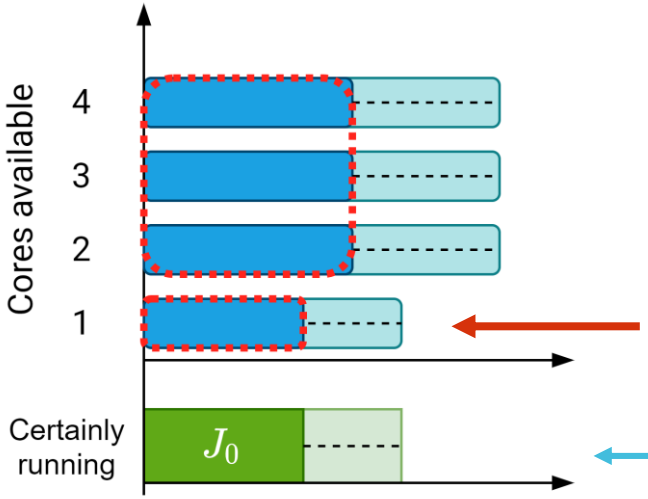

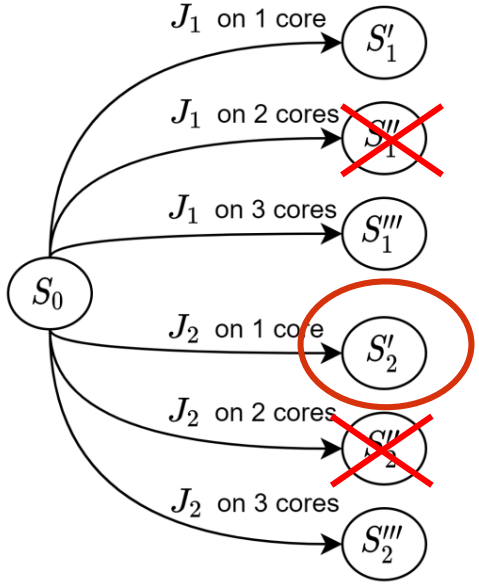

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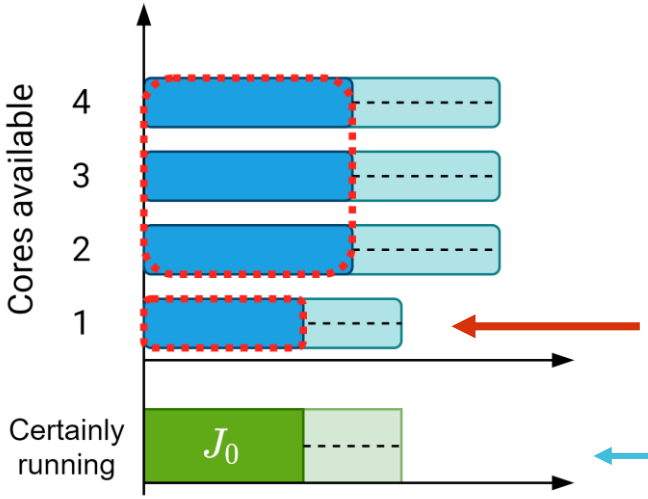

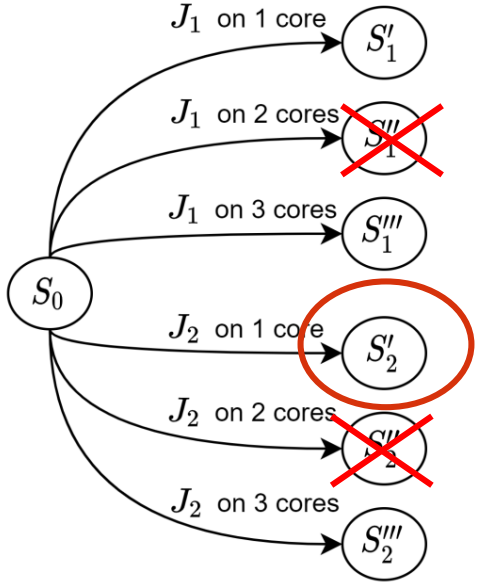

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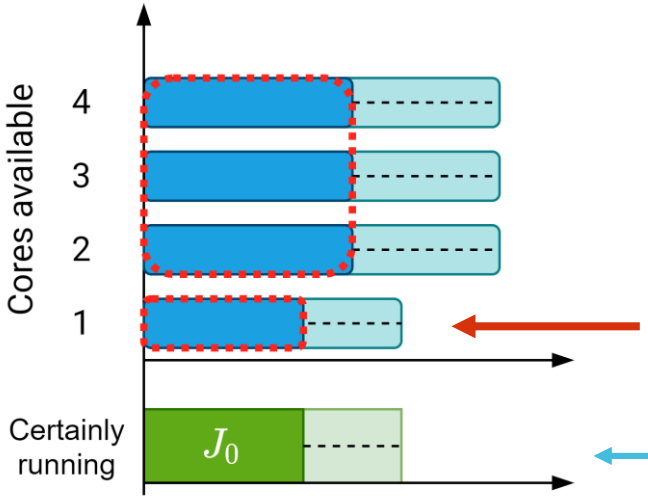

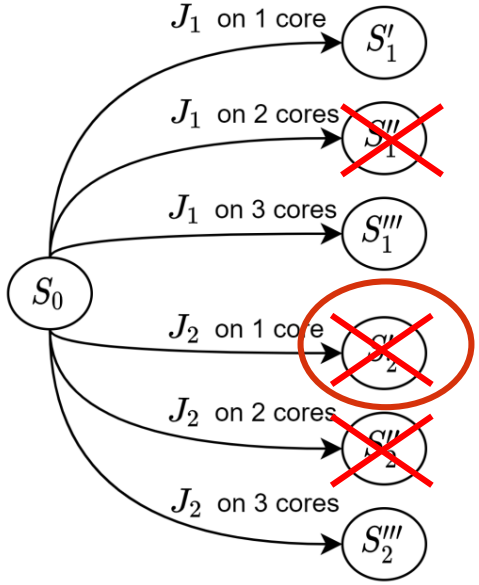

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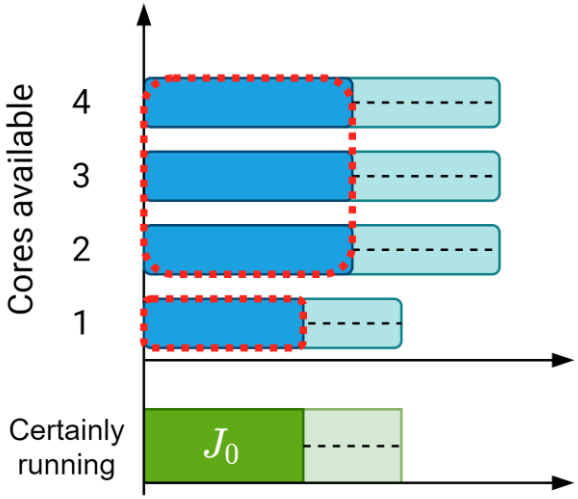

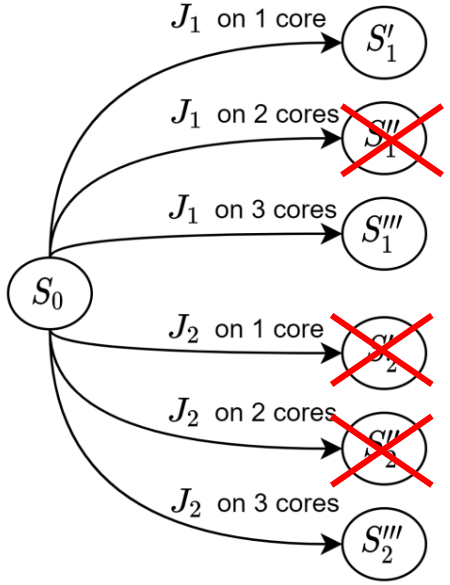

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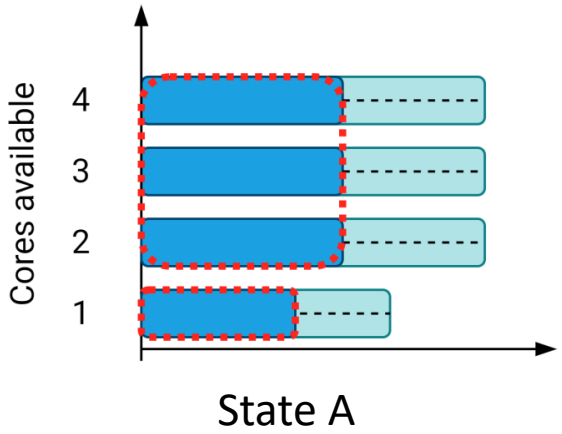

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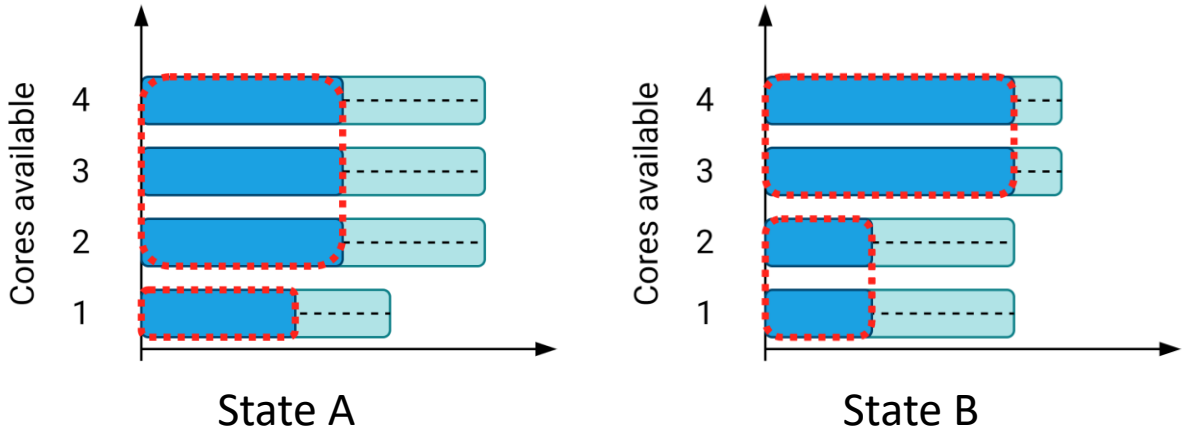

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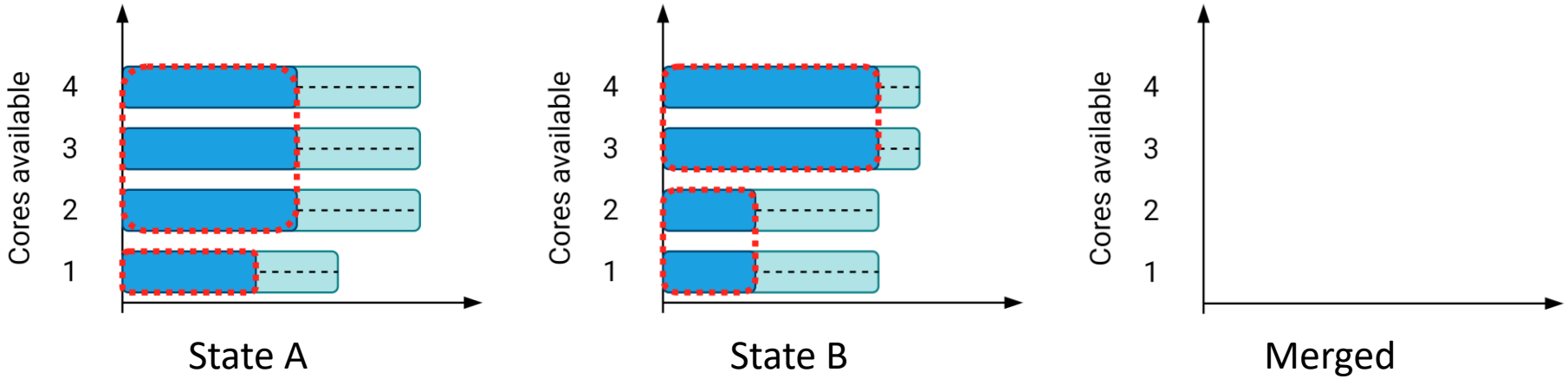

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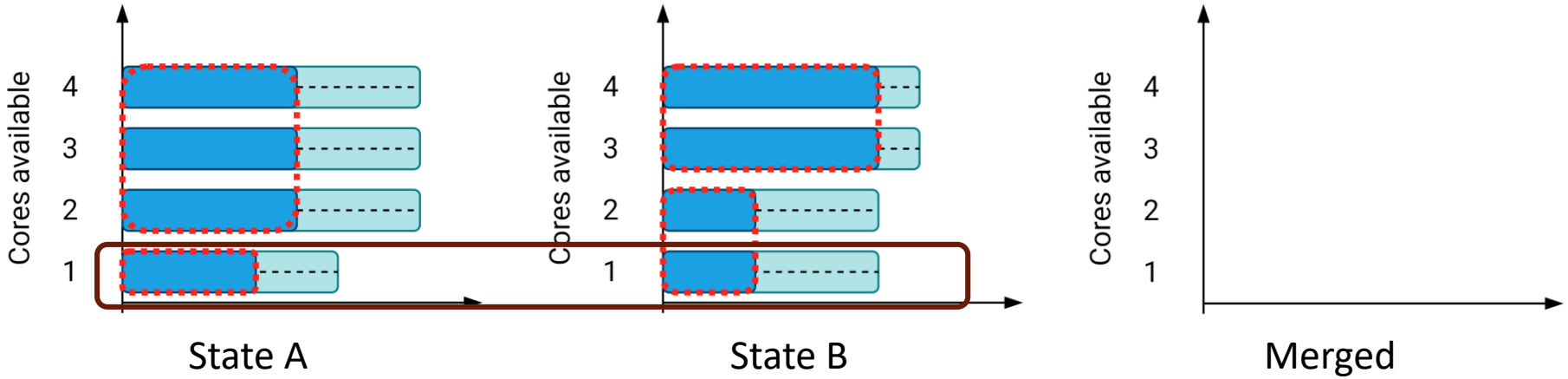

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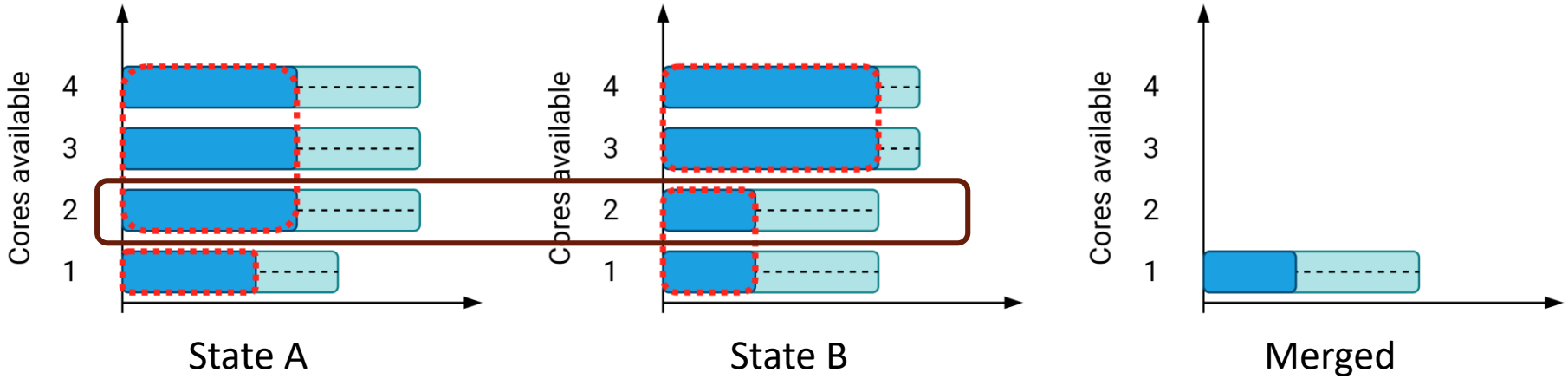
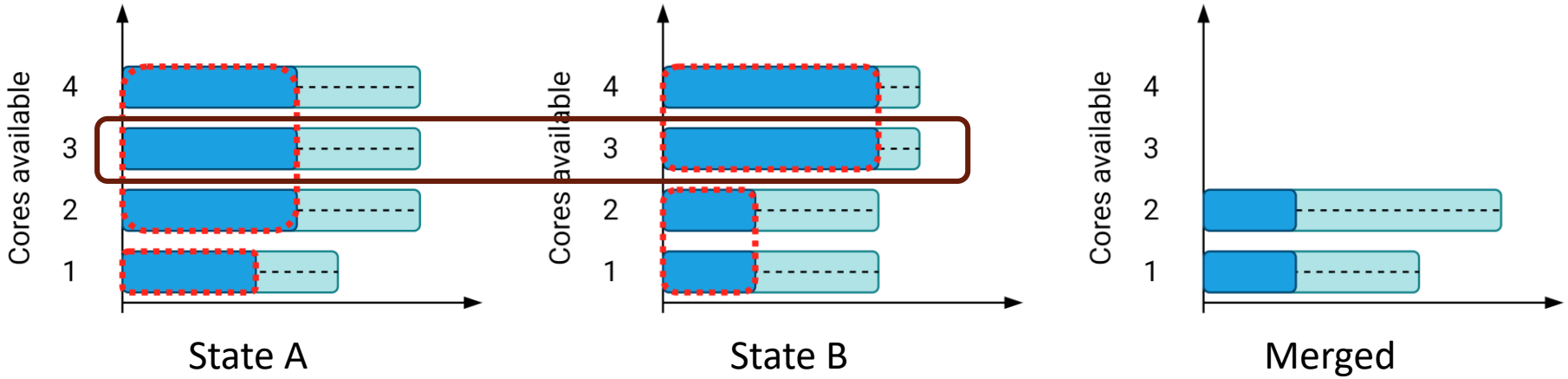


New SAG merge rules

- We have to merge
  - Availability times → Extend the intervals
  - Groups of cores
  - Set of certainly running jobs



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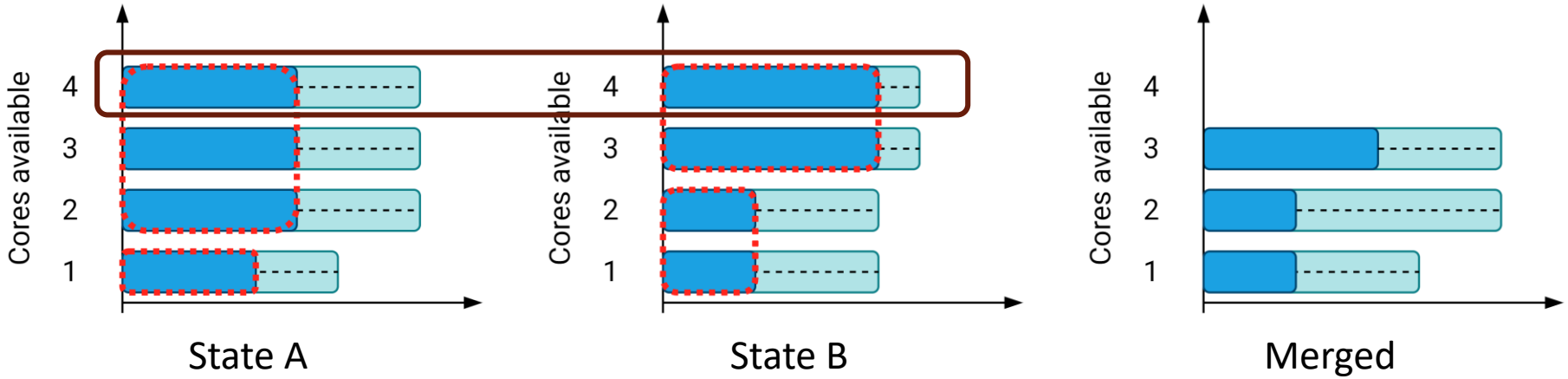

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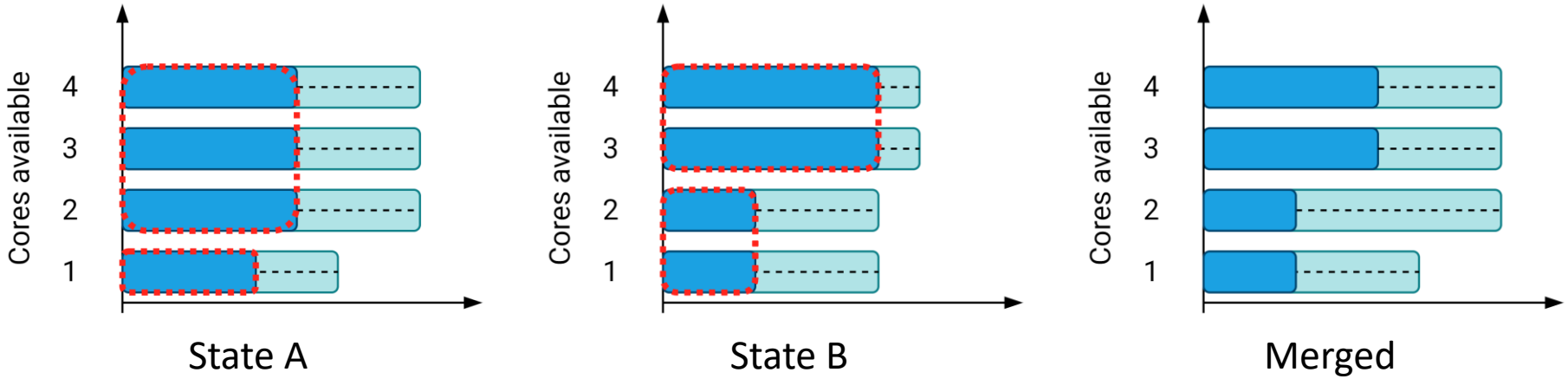
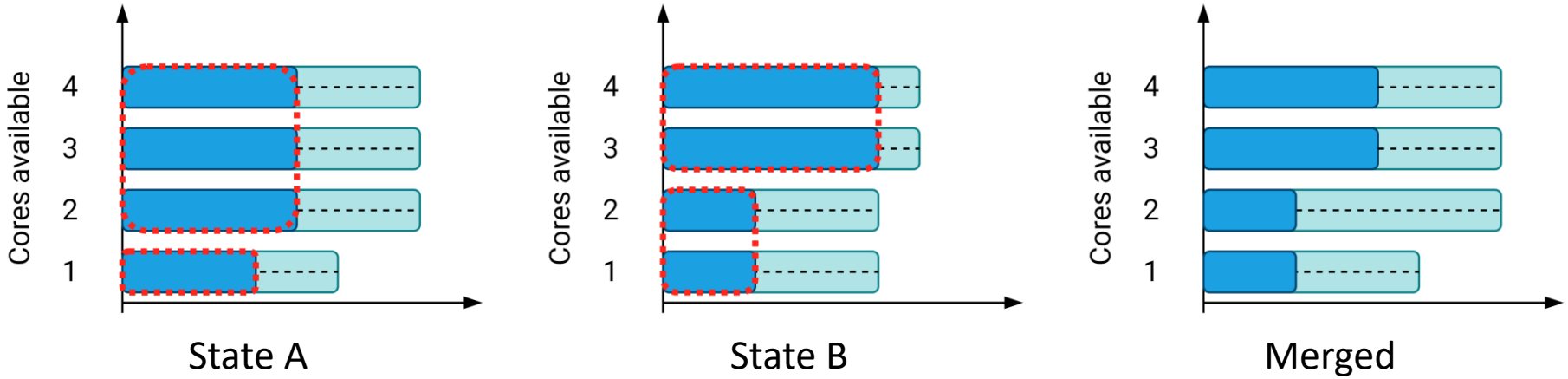


New SAG merge rules

- We have to merge
  - Availability times → Extend the intervals
  - Groups of cores → Break the groups into same size
  - Set of certainly running jobs



