Schedulability Analysis of Synchronous Digraph Real-Time Tasks

Morteza Mohaqeqi, Jakaria Abdullah, Nan Guan, Wang Yi

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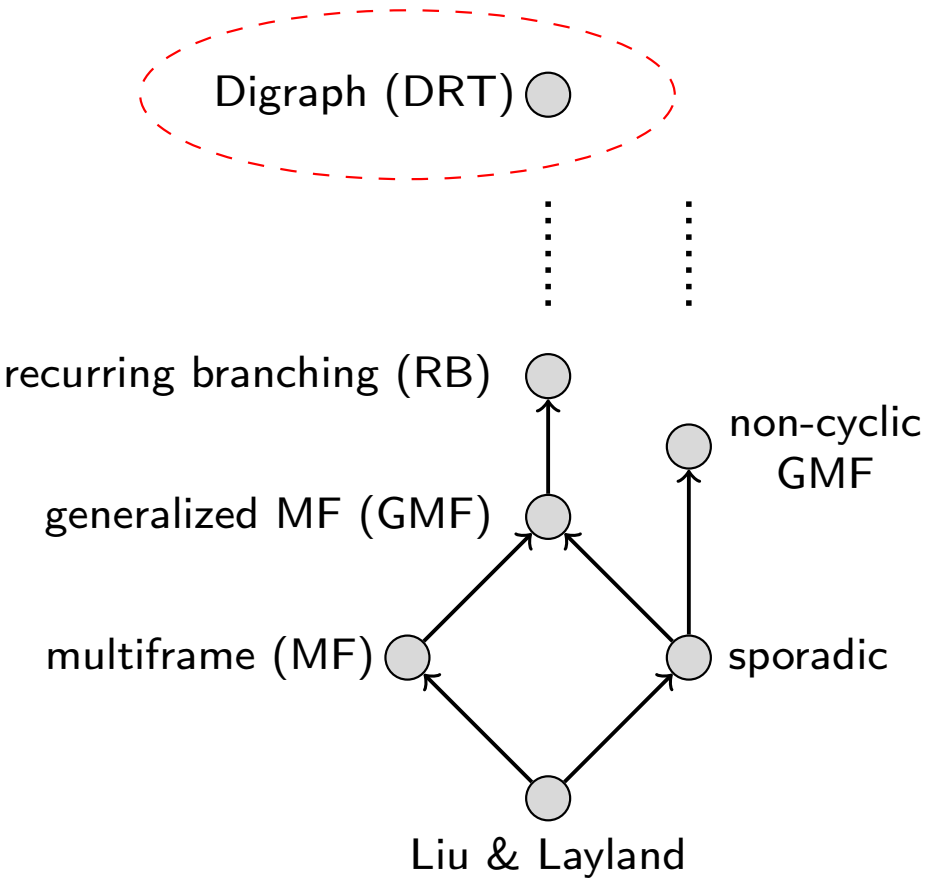
ECRTS 2016

Introduction

Real-Time Task Models:



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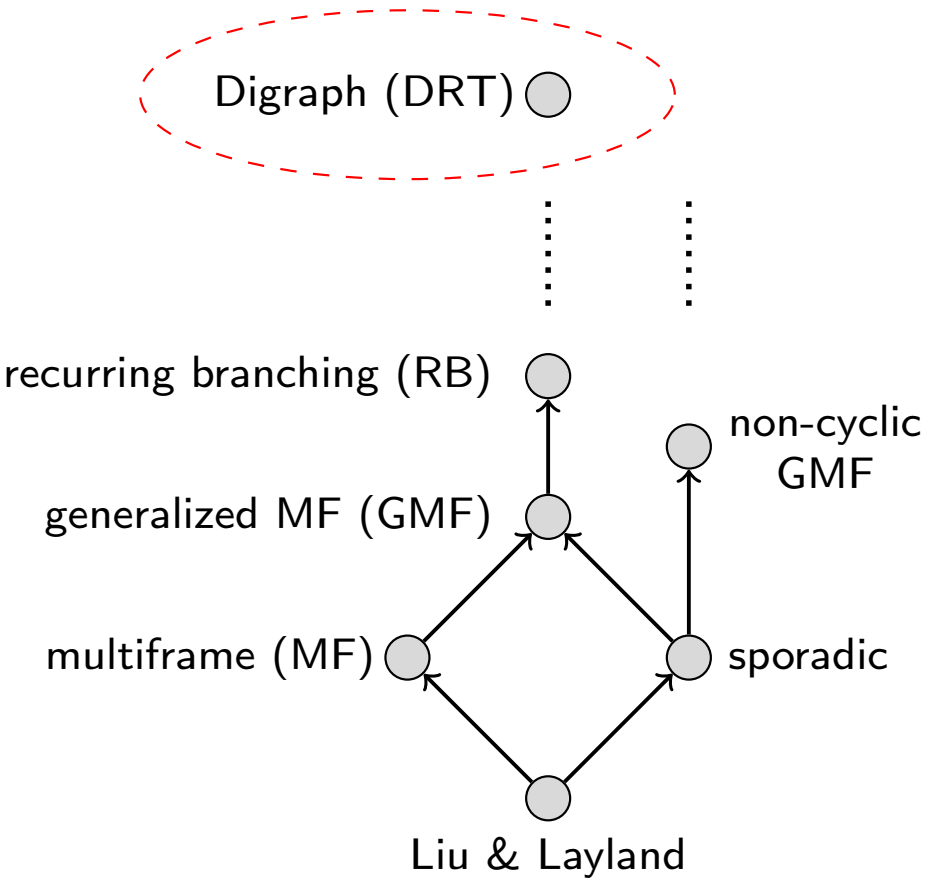
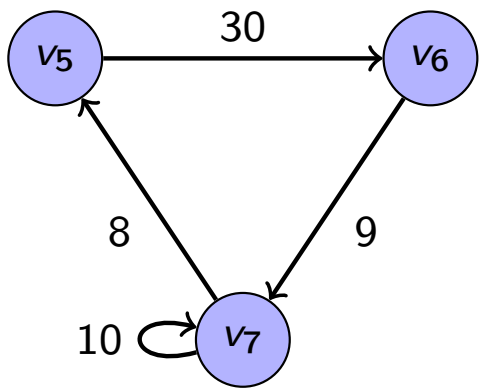
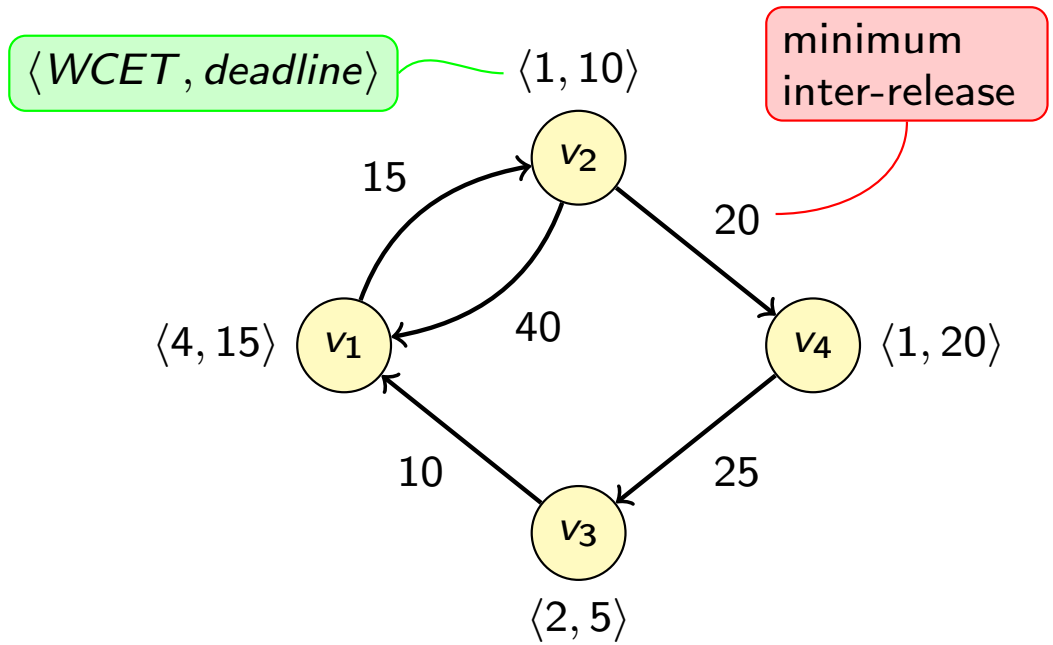