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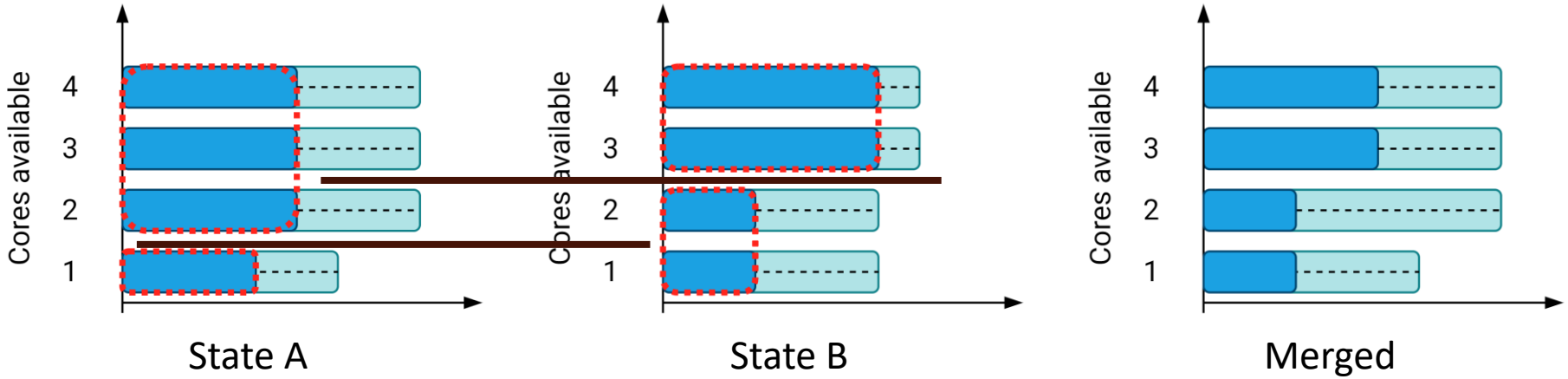

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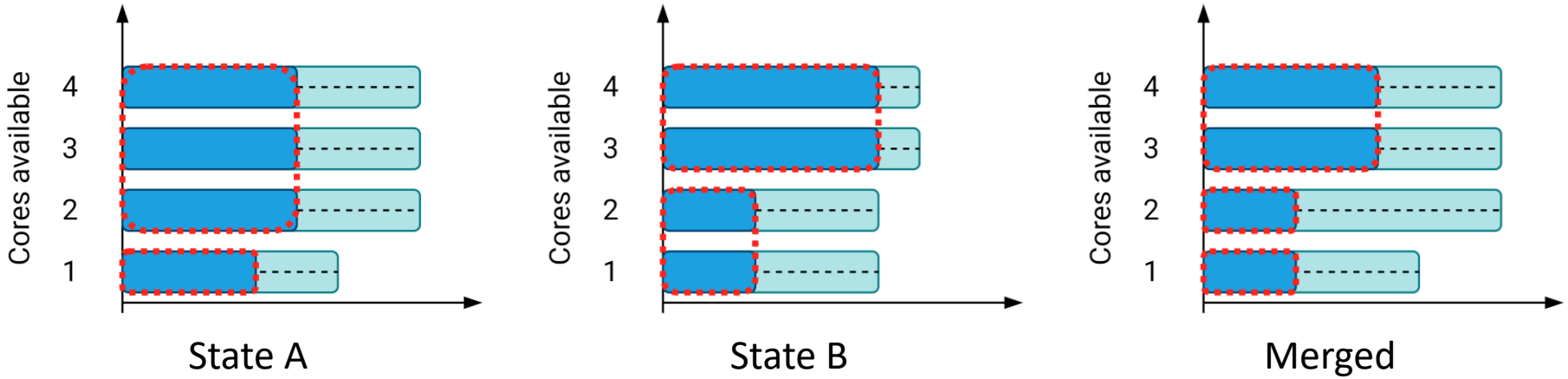
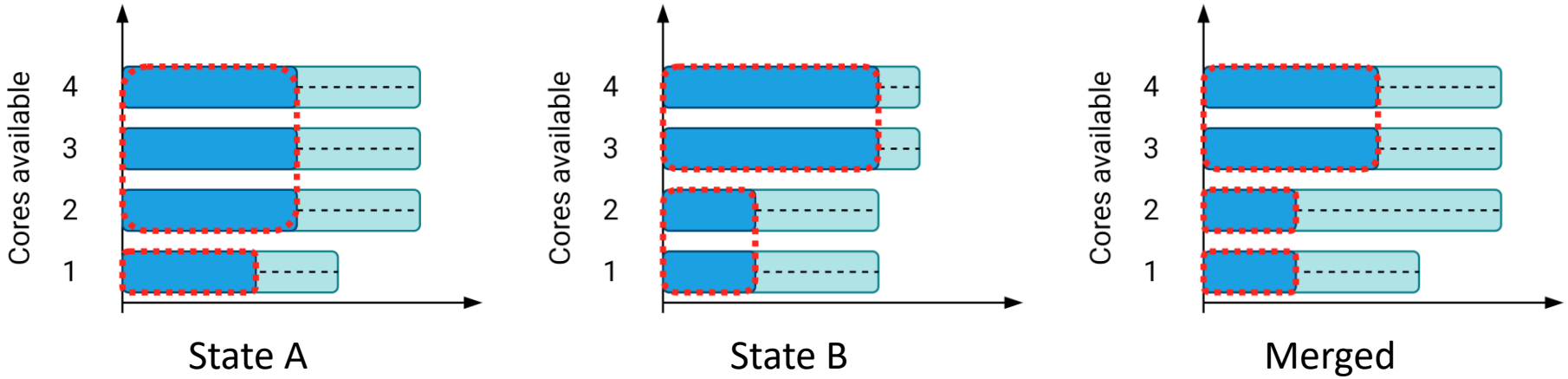


New SAG merge rules

- We have to merge
  - Availability times → Extend the intervals
  - Groups of cores → Break the groups into same size
  - Set of certainly running jobs → Keep only jobs running in both states



New SAG merge rules

- We have to merge
  - Availability times → Extend the intervals
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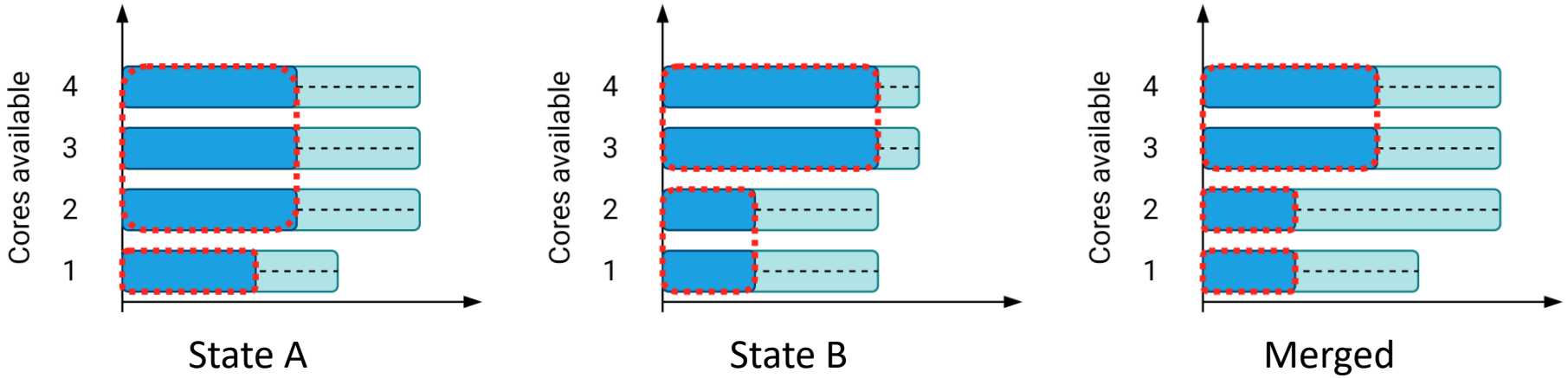
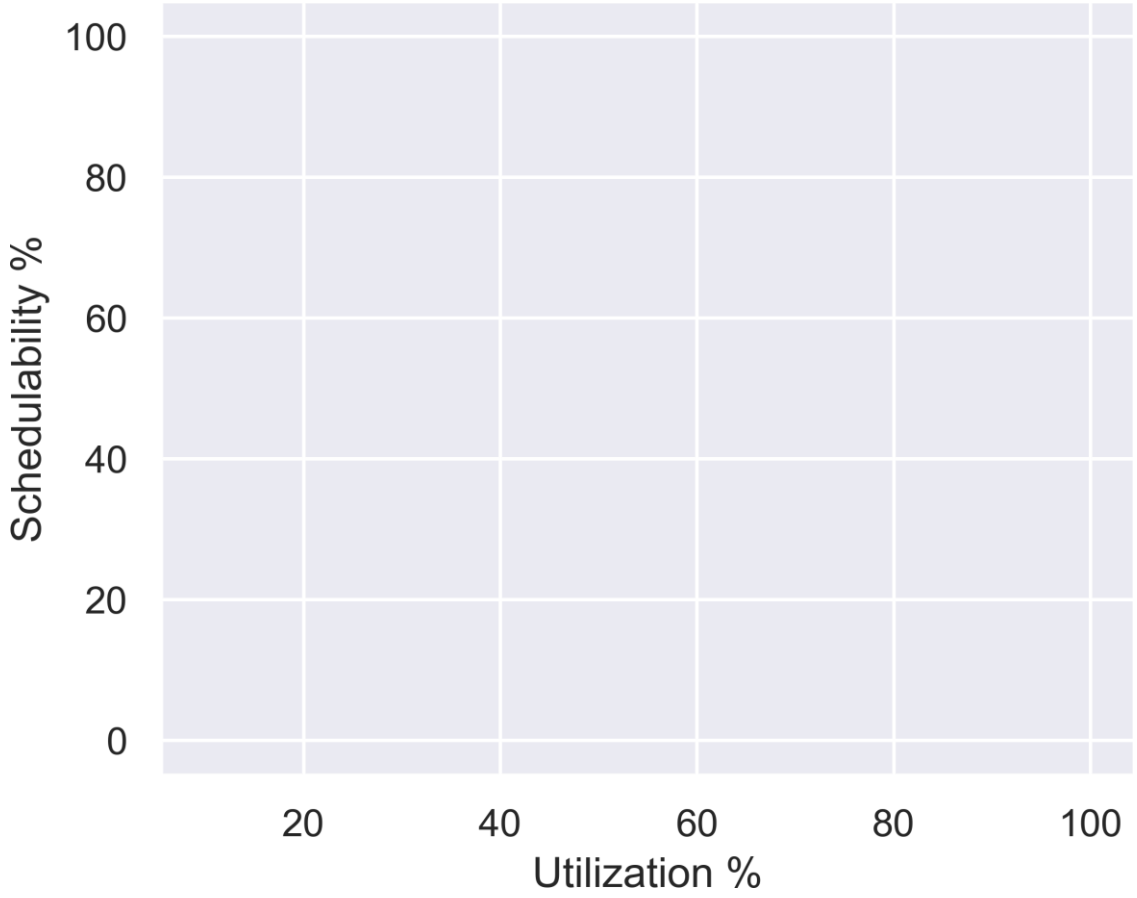
  - Set of certainly running jobs → Keep only jobs running in both states

Reachable states from merged state are all the states that can be reached from state A and state B



Our analysis results

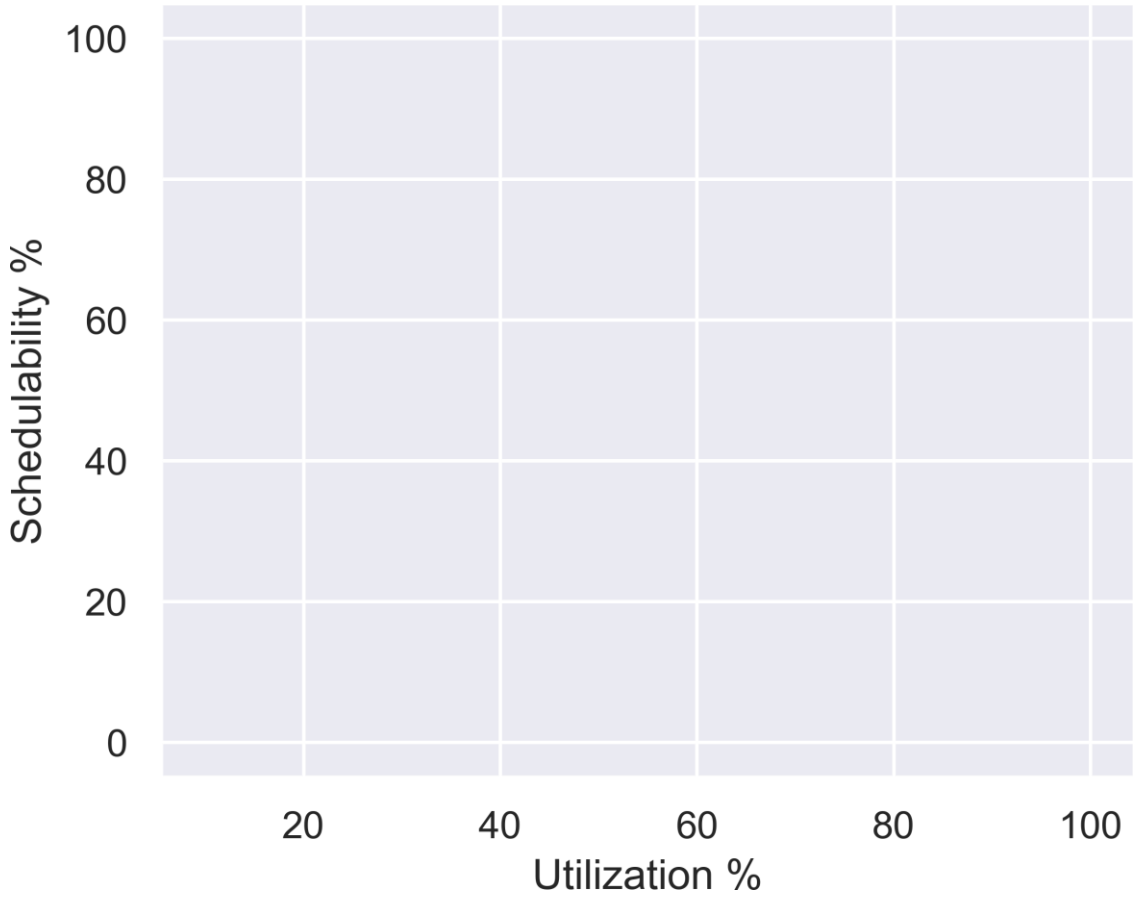
Our analysis results



Our analysis results

Randomly generated task sets

- System cores: 8
- System tasks: 20 rigid tasks
- Execution time variation: 50%
- Implicit deadlines
- Rate monotonic



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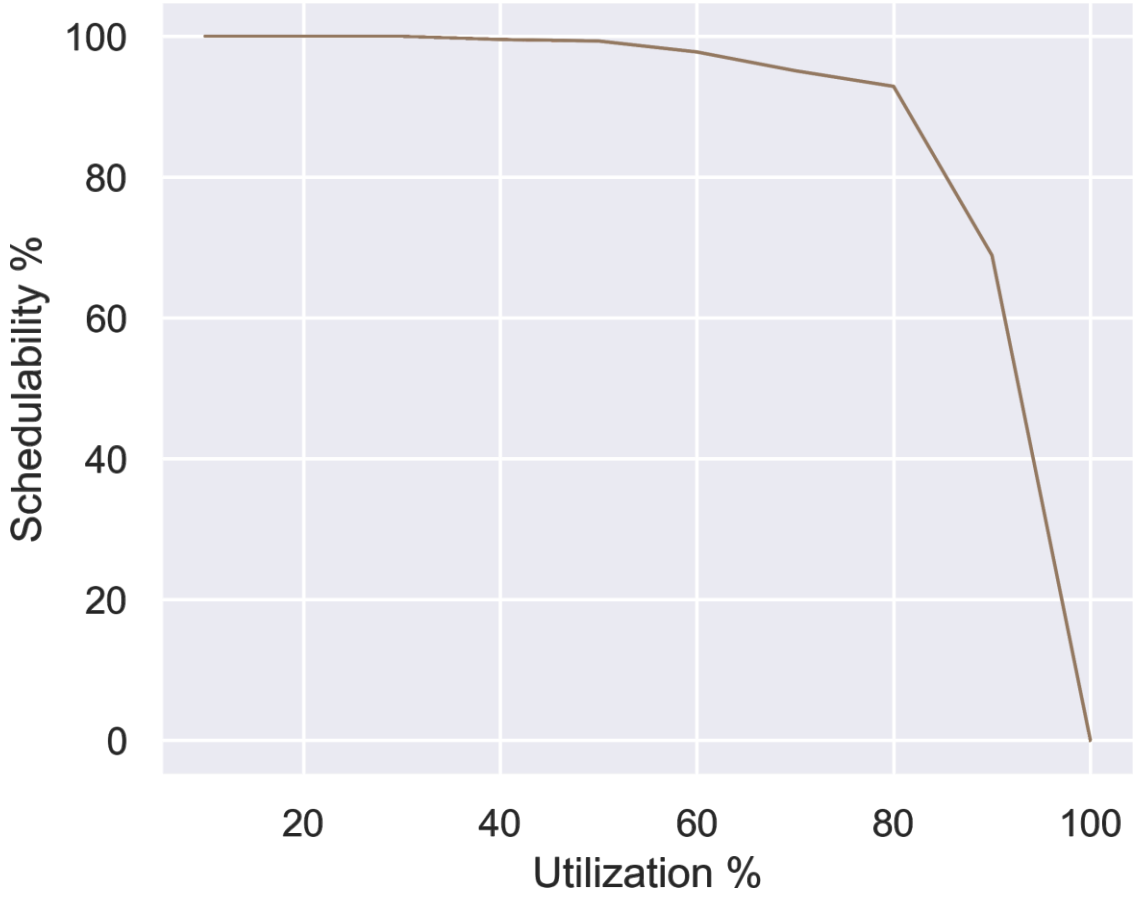

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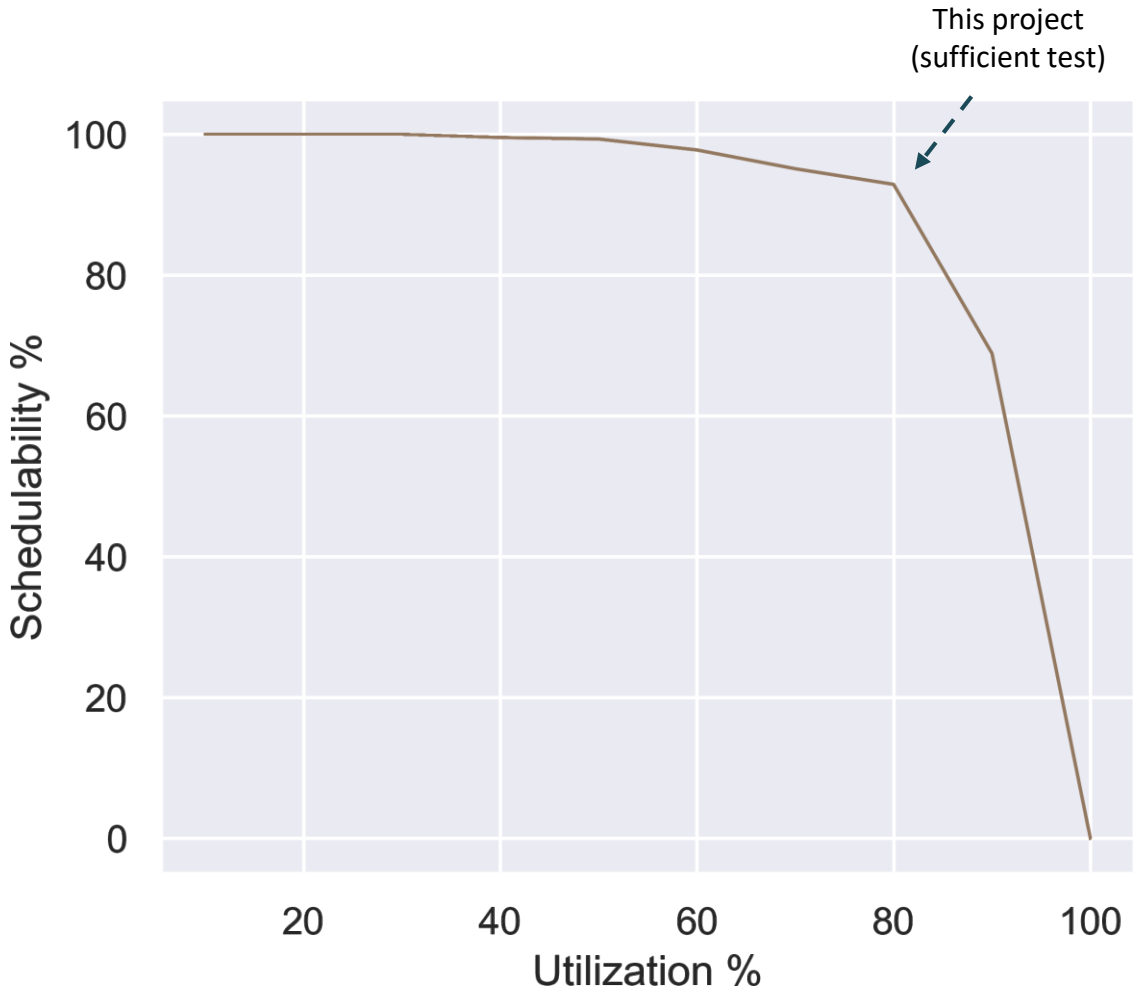

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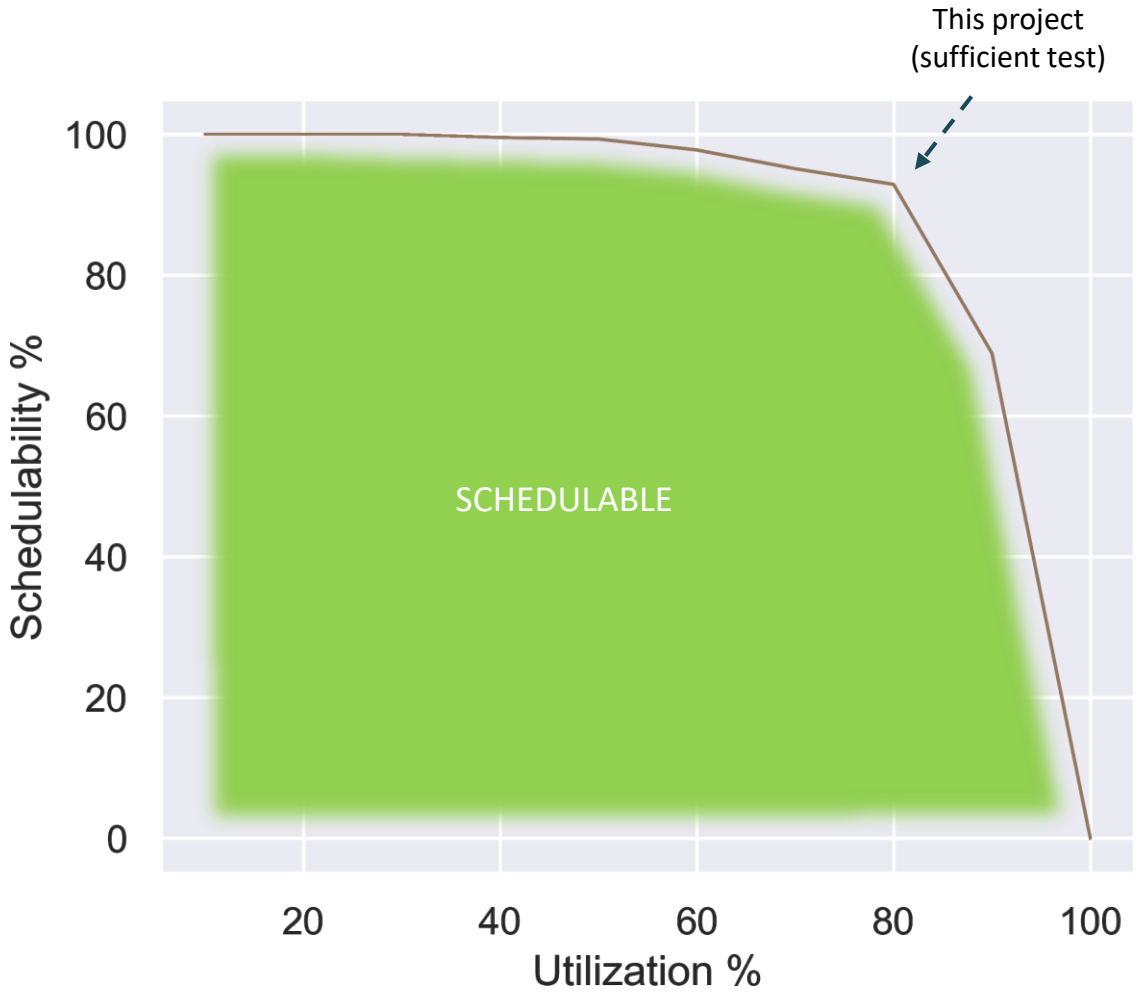

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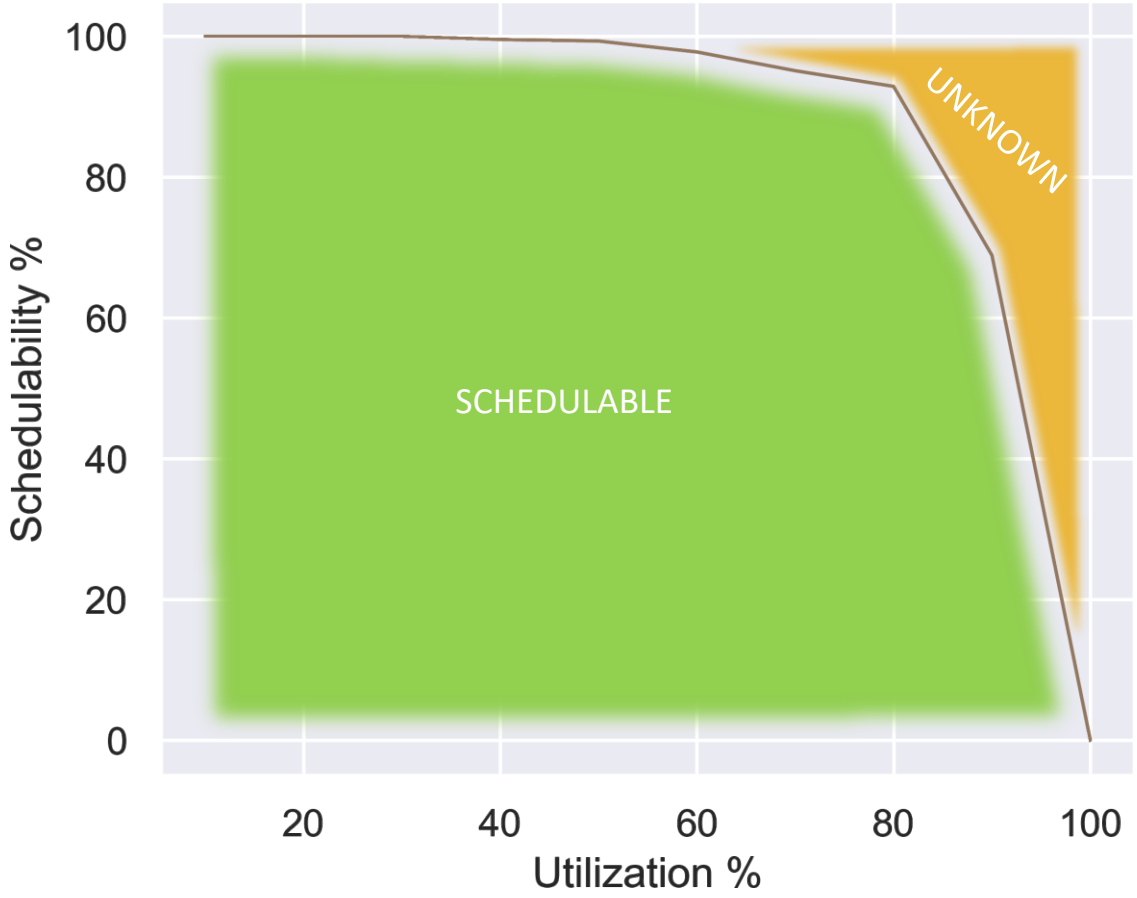

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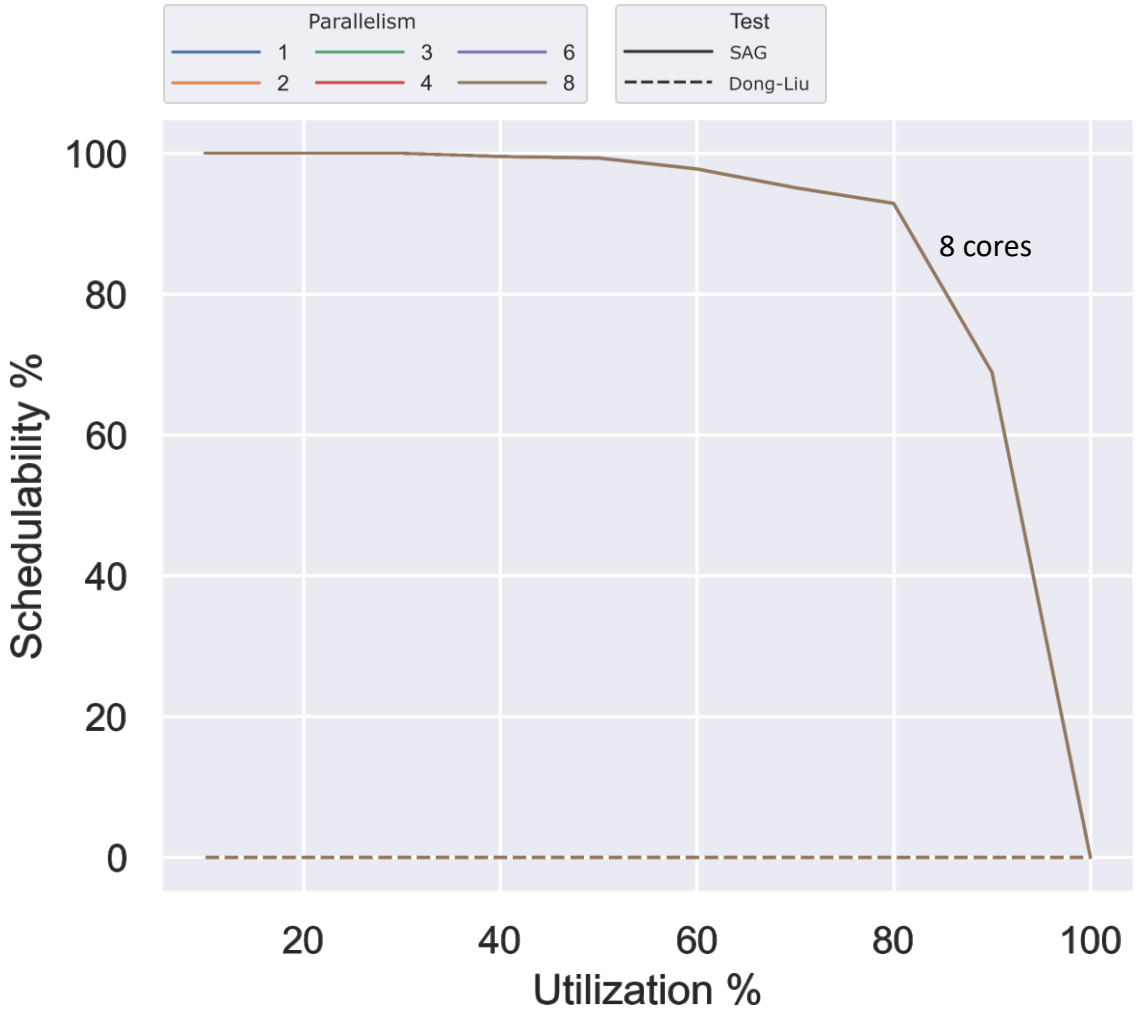

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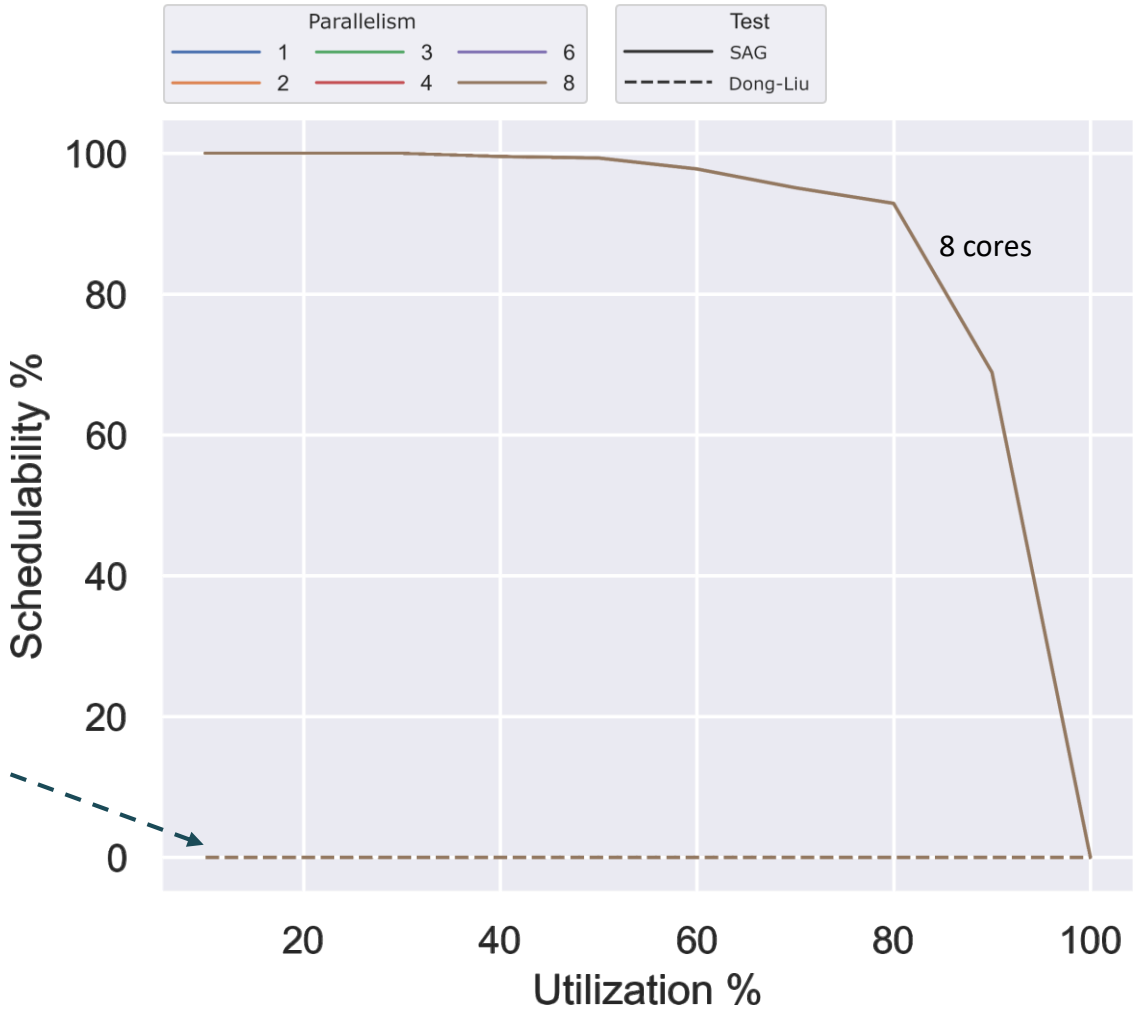

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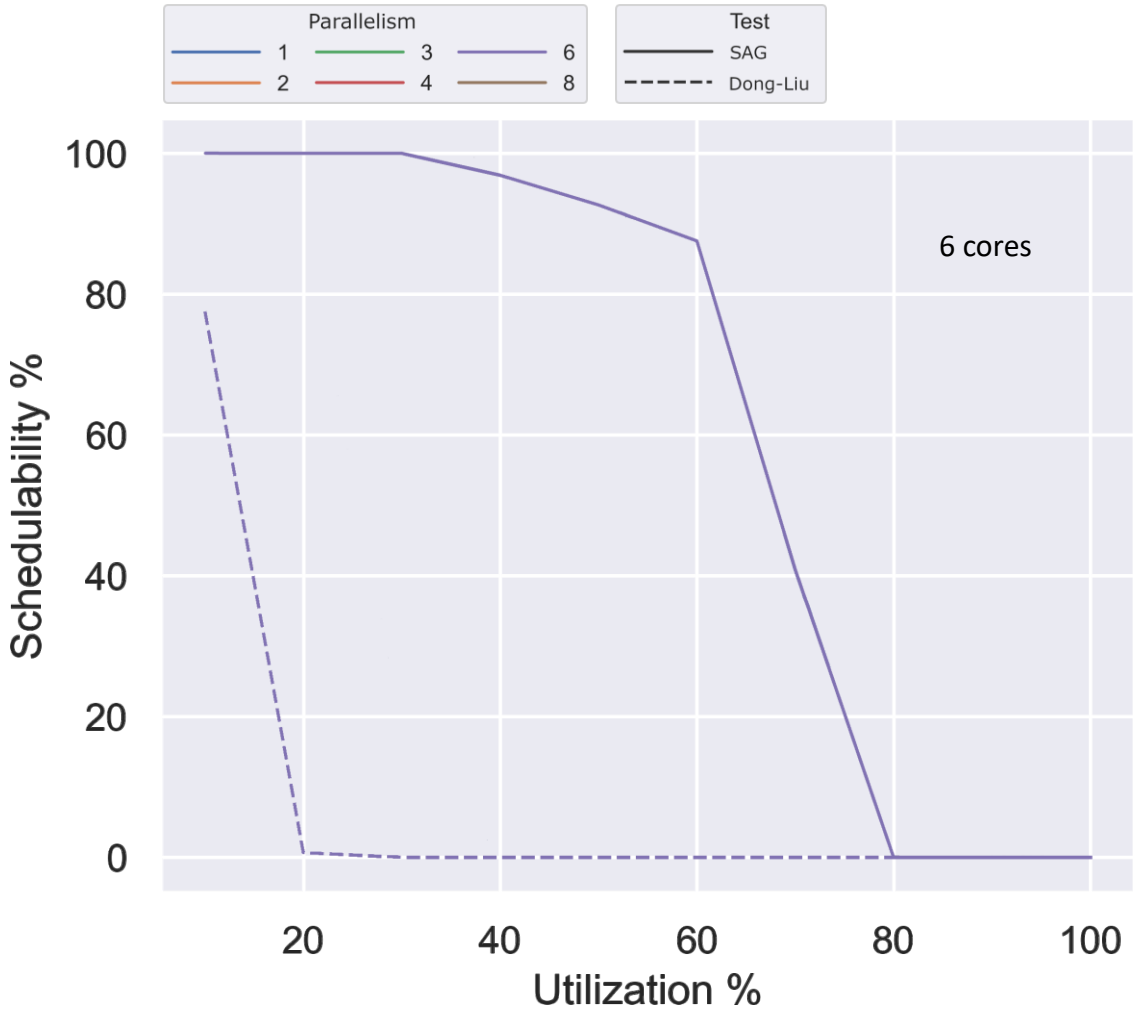

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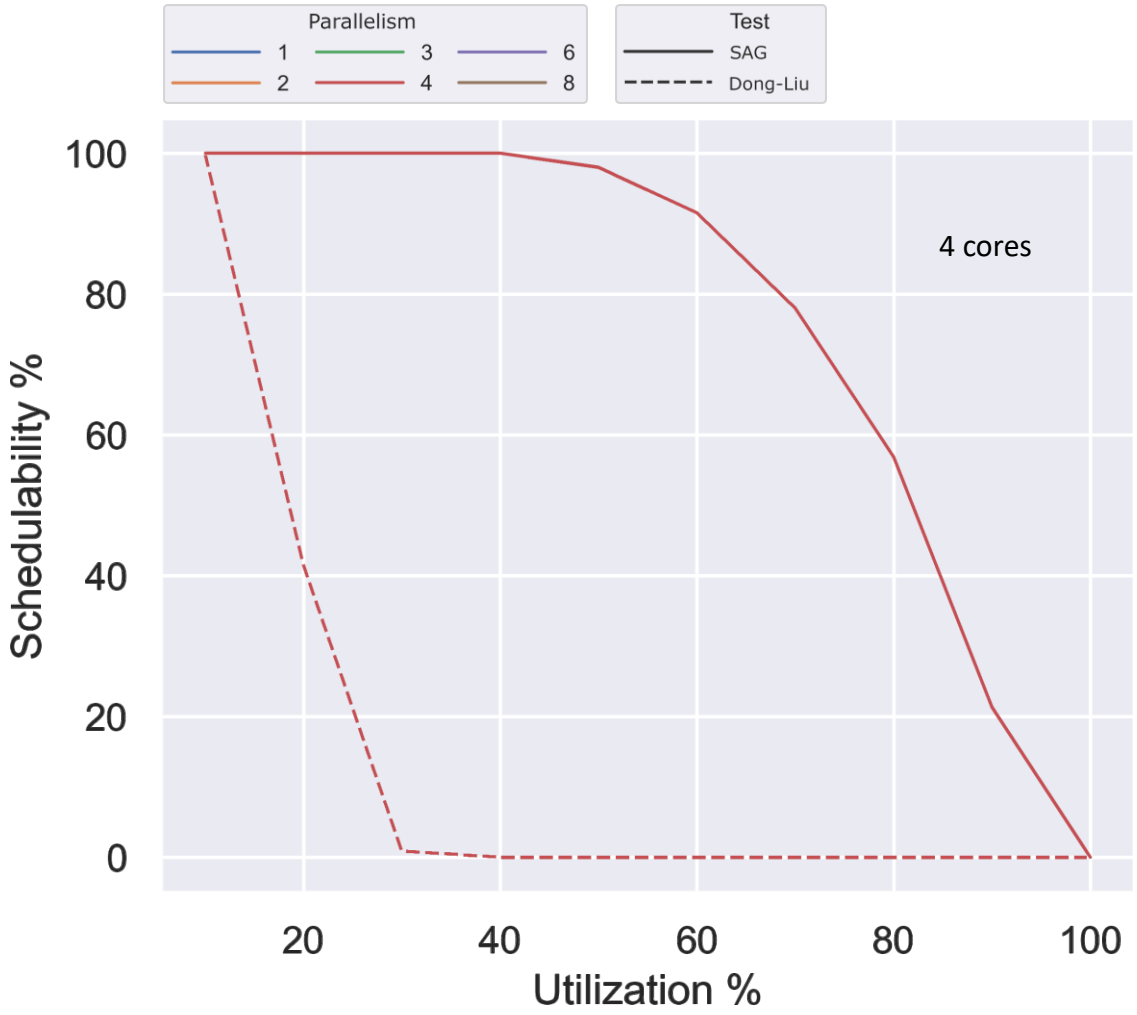

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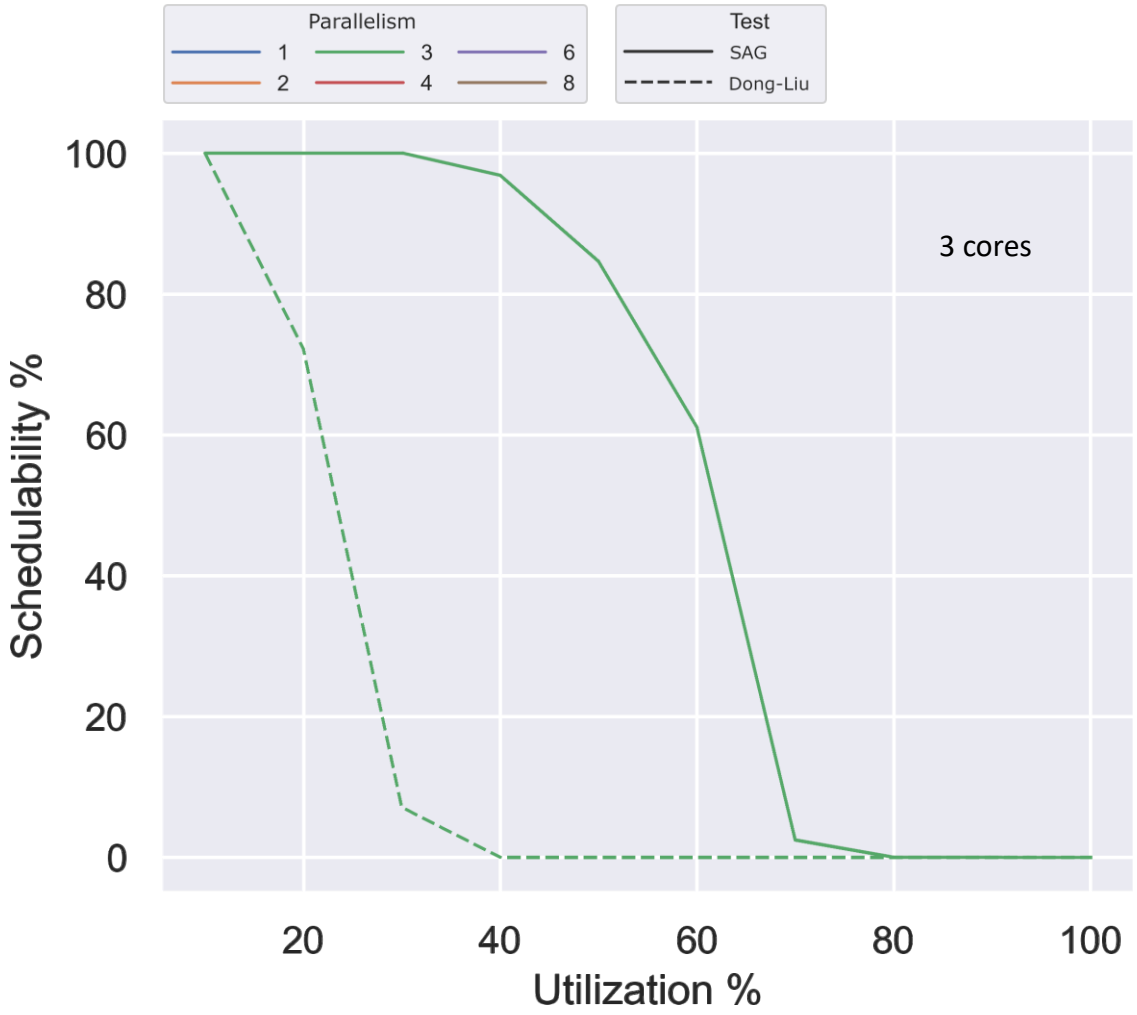

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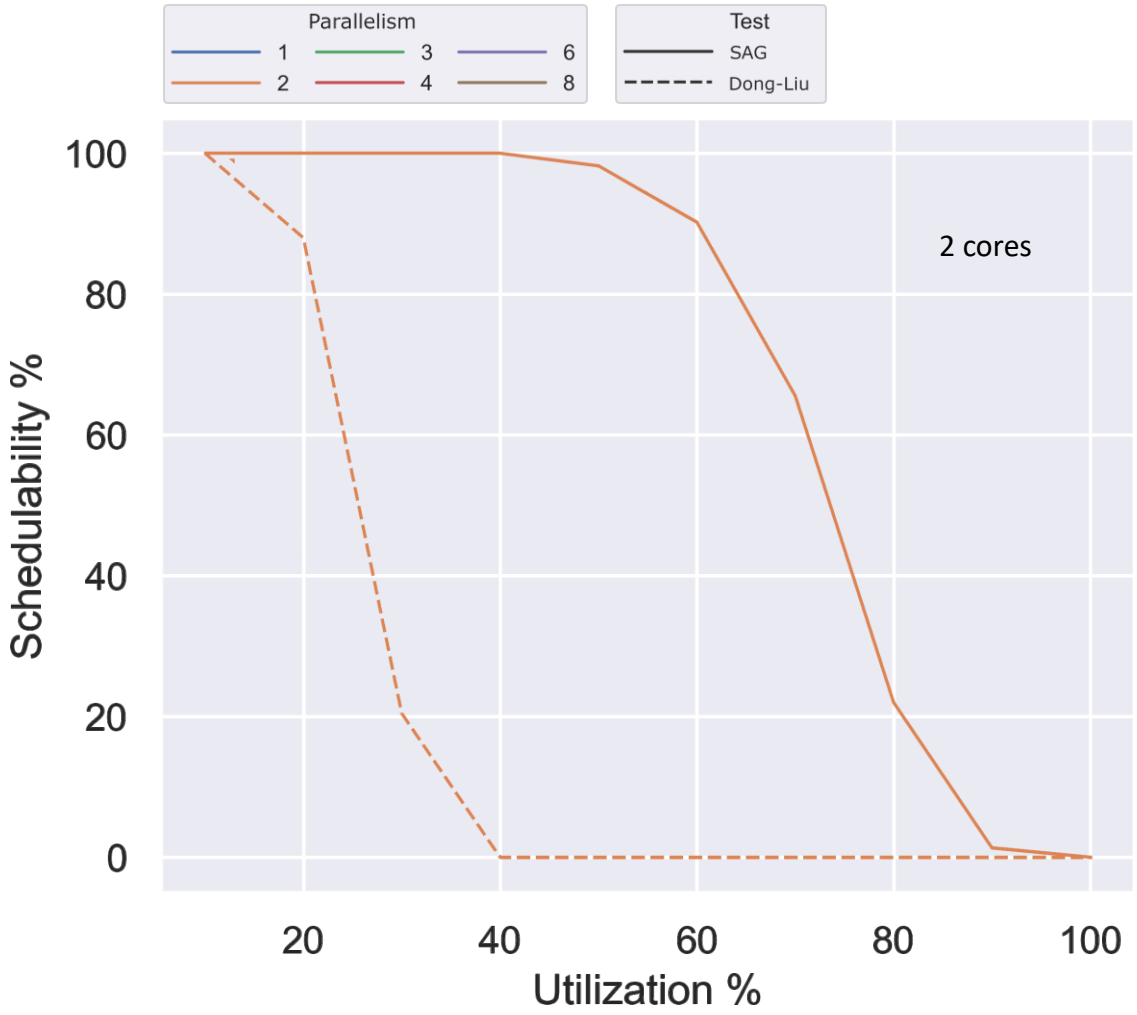