- Proposed by M. Stigge et al. (2011)
- Real-time tasks with different job types



The Digraph Real-Time (DRT) Task Model

- Job Types
  - WCET
  - Relative deadline
- Conditional flow (Branch)



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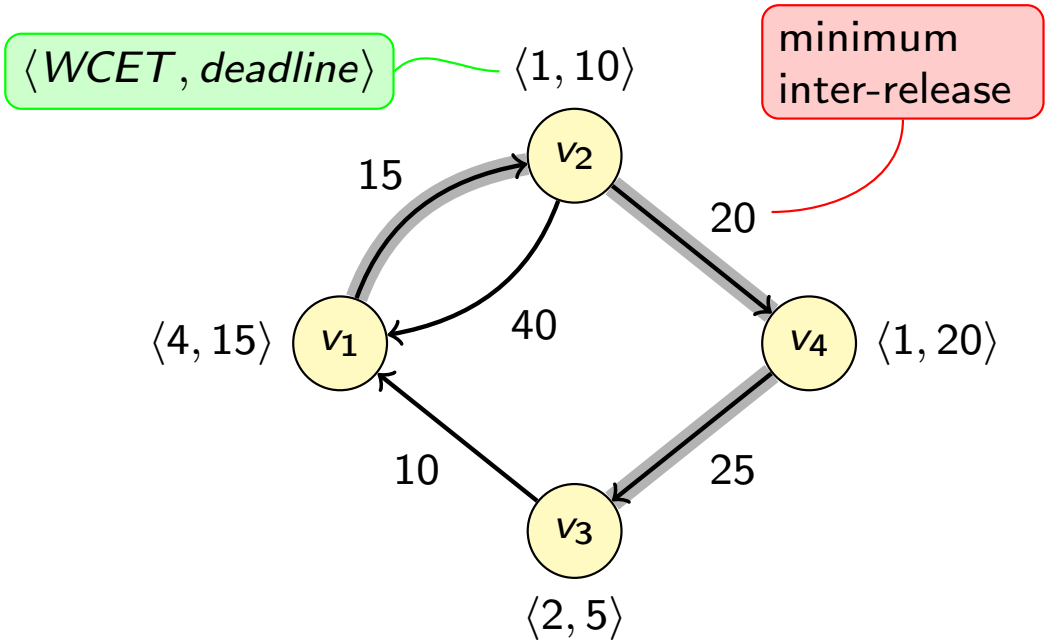