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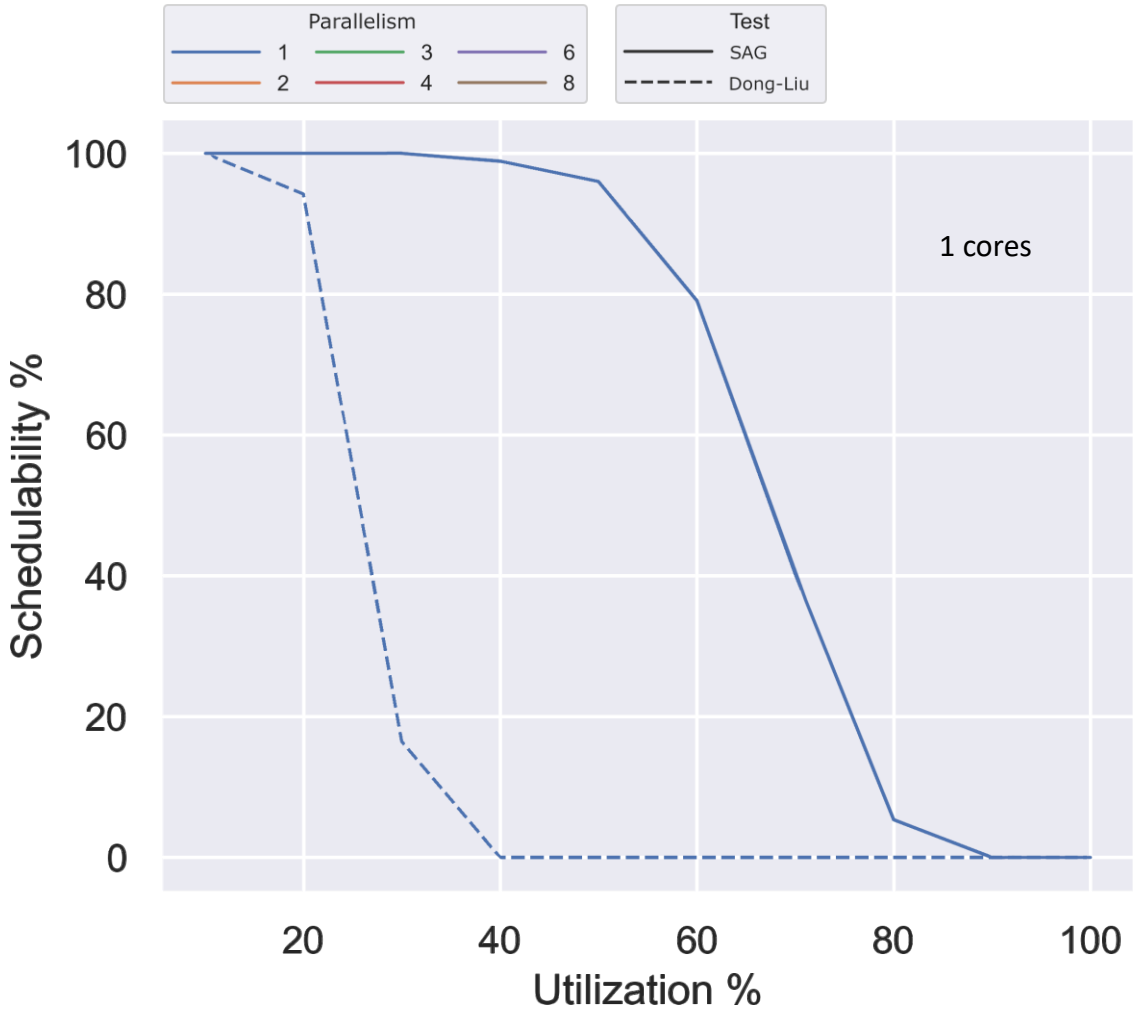

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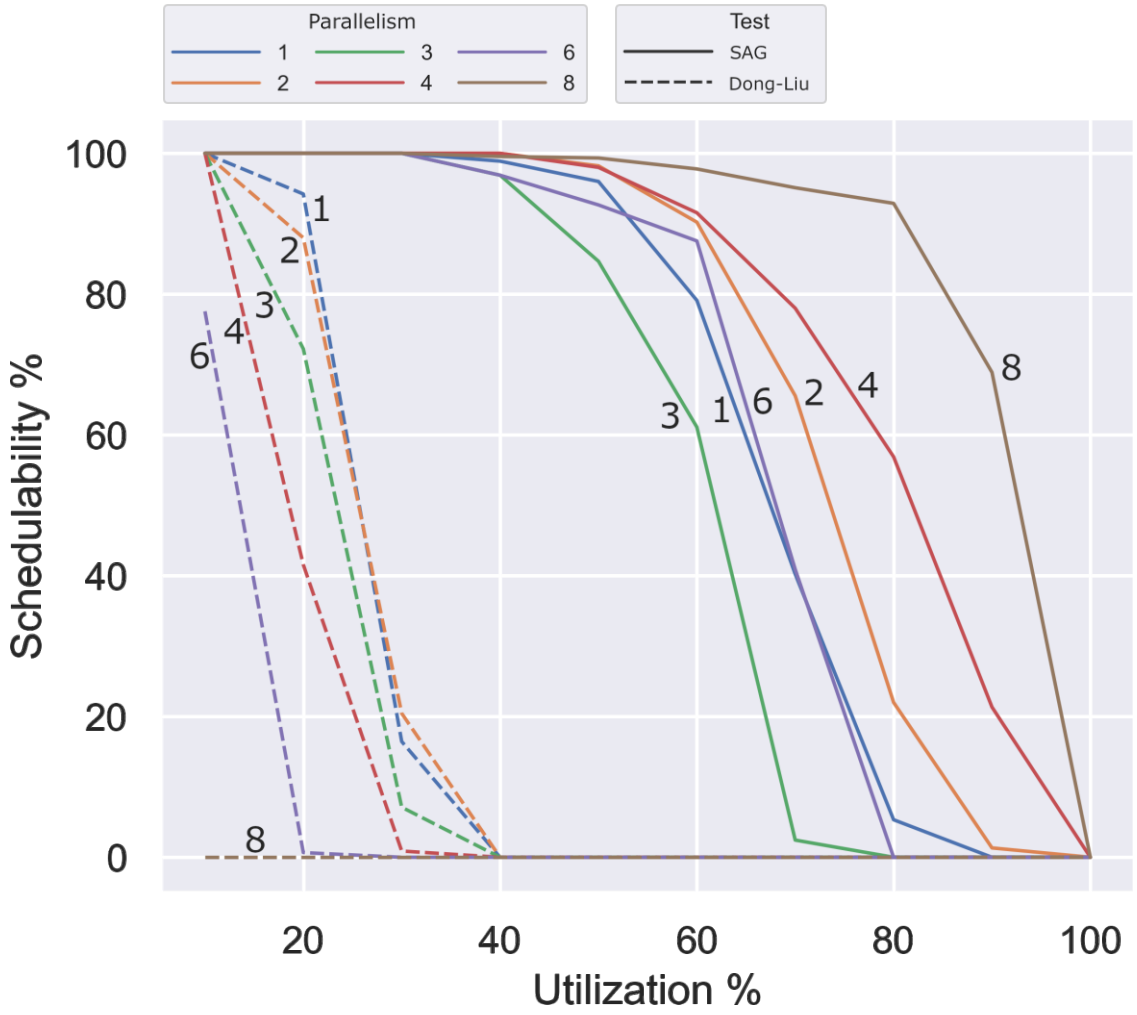
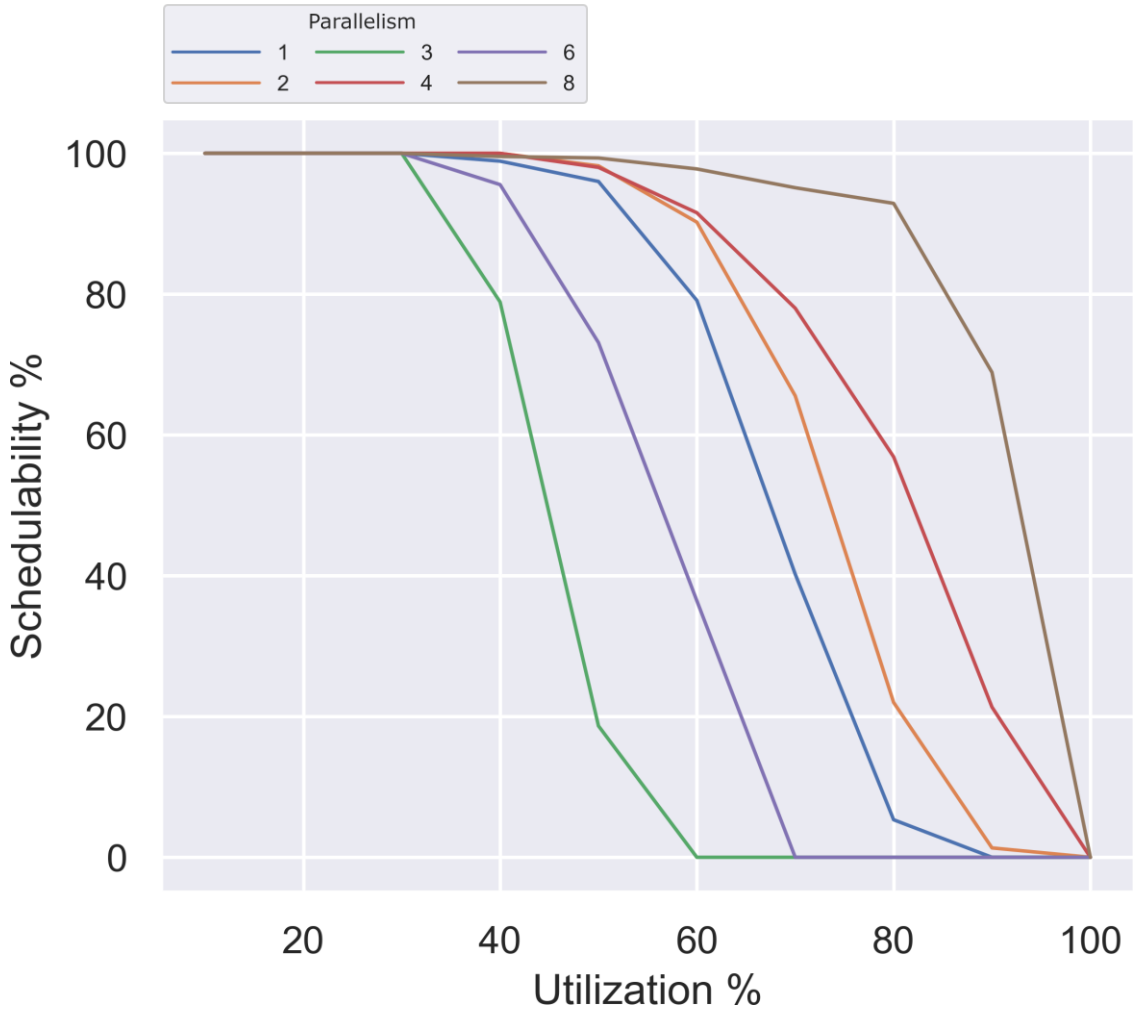


Our analysis results

Randomly generated task sets

- System cores: 8
- System tasks: 20 moldable tasks
- Execution time variation: 50%
- Implicit deadlines
- Rate monotonic



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Randomly generated task sets

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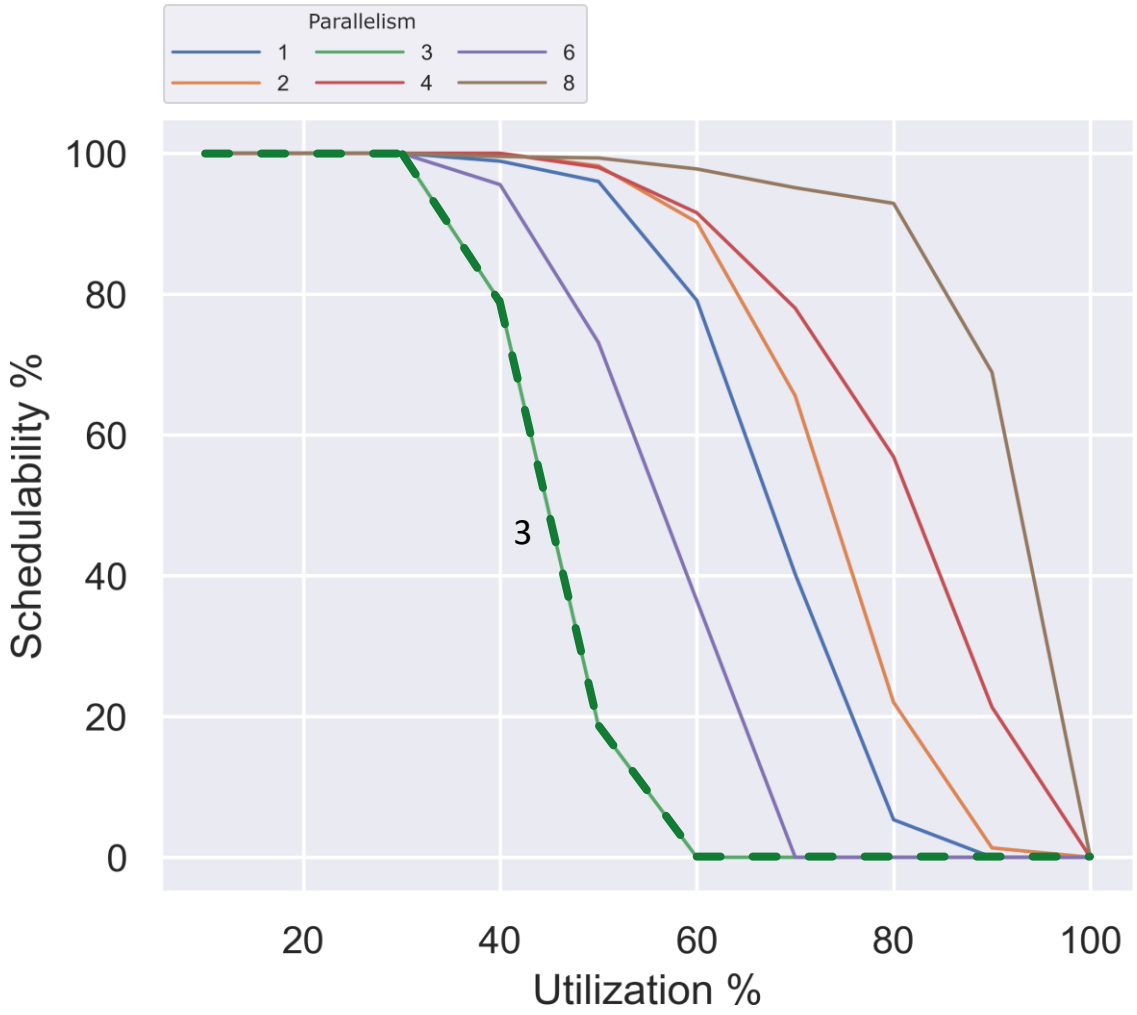
- System tasks: 20 moldable tasks
- Execution time variation: 50%
- Implicit deadlines
- Rate monotonic



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- Execution time variation: 50%
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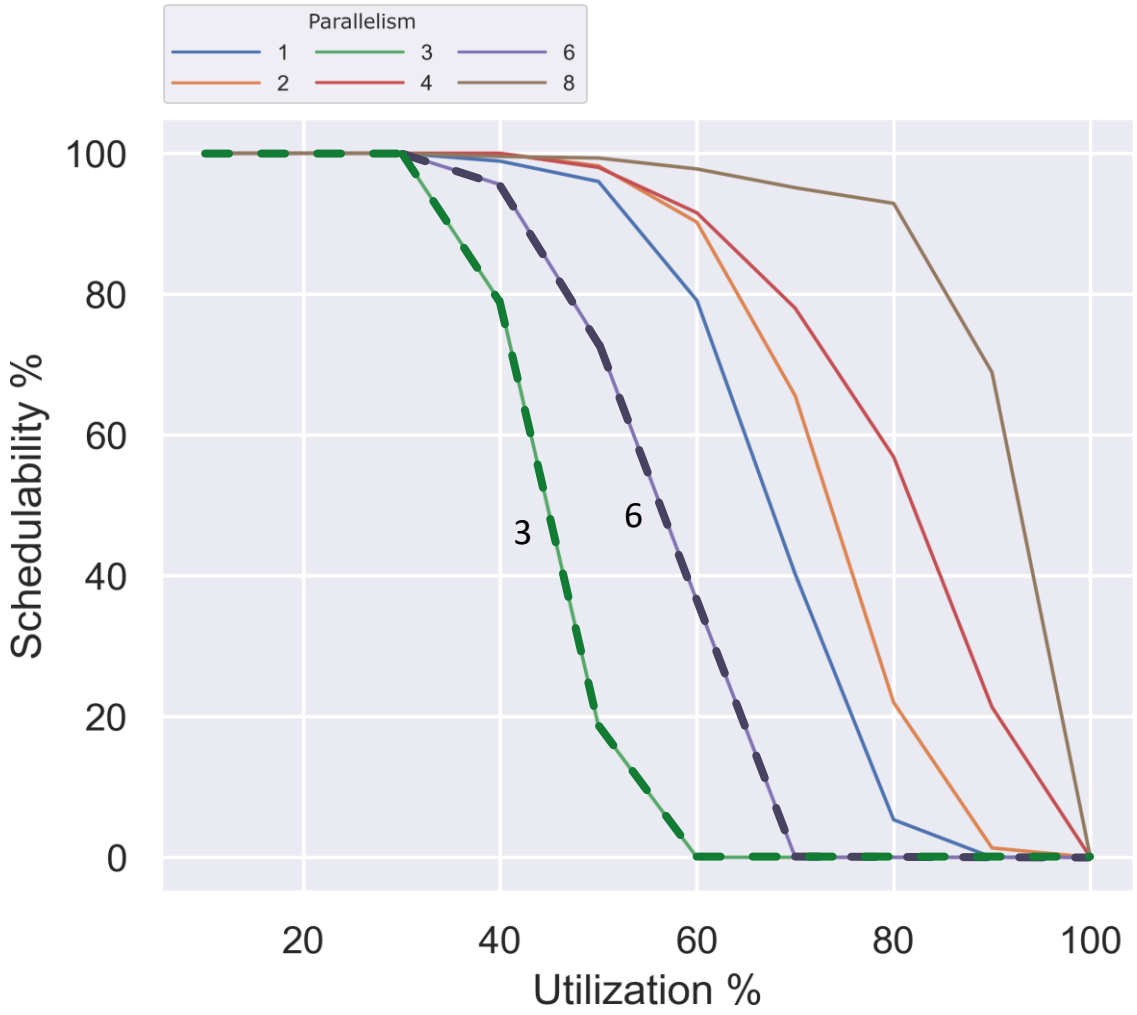
- Rate monotonic



Our analysis results

Randomly generated task sets

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- System tasks: 20 moldable tasks
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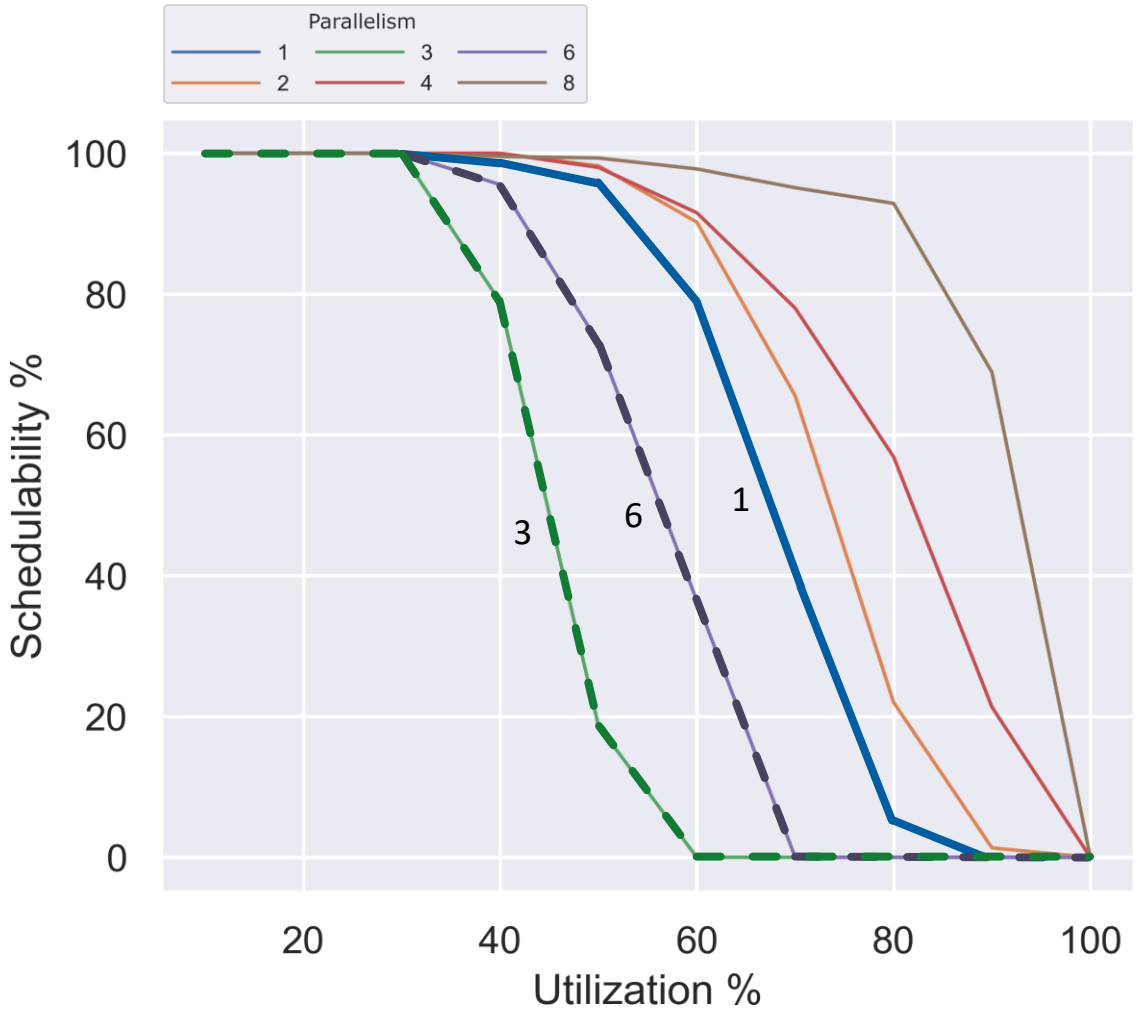

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Randomly generated task sets

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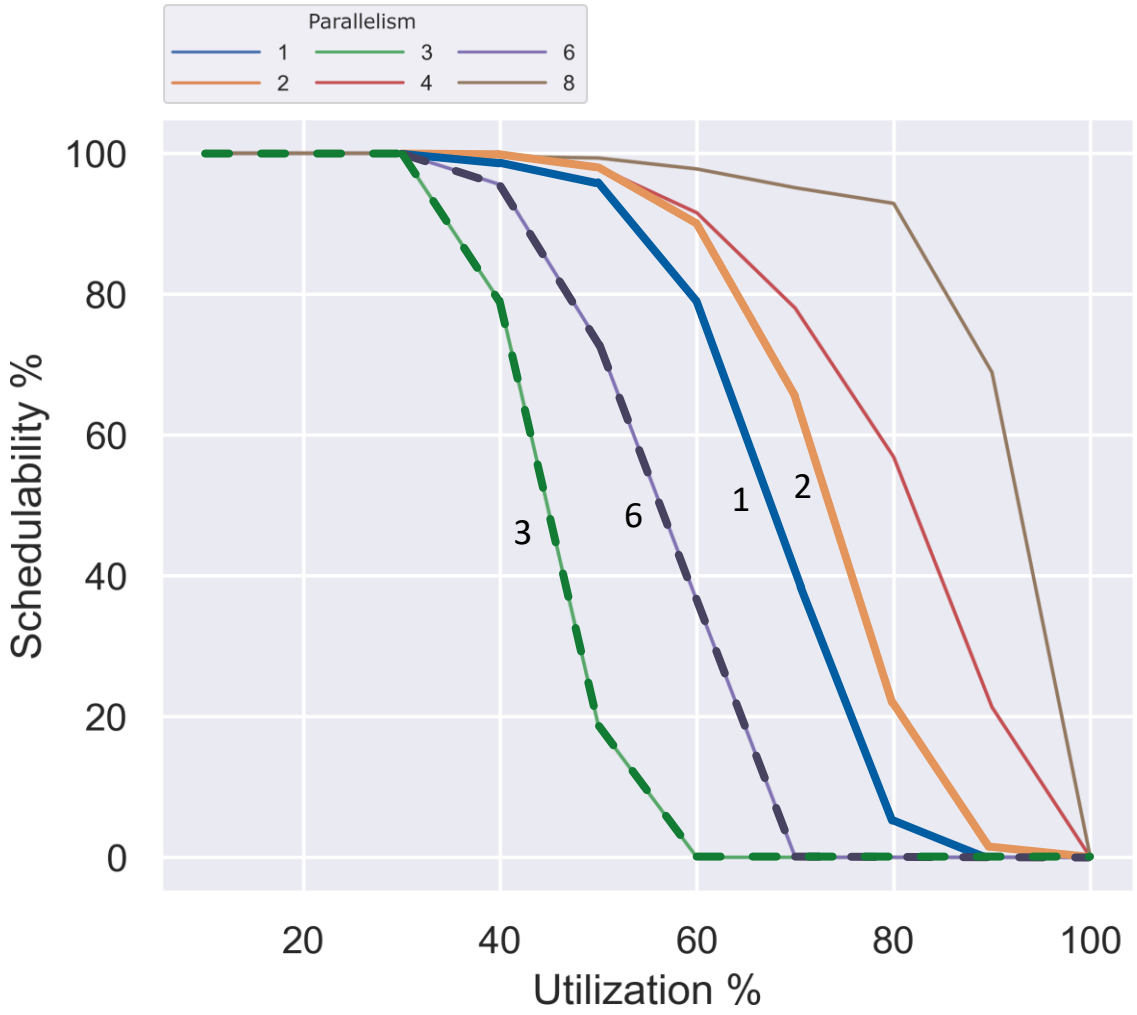

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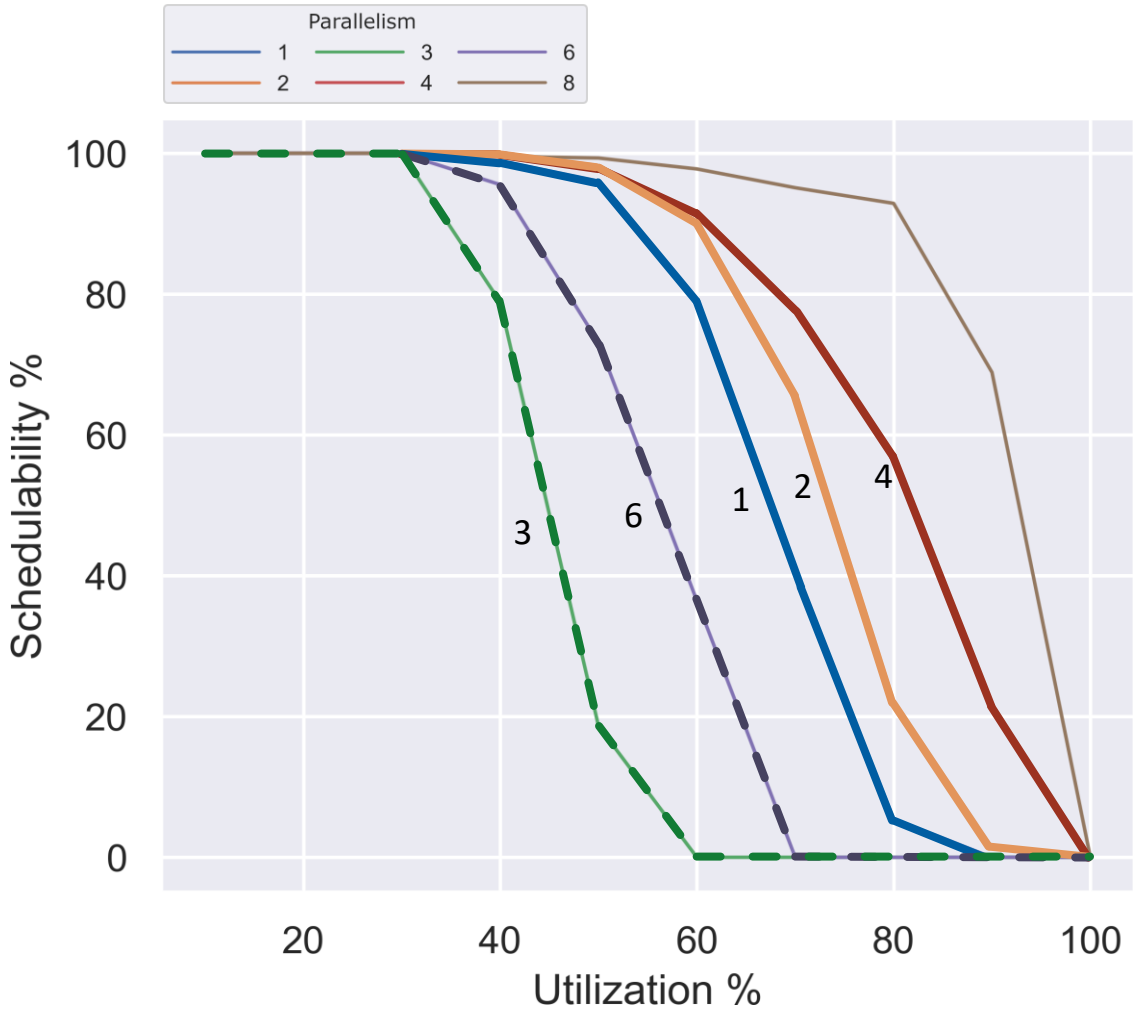
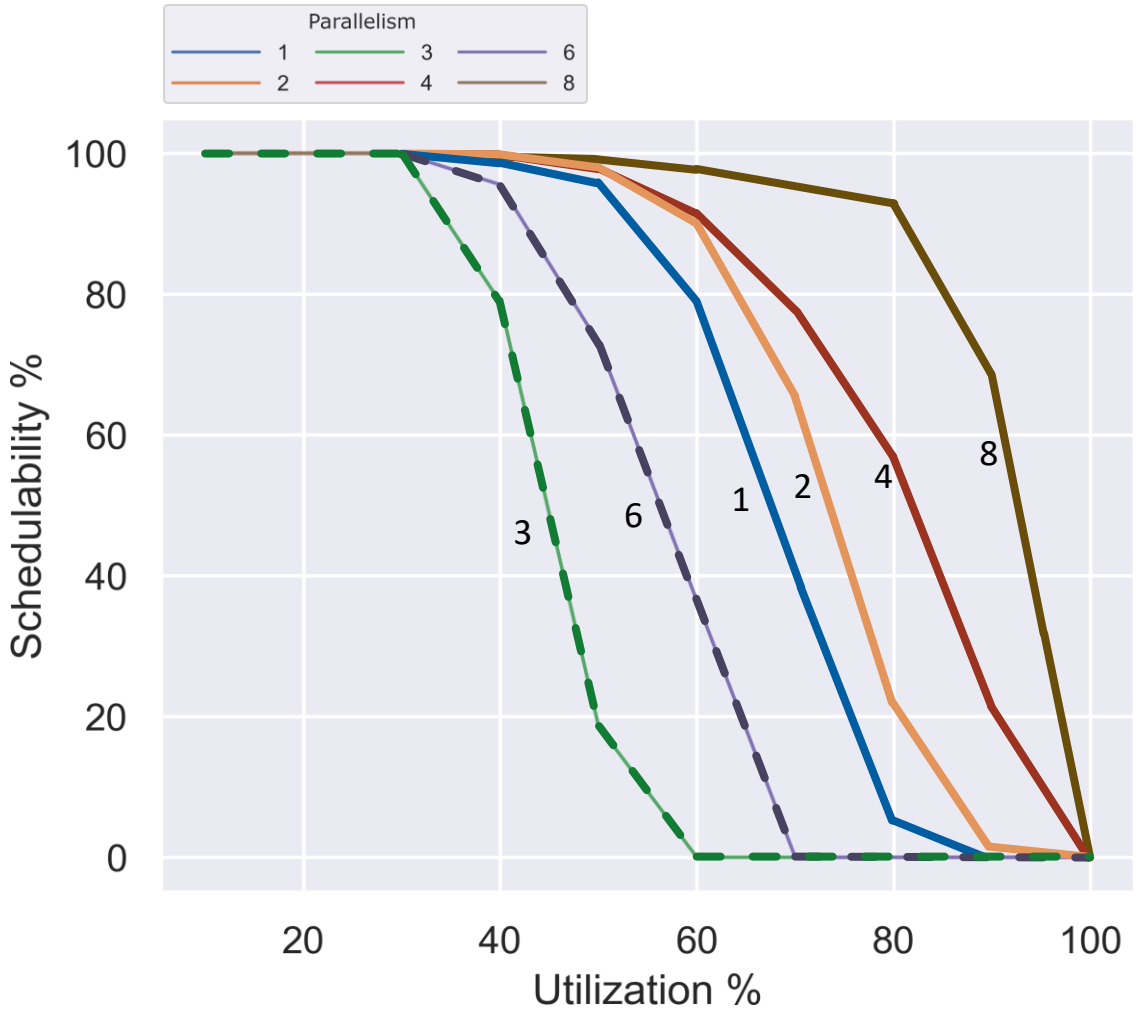


Our analysis results

Randomly generated task sets

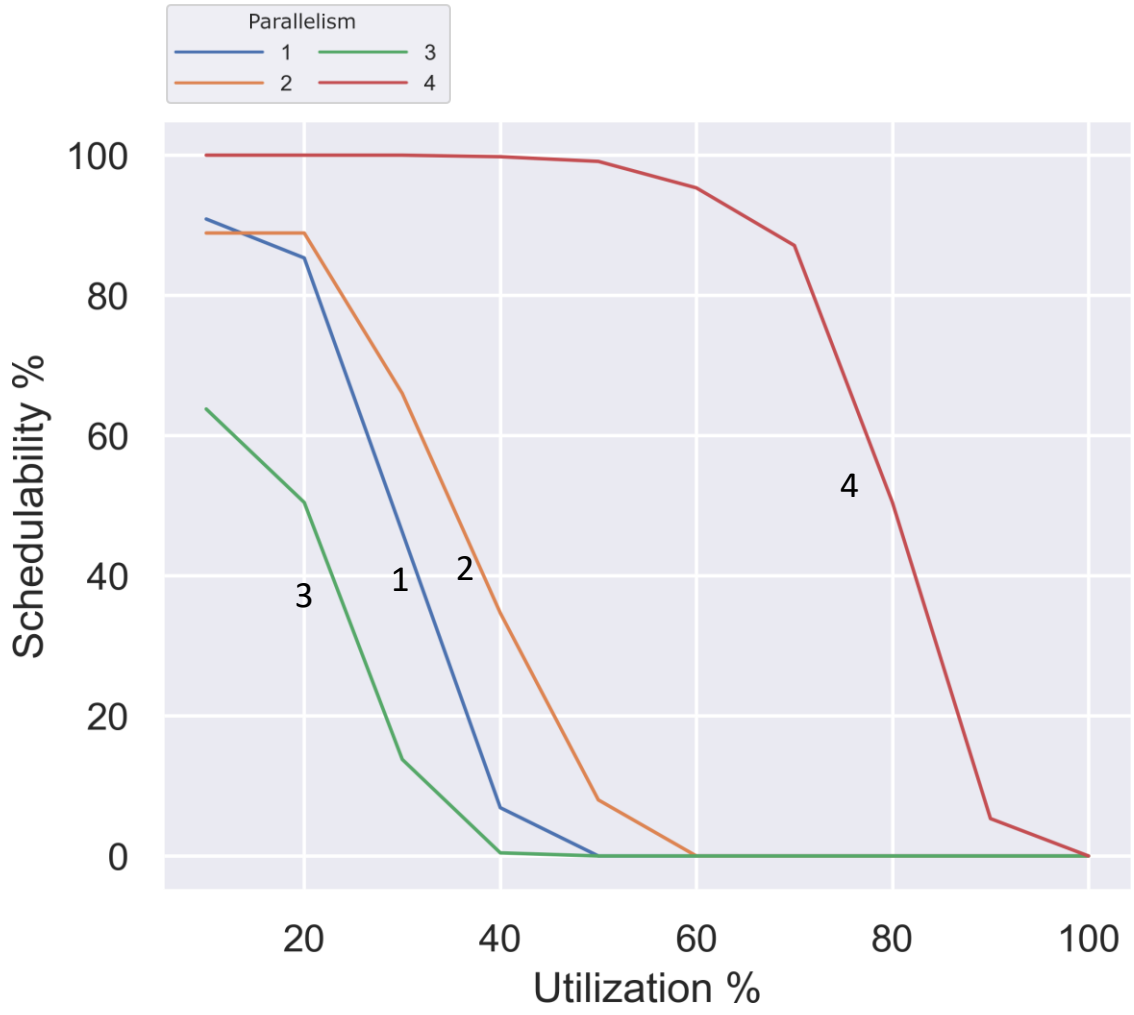
- System cores: 8
- System tasks: 20 moldable tasks
- Execution time variation: 50%
- Implicit deadlines
- Rate monotonic



Our analysis results

Randomly generated task sets

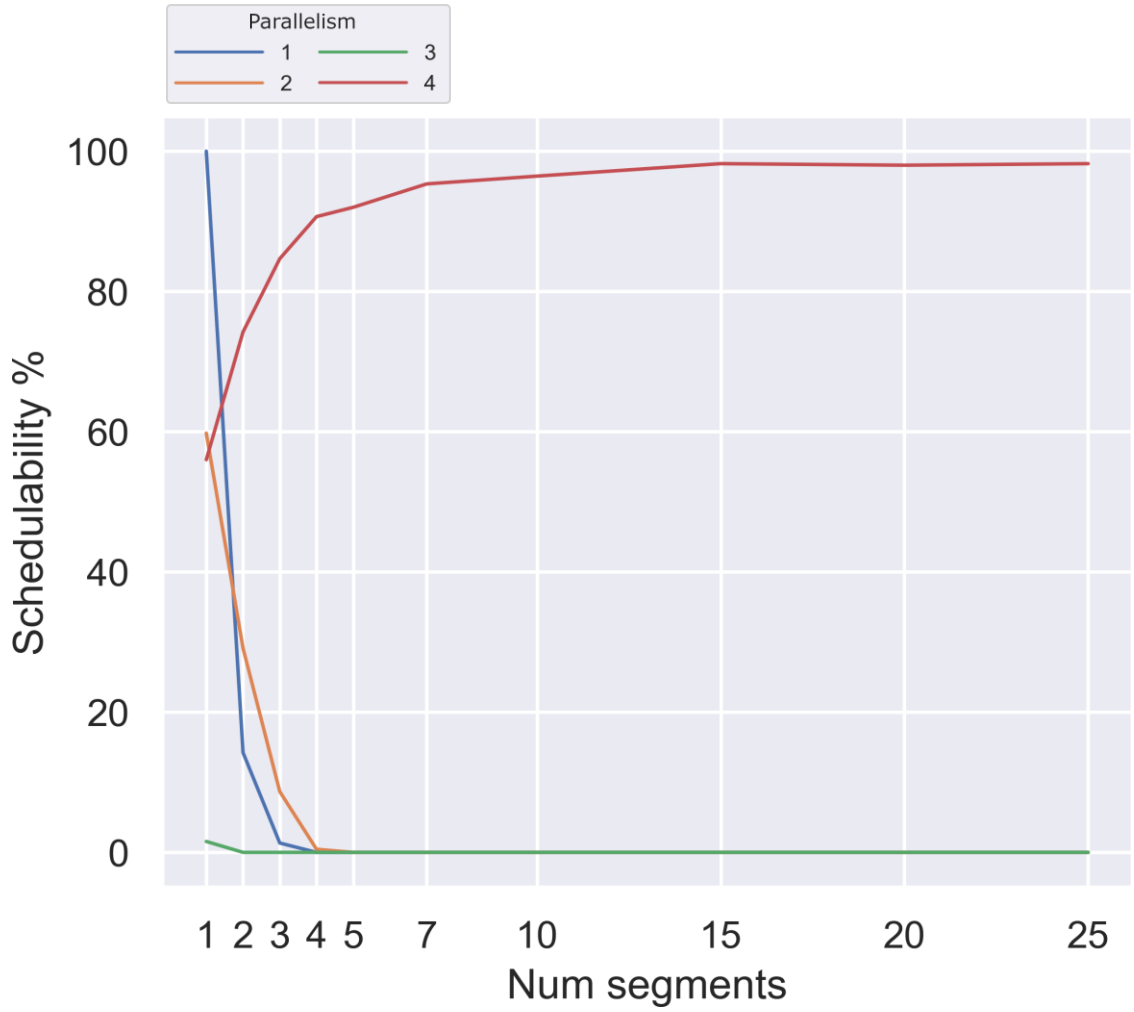
- System cores: 4
- System tasks:
  - 4 moldable tasks
  - 5 segments per task
- Execution time variation: 50%
- Implicit deadlines
- Rate monotonic



Our analysis results

Randomly generated task sets

- System cores: 4
- System tasks: 4 moldable tasks
- Execution time variation: 50%
- System utilization: 70%



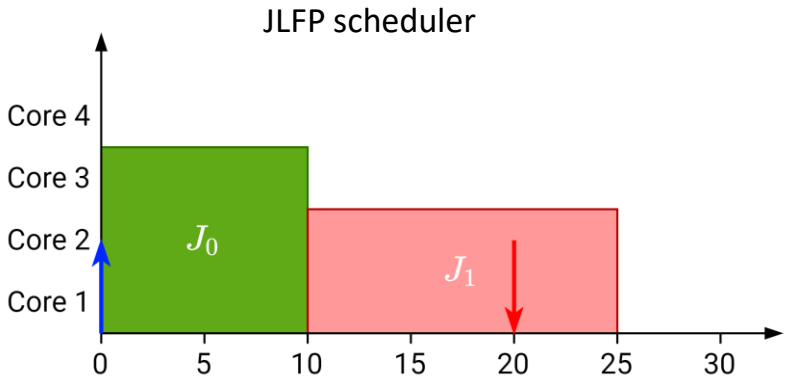
Agenda

- ✔ Gang schedulability analysis
- New scheduling policy

Core assignment

Core assignment

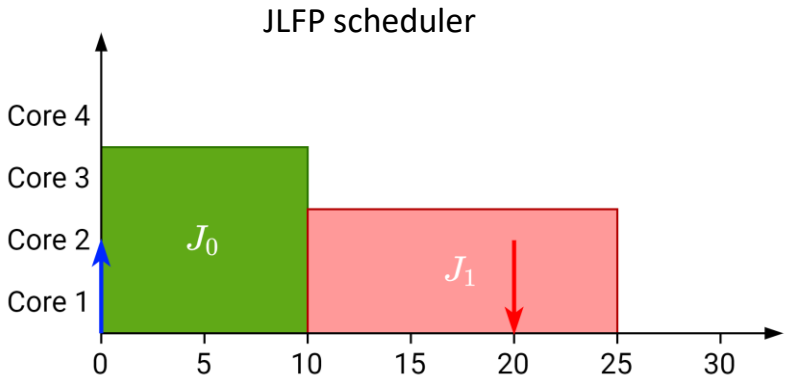
- JLFP assigns the maximum possible cores to a job



	Priority	Min cores	Max cores	Deadline	Execution time
J_0	High	1	3	20	30, 15, 10
J_1	Low	2	2	20	15

Core assignment

- JLFP assigns the maximum possible cores to a job
- Assign minimum number of cores that meet deadline



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J_0	High	1	3	20	30, 15, 10
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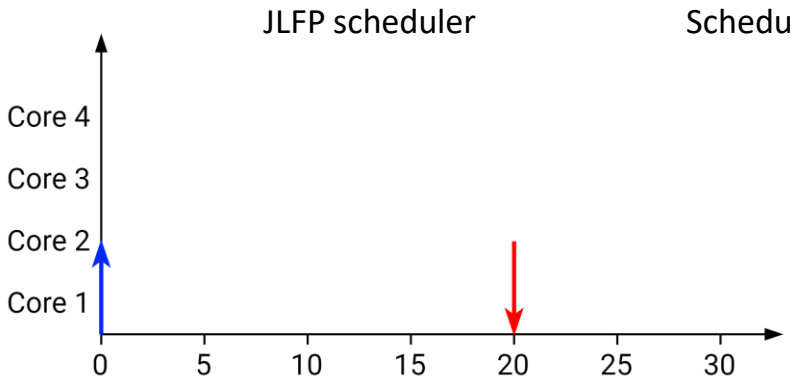

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J_0	High	1	3	20	30, 15, 10
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Core assignment

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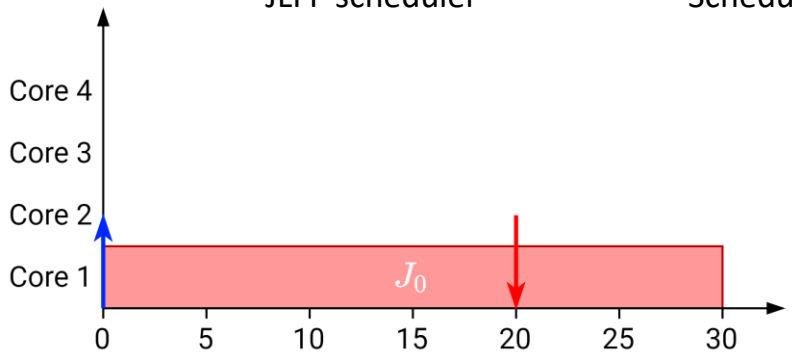
JLFP scheduler

Scheduling: J_0



	Priority	Min cores	Max cores	Deadline	Execution time
J_0	High	1	3	20	30, 15, 10
J_1	Low	2	2	20	15

Core assignment

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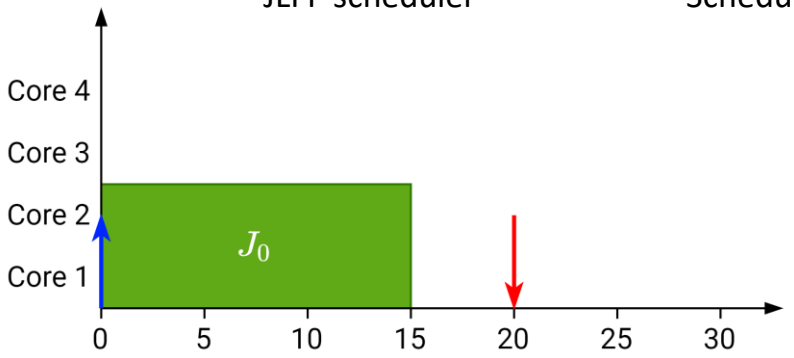
JLFP scheduler

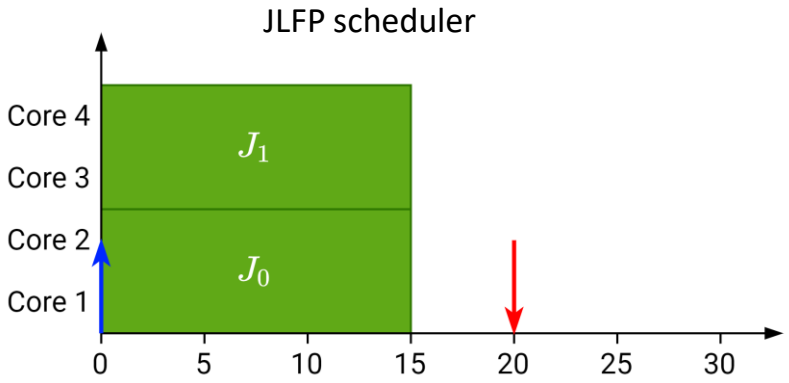


Scheduling: J_1

	Priority	Min cores	Max cores	Deadline	Execution time
J_0	High	1	3	20	30, 15, 10
J_1	Low	2	2	20	15

Core assignment

- JLFP assigns the maximum possible cores to a job
- Assign minimum number of cores that meet deadline