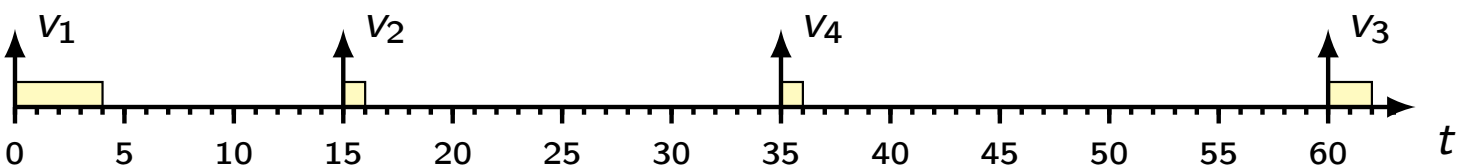

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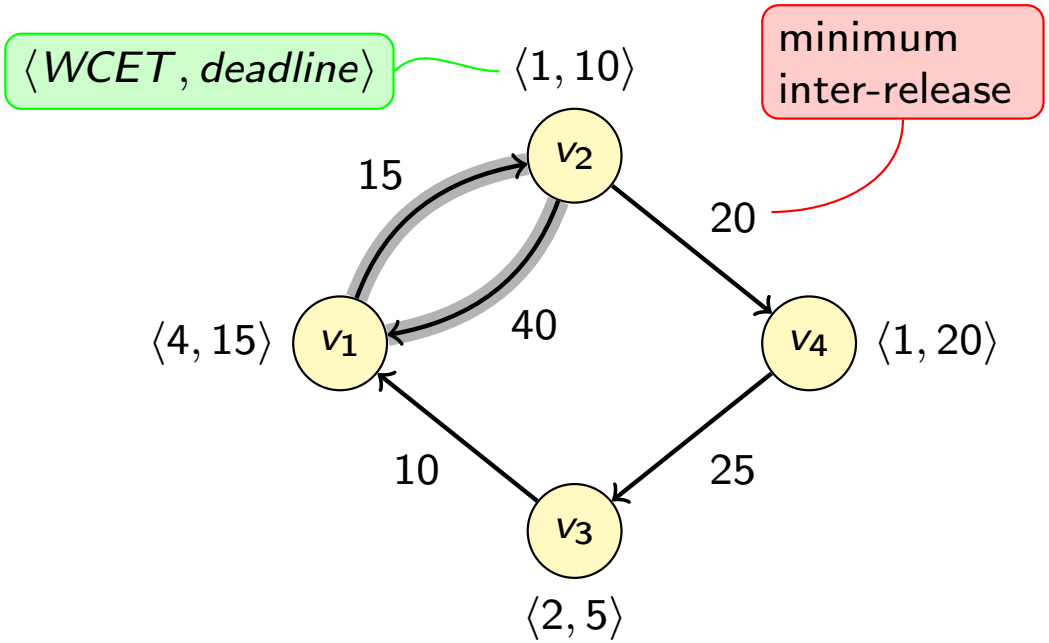
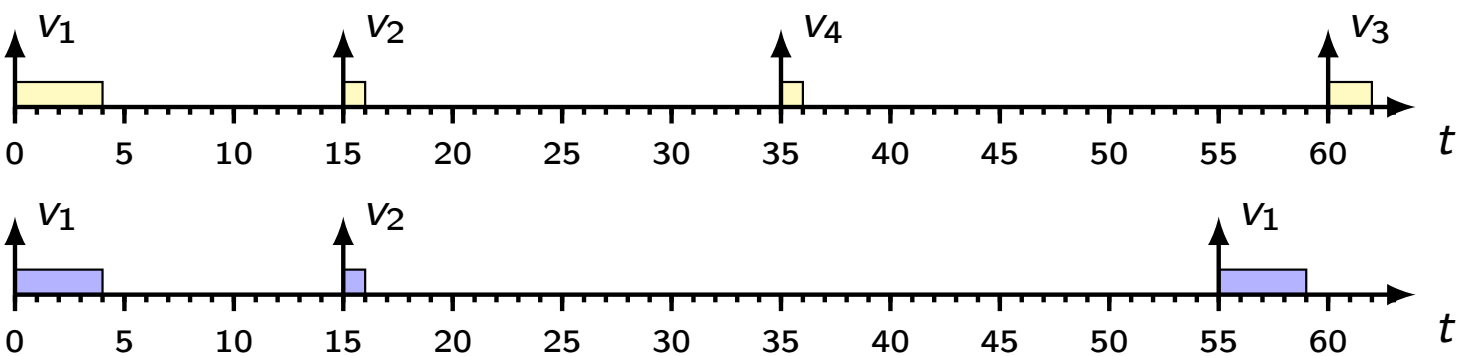




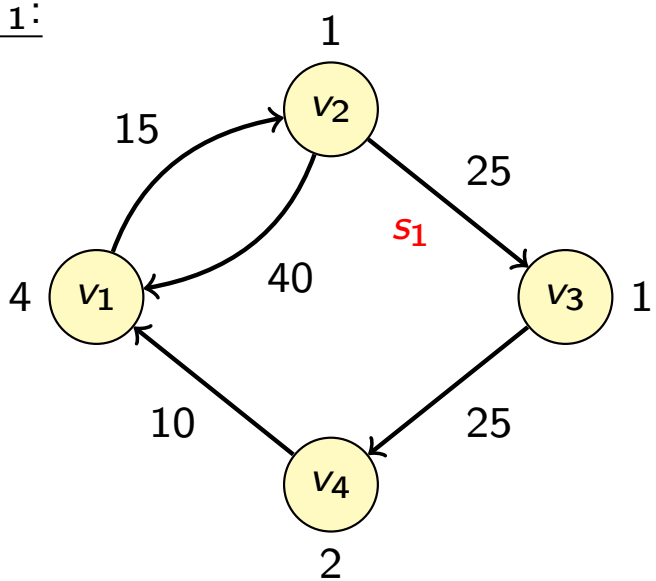
Outline

Synchronous DRT

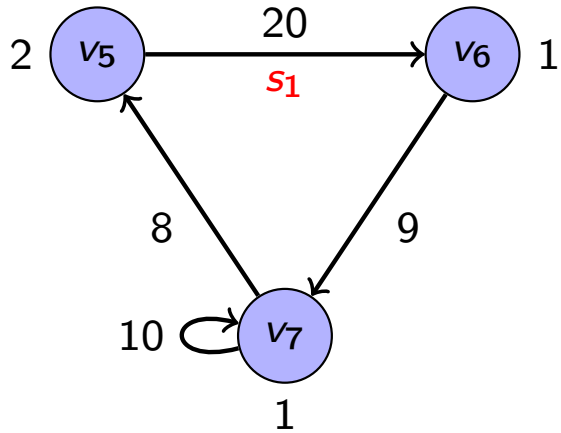
- Synchronized Release

Semantics

Task T_1:

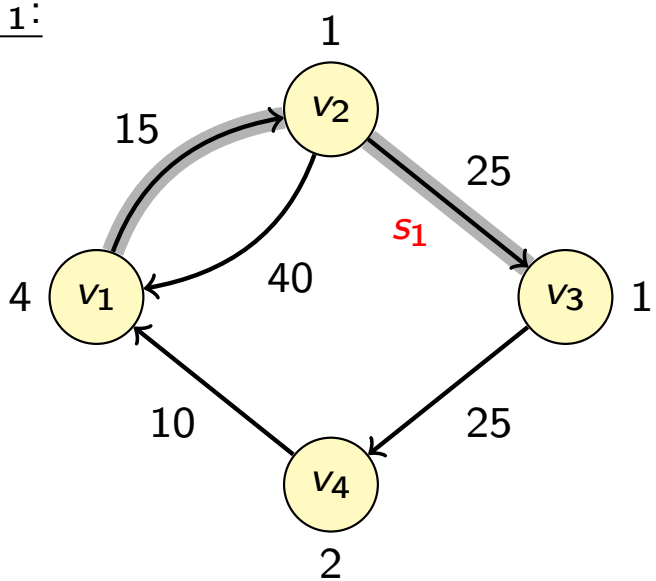


Task T_2:

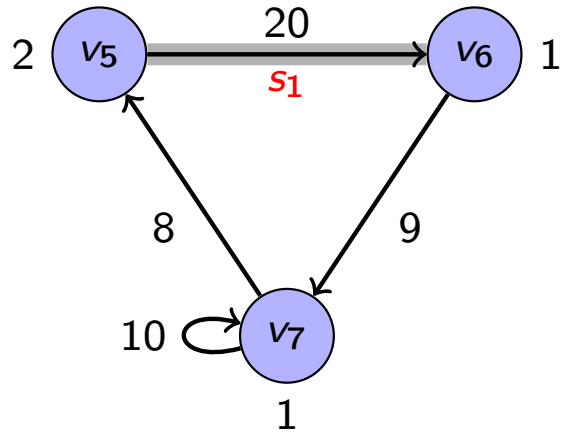


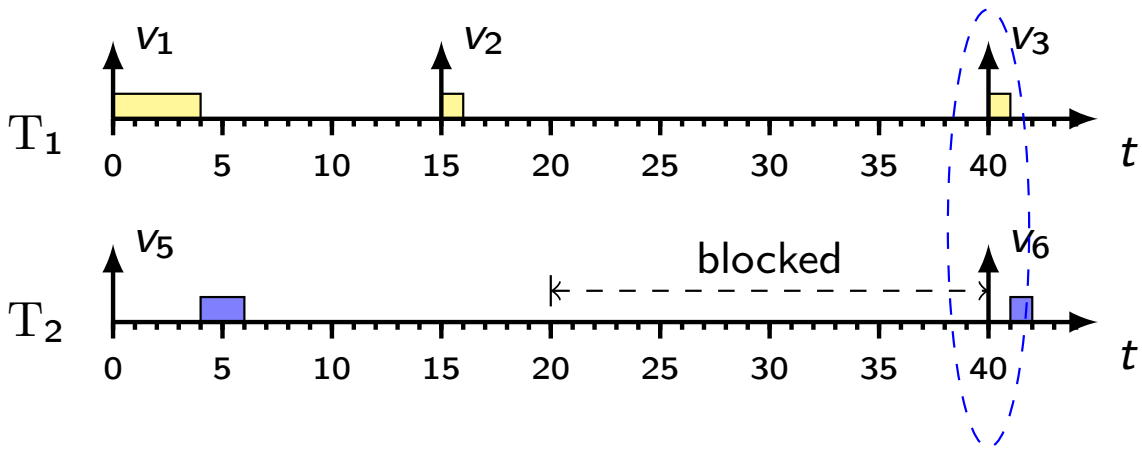
Semantics

Task T_1:



Task T_2:





Overview

Assumptions

- Uniprocessor
- Preemptive scheduling
- Fixed priority

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Contributions

- Schedulability analysis
- Heuristics for better efficiency

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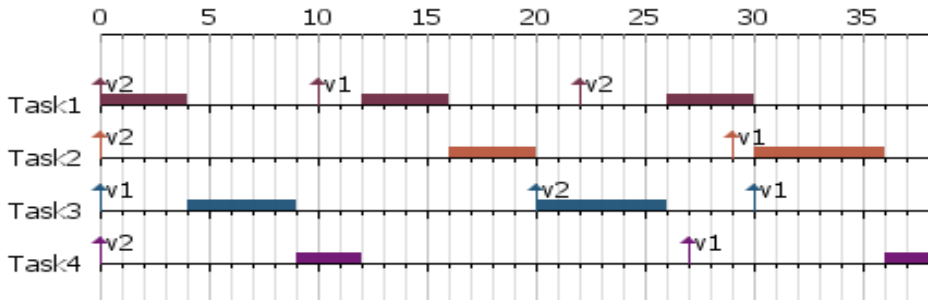
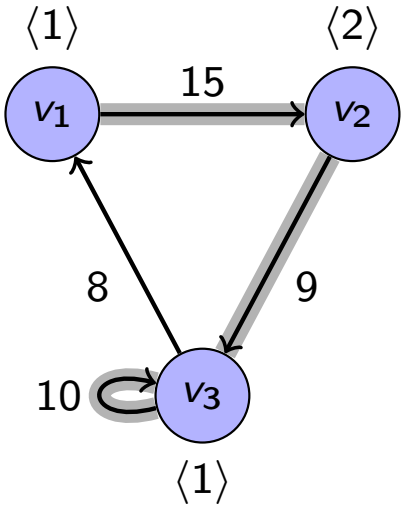
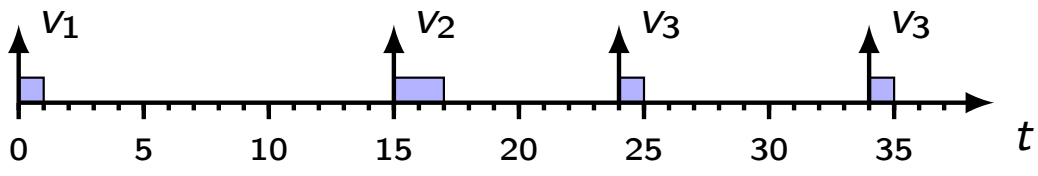


DRT Schedulability





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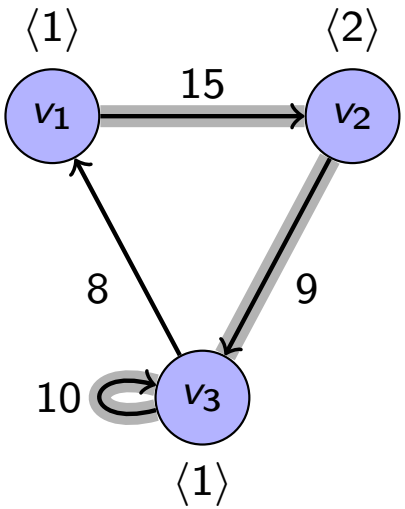