	Priority	Min cores	Max cores	Deadline	Execution time
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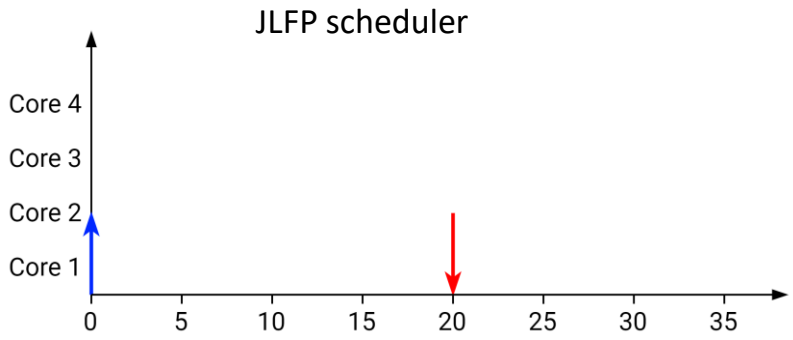
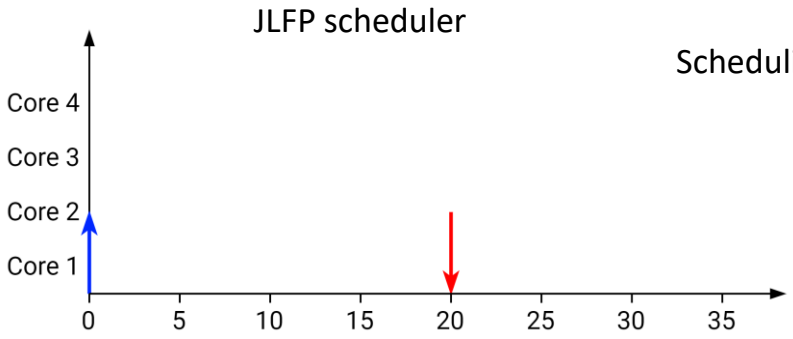
JLFP limitations with moldable gang

JLFP limitations with moldable gang



	Priority	Cores	Deadline	Execution time
J_0	High	2	∞	10
J_1	Mid-high	3	20	5
J_2	Mid-low	1	∞	20
J_3	Low	1	∞	20

JLFP limitations with moldable gang



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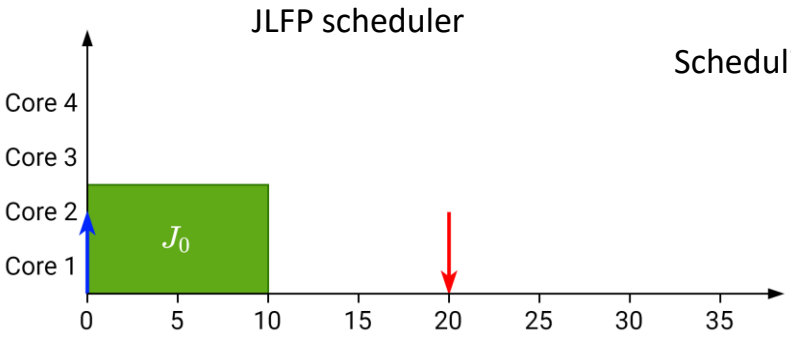
J_1	Mid-high	3	20	5
J_2	Mid-low	1	∞	20
J_3	Low	1	∞	20

JLFP limitations with moldable gang



	Priority	Cores	Deadline	Execution time
J_0	High	2	∞	10
J_1	Mid-high	3	20	5
J_2	Mid-low	1	∞	20
J_3	Low	1	∞	20

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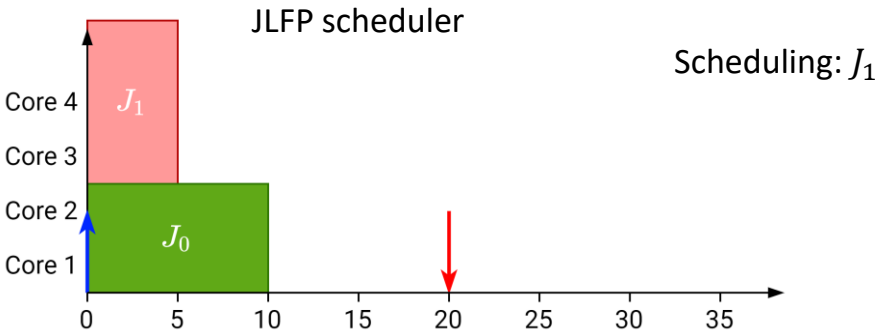

	Priority	Cores	Deadline	Execution time
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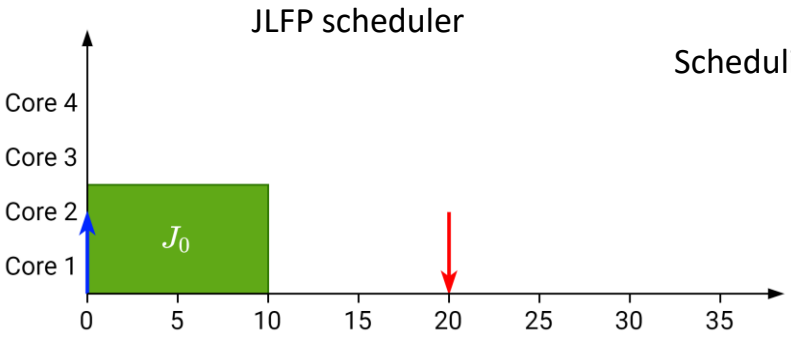

	Priority	Cores	Deadline	Execution time
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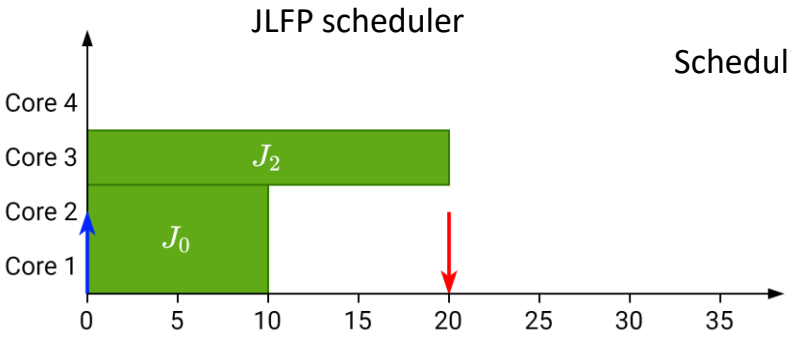

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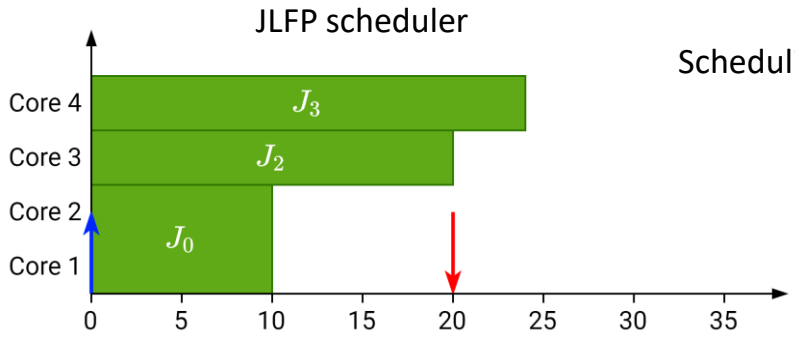

Scheduling: J_1

	Priority	Cores	Deadline	Execution time
J_0	High	2	∞	10
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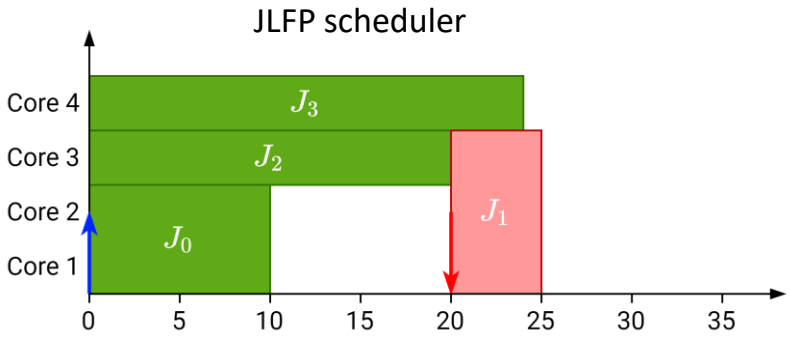
JLFP limitations with moldable gang



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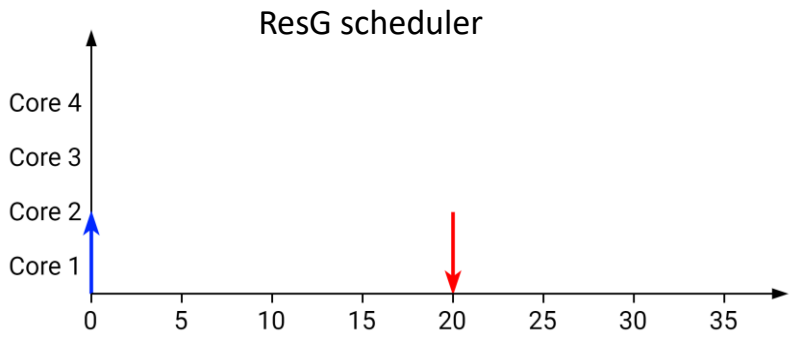
Reservation-based gang scheduler

- Reservation-based



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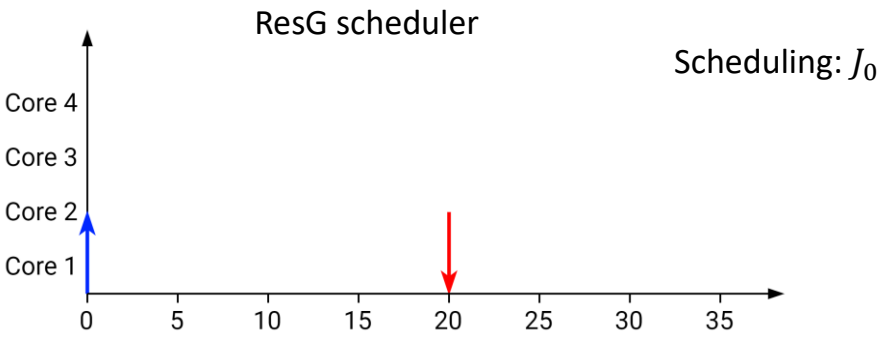

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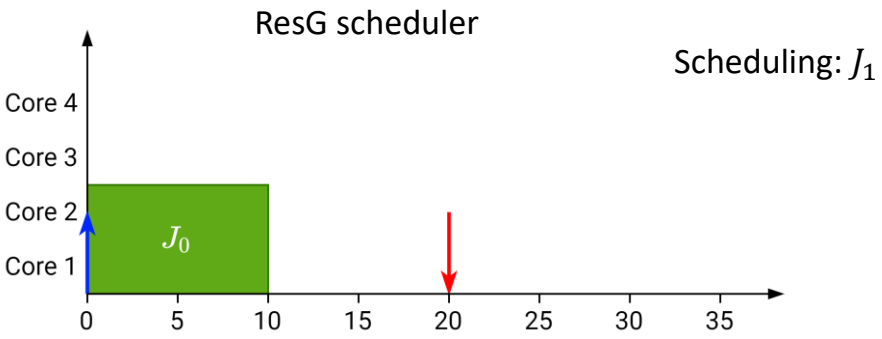

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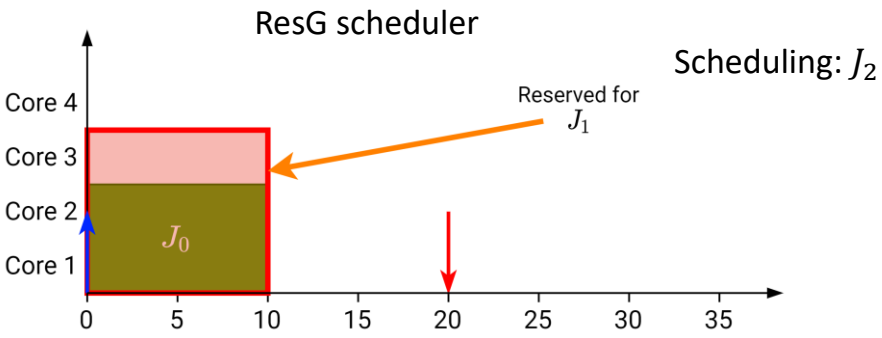
- Reserve cores of higher-priority tasks and distribute the remaining ones among lower priority tasks



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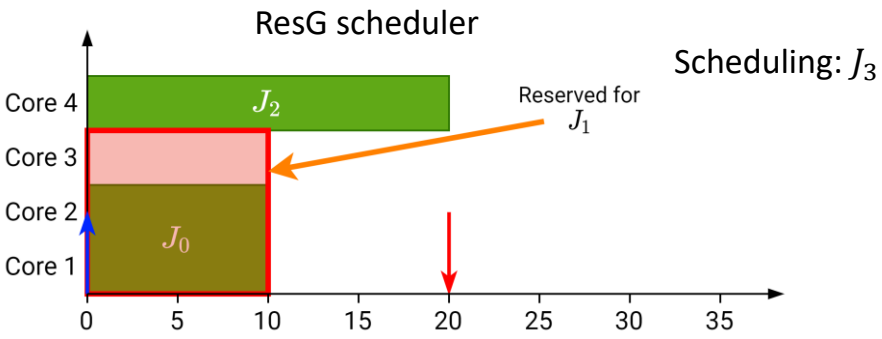

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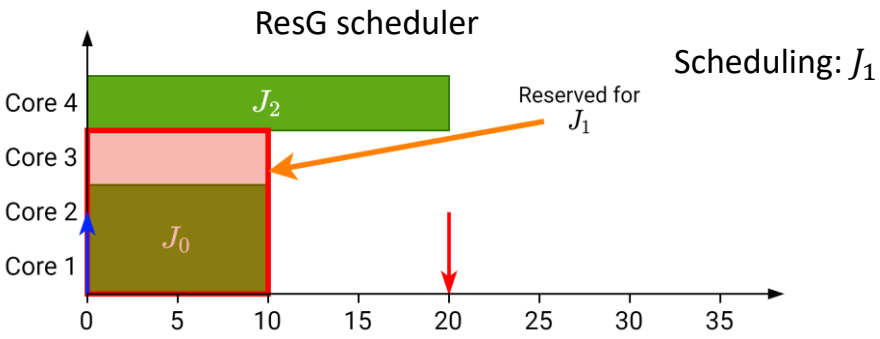

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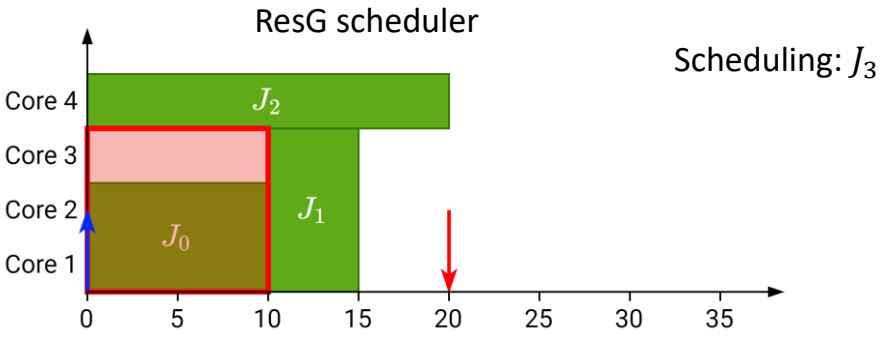

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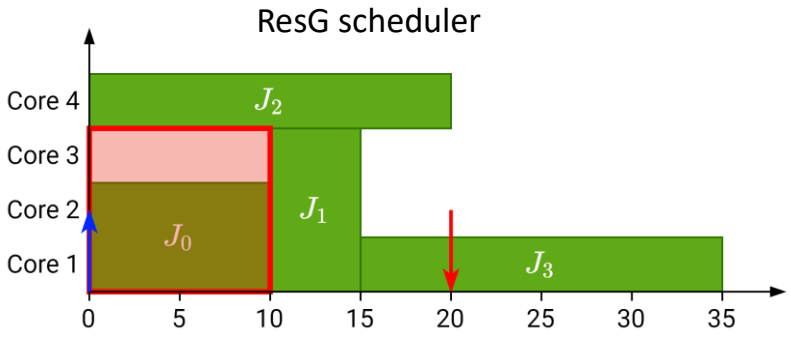

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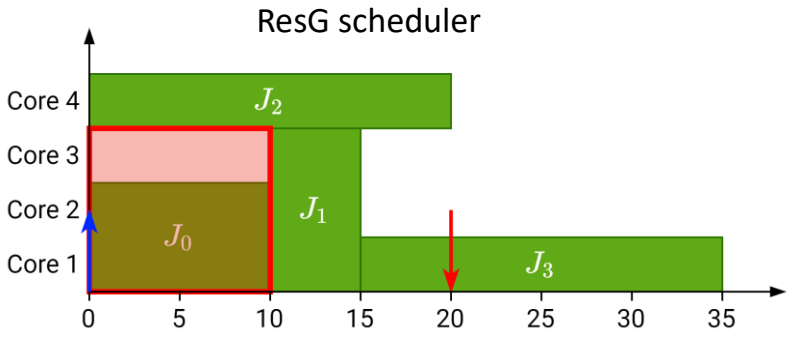
Reservation-based gang scheduler

- Reservation-based
- Reserve cores of higher-priority tasks and distribute the remaining ones among lower priority tasks
- Non-work conserving scheduler



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Results JLFP vs ResG in simulator

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- Randomly generated task sets
  - System cores: 8
  - 20 moldable tasks
  - Implicit deadlines
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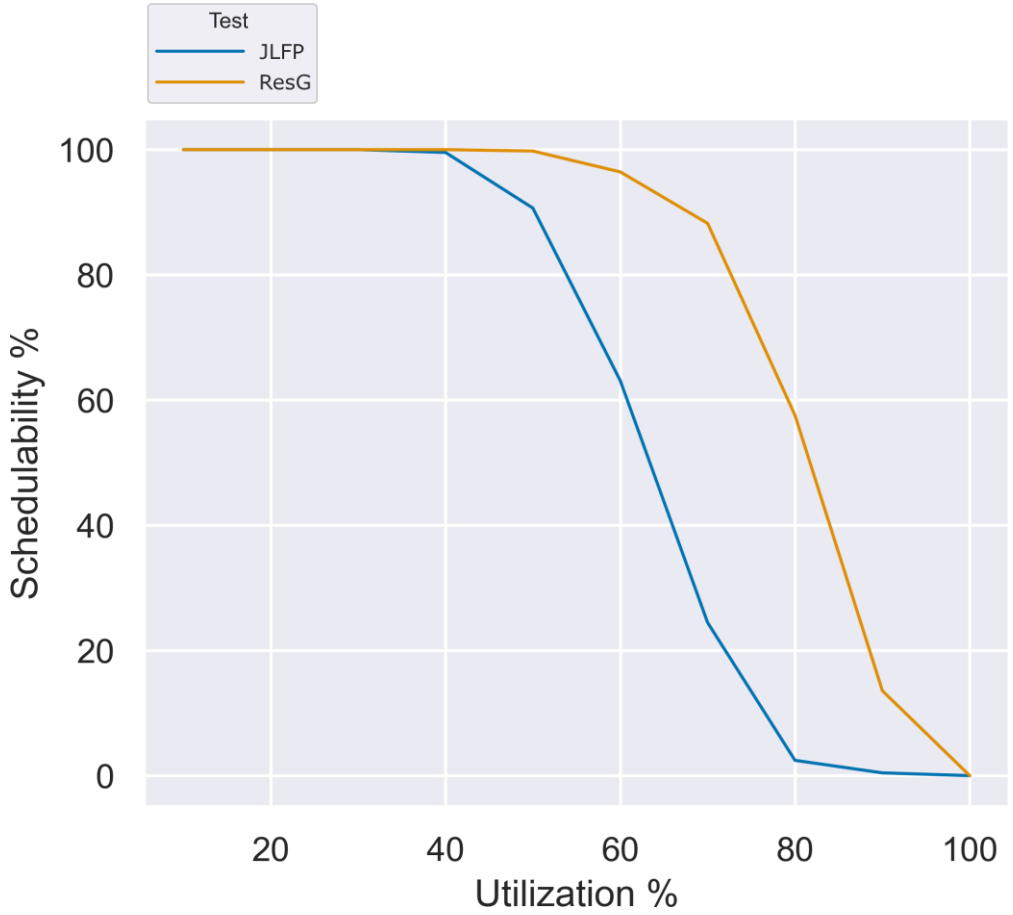

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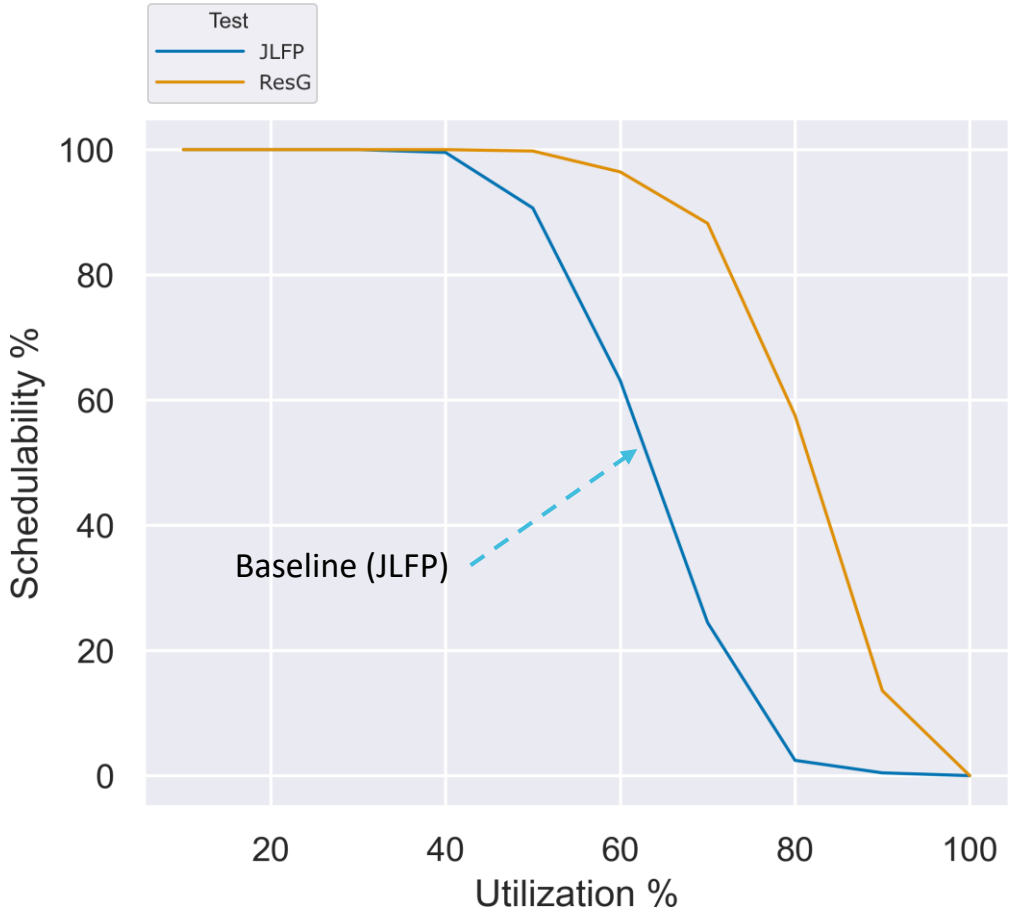

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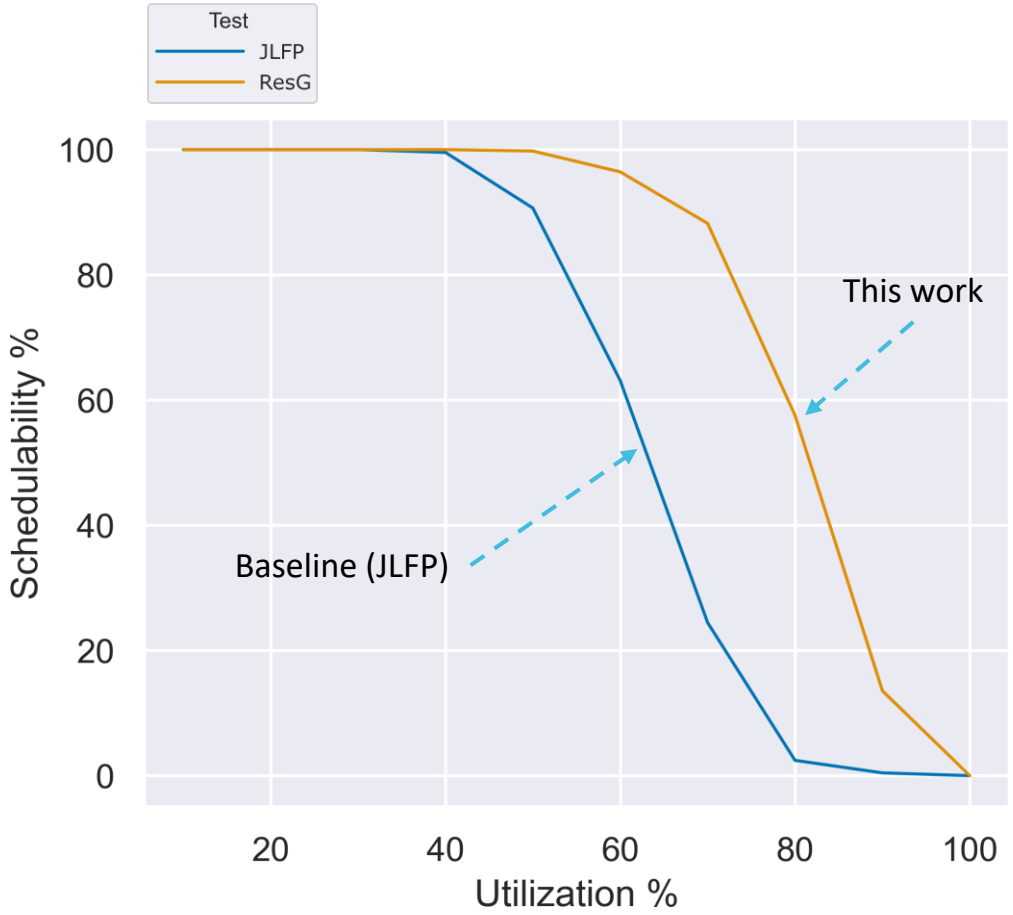

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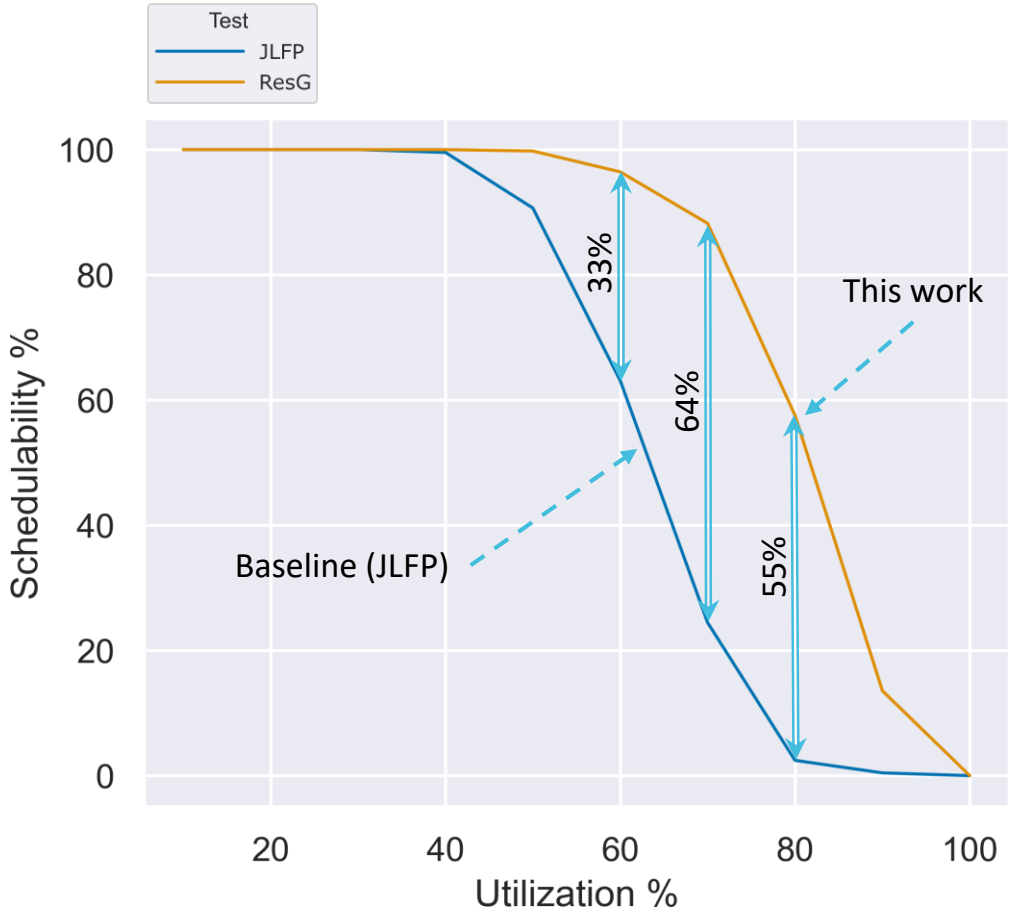

Conclusions

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- The maximum parallelism of a gang task has a big role in the schedulability

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- The maximum parallelism of a gang task has a big role in the schedulability
- With a better scheduling policy one can improve the schedulability of moldable gang tasks

Future work

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- Further reduce sources of pessimism with precedence constraints

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- Further reduce sources of pessimism with precedence constraints
- Provide an SAG analysis for the new scheduling policy

Contributions

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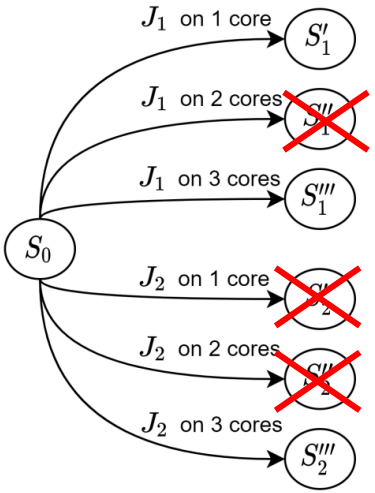
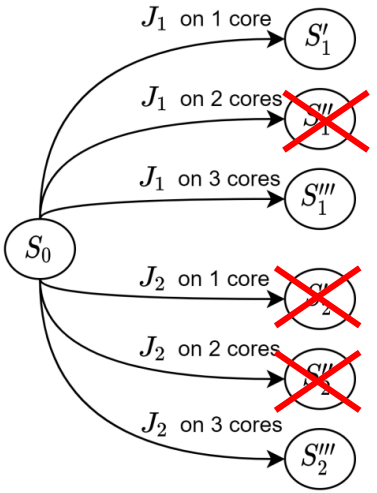
New schedulability analysis



Contributions

New schedulability analysis

Moldable gang tasks evaluation

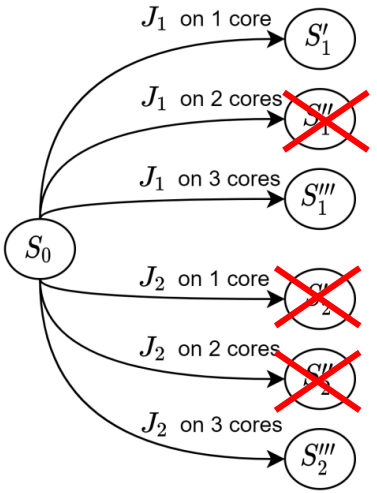


Contributions

New schedulability analysis

Moldable gang tasks evaluation

Paper submitted to RTSS 2020 for the non-preemptive analysis



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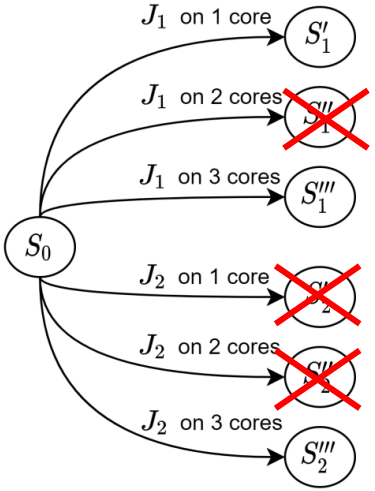

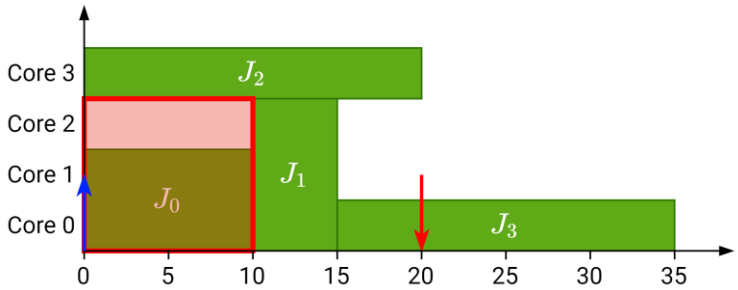

Contributions

New schedulability analysis

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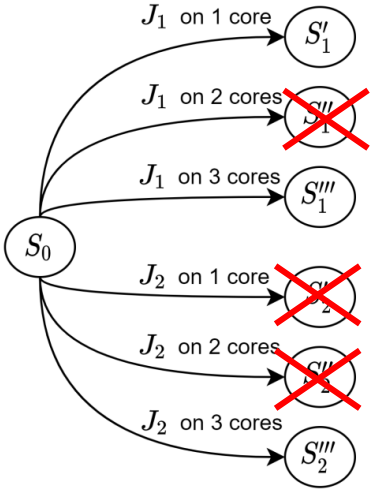
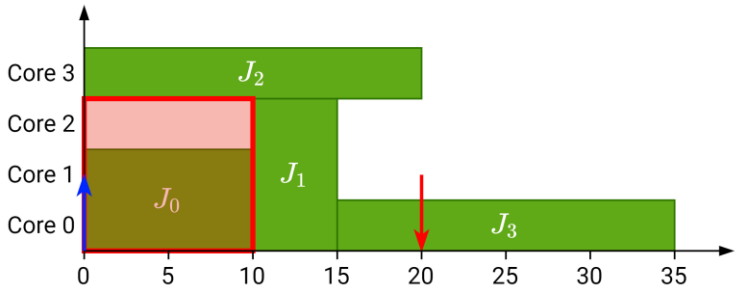
Presented in CAPITAL workshop





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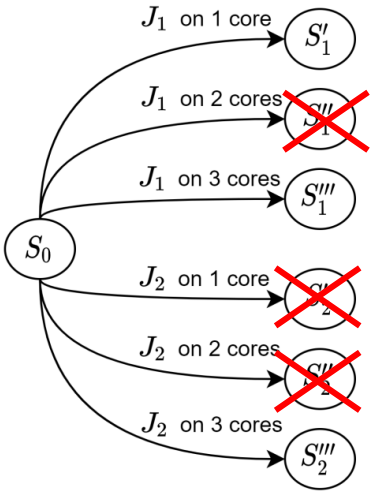
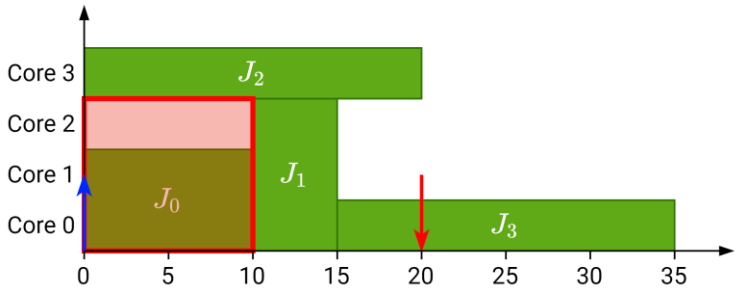
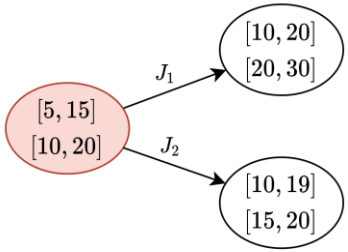


Thank you!

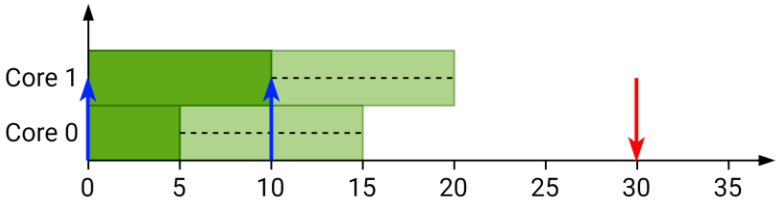


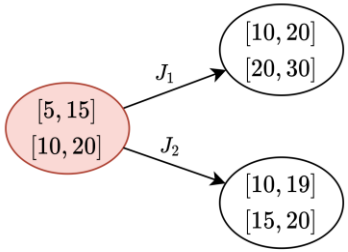
How does SAG work?



How does SAG work?

J_i	C_i^{min}	C_i^{max}	r_i	d_i	P_i
J_1	10	15	10	30	1
J_2	5	5	0	100	2





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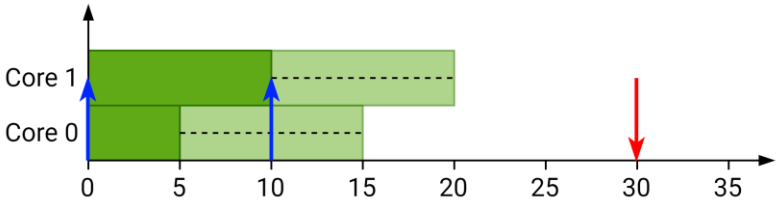

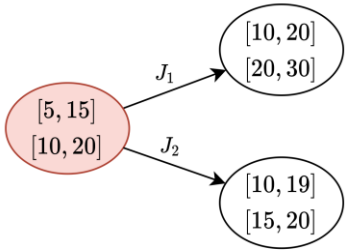

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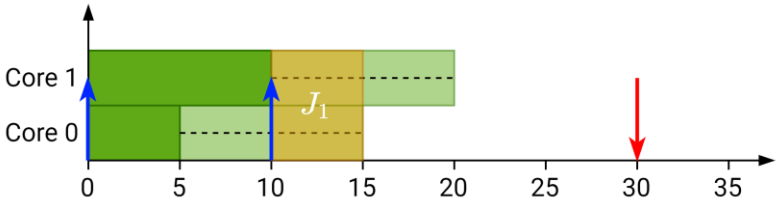

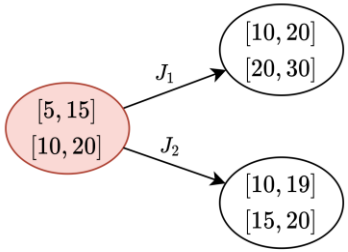

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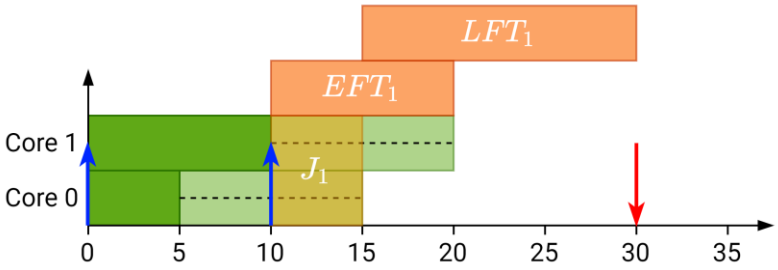

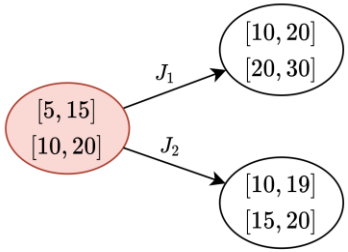

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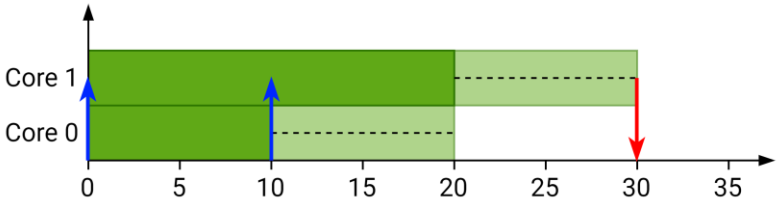

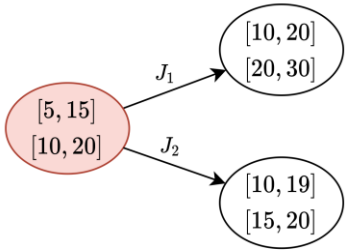

How does SAG work?

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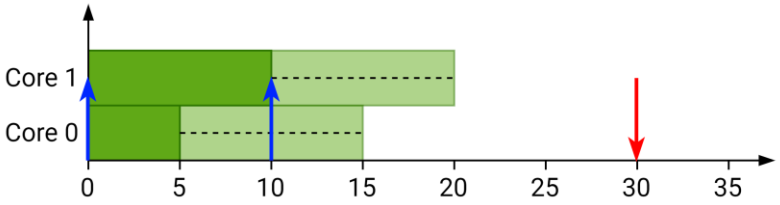

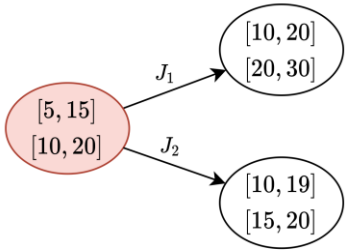

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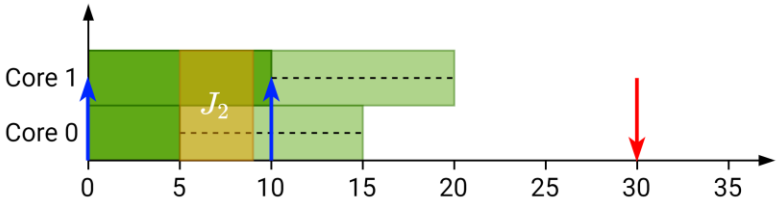

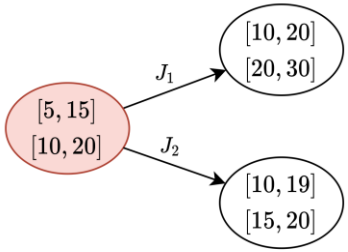

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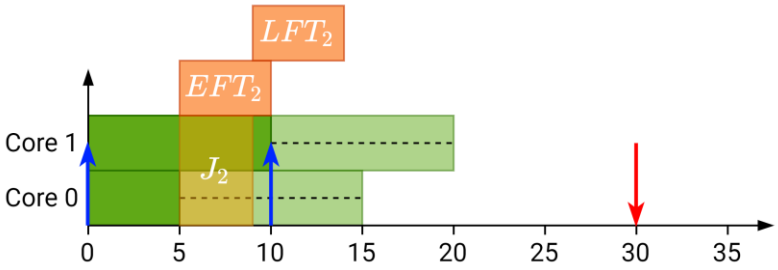

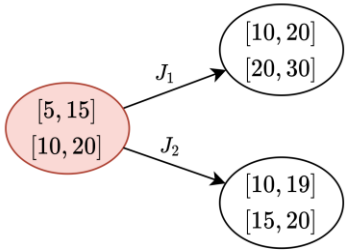

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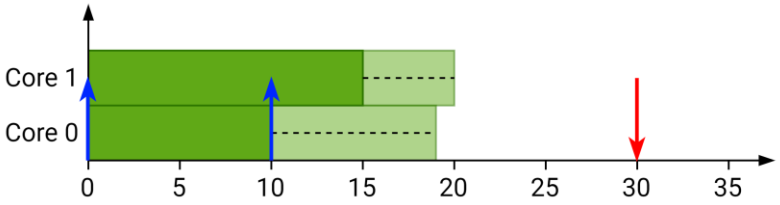

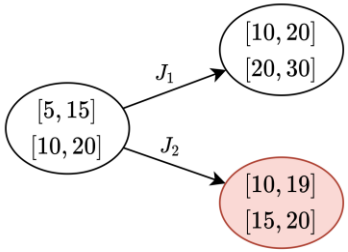

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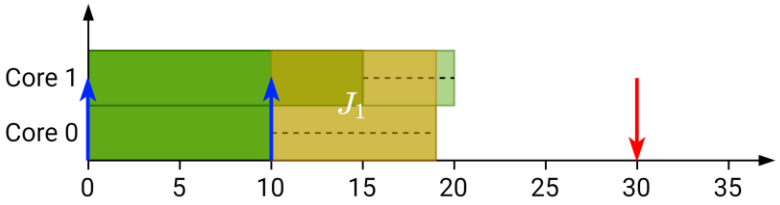

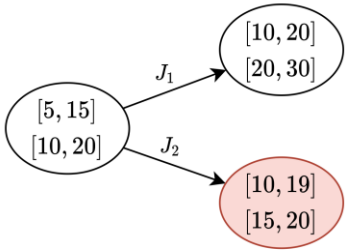

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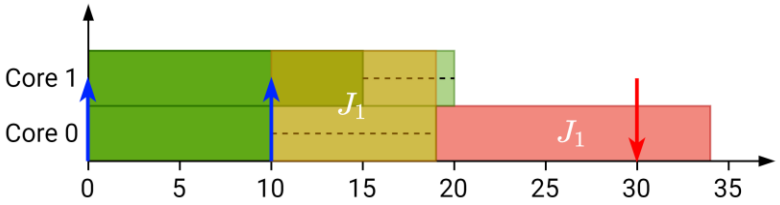
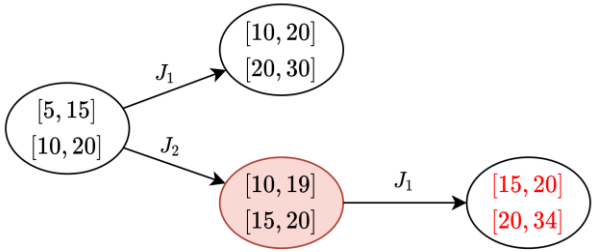
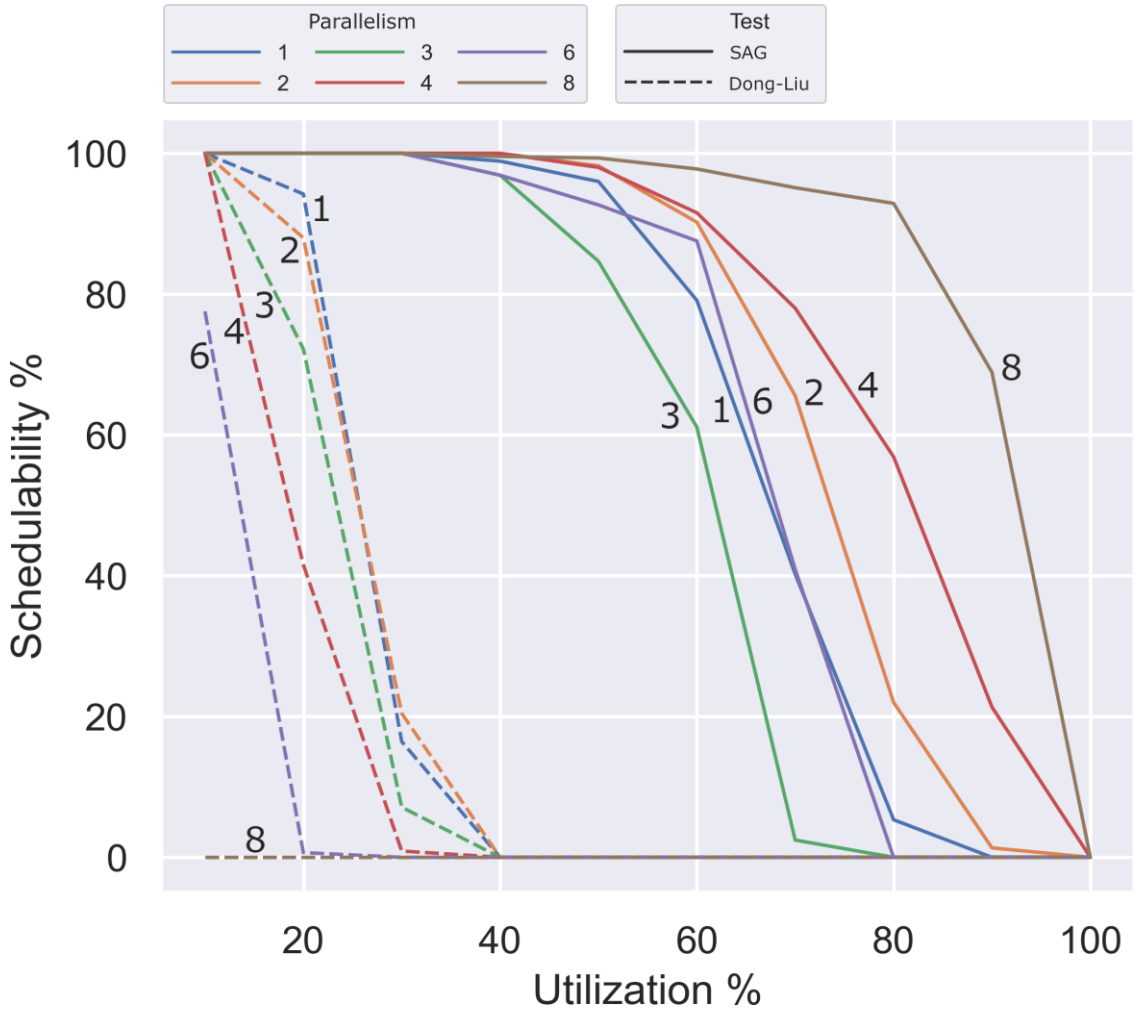




Runtime analysis

Randomly generated task sets

- System cores: 8
- System tasks: 20 rigid tasks
- Execution time variation: 50%
- Implicit deadlines
- Rate monotonic



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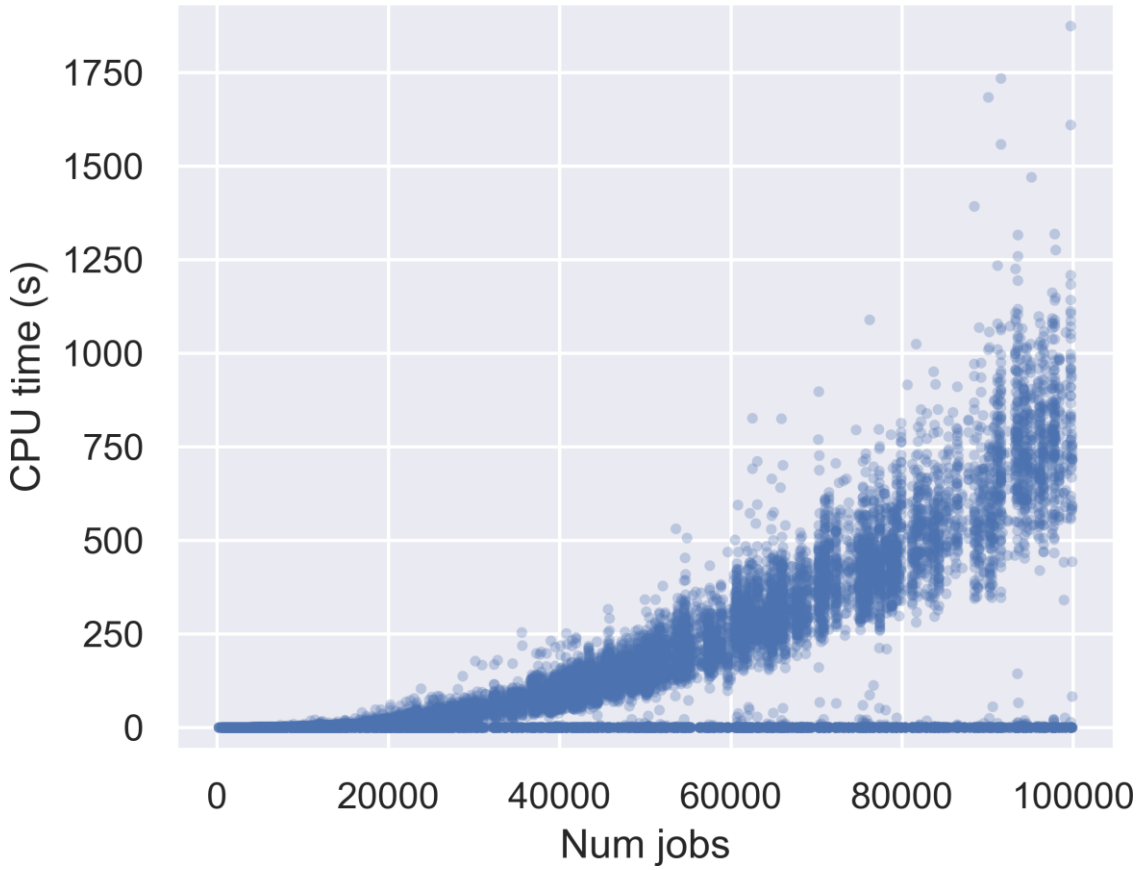

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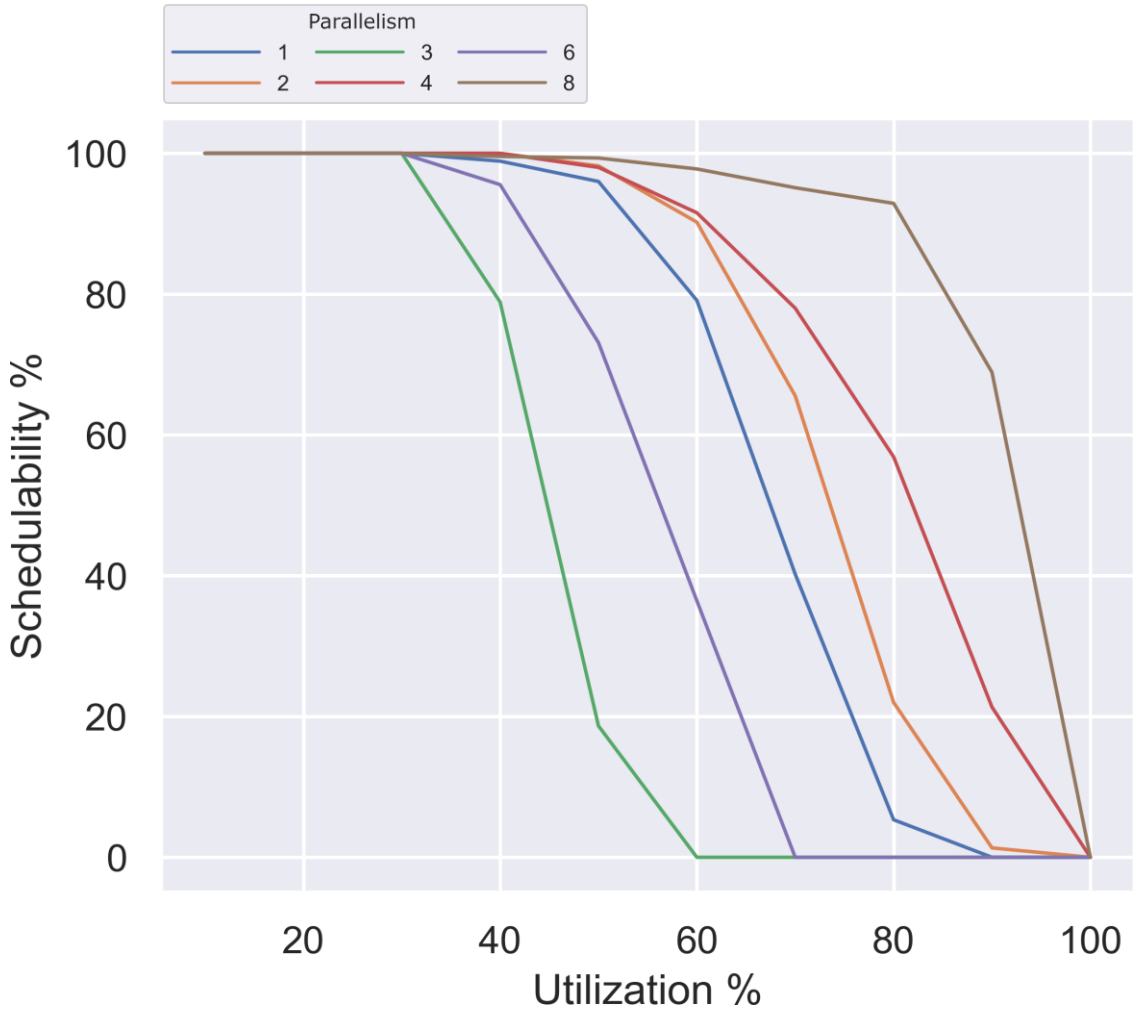

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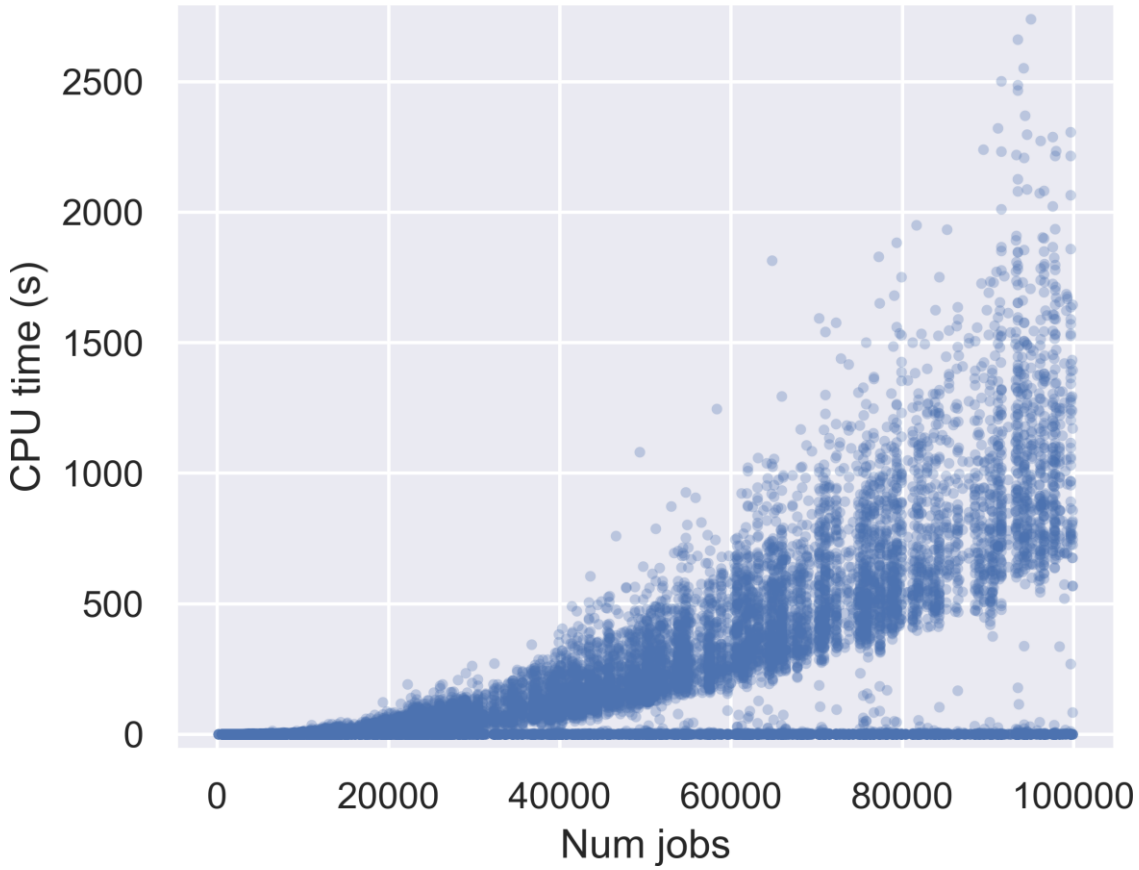

Our analysis results

Randomly generated task sets

- System cores: 4
- System tasks:
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  - 5 segments per task
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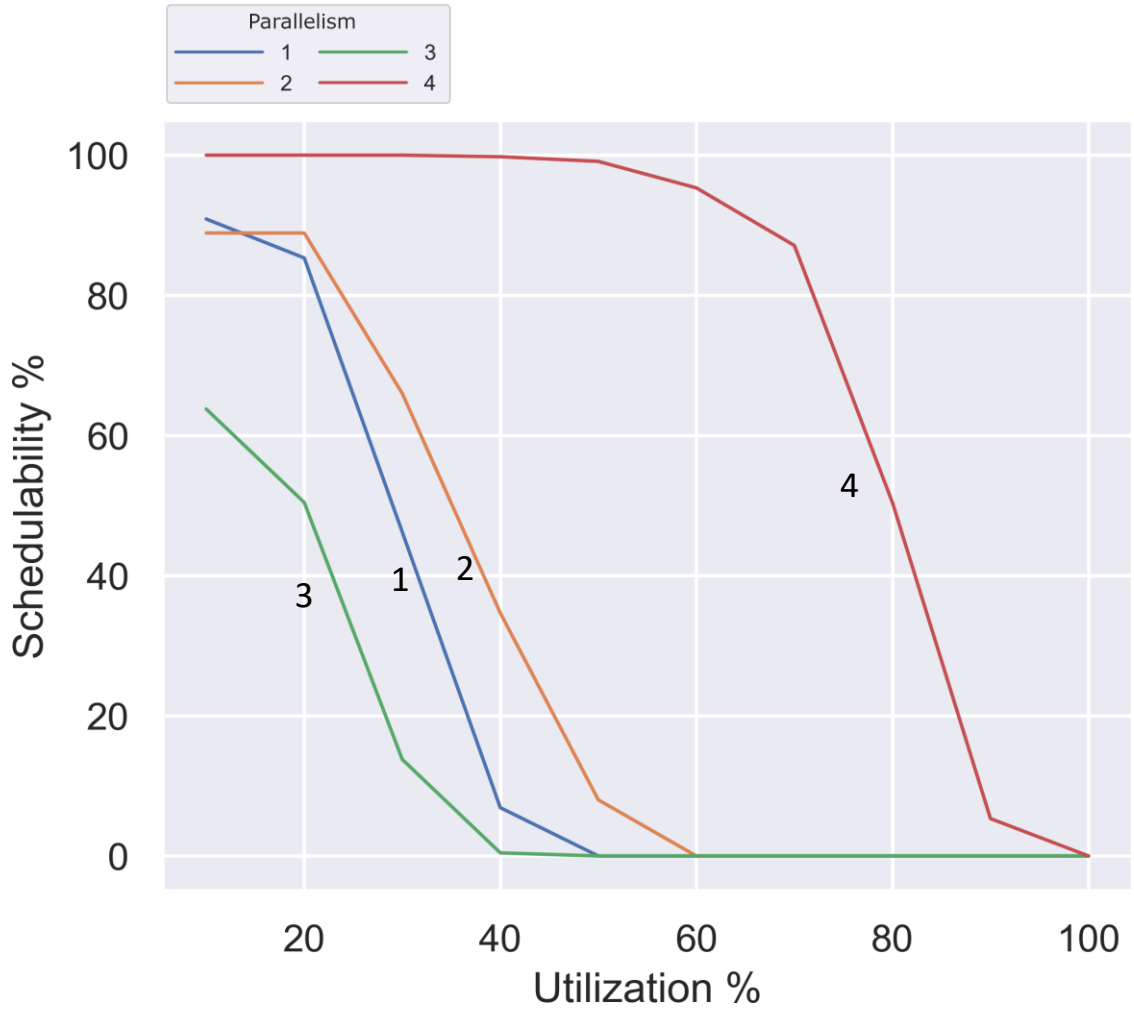

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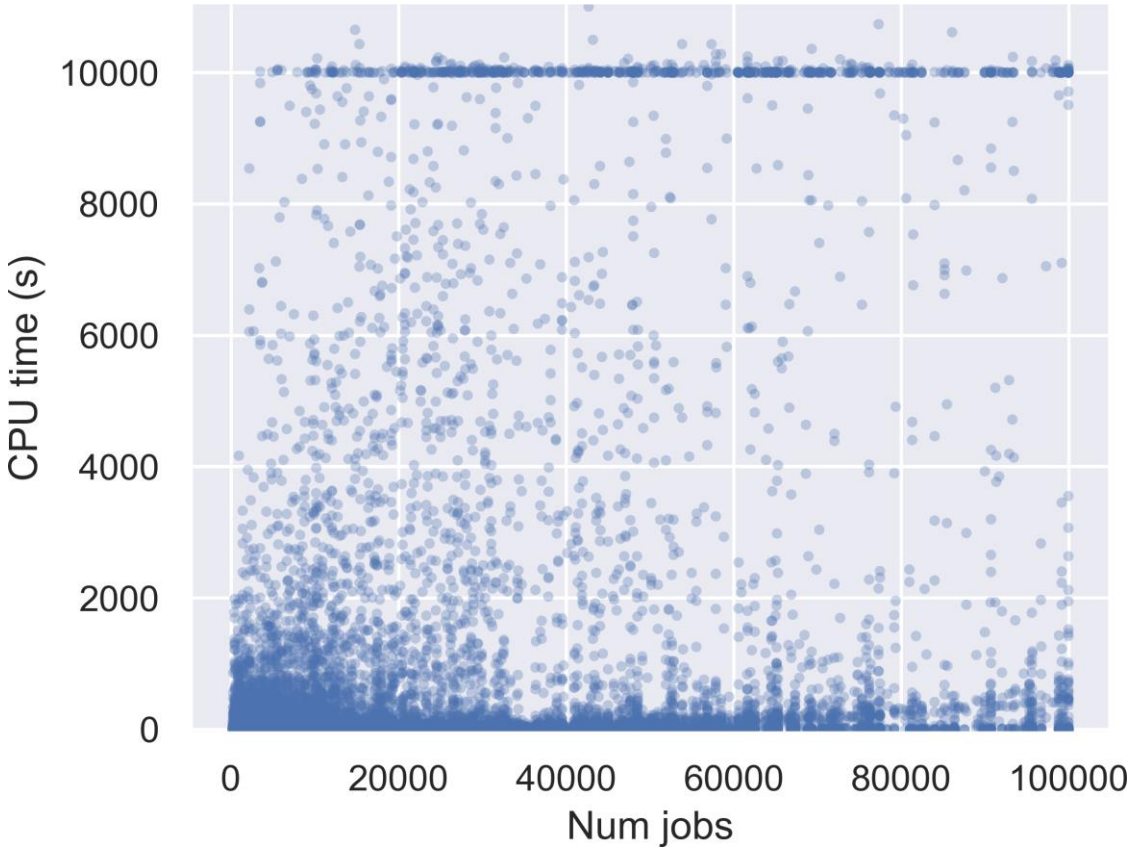
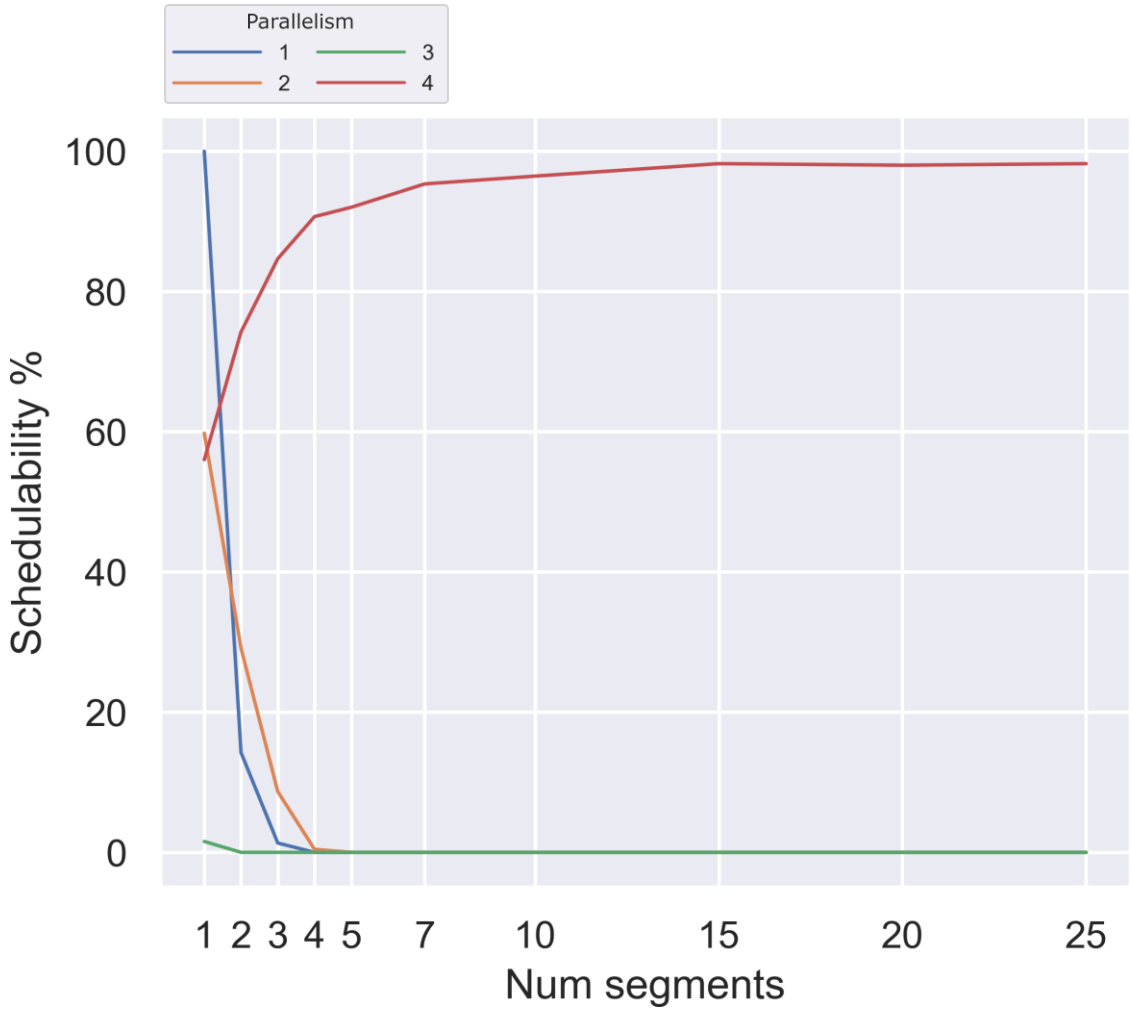


Our analysis results

Randomly generated task sets

- System cores: 4
- System tasks: 4 moldable tasks
- Execution time variation: 50%
- System utilization: 70%



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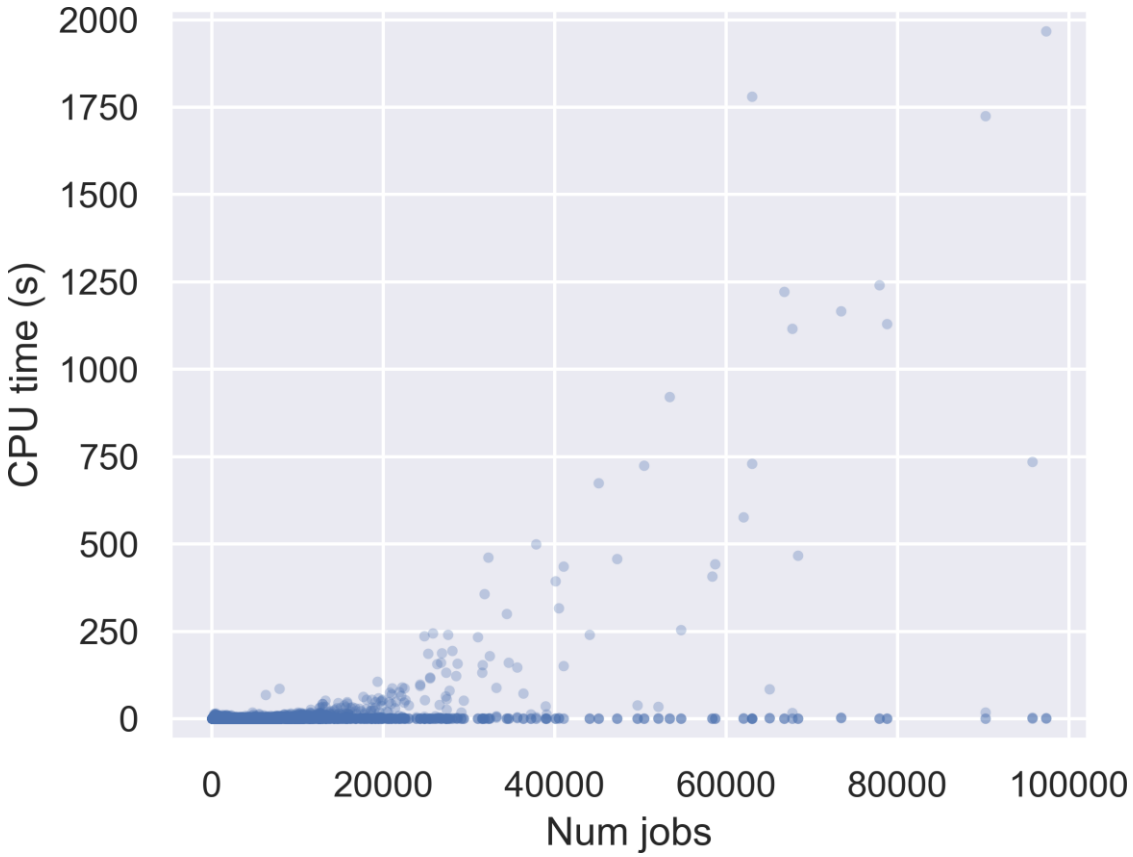

Computational complexity

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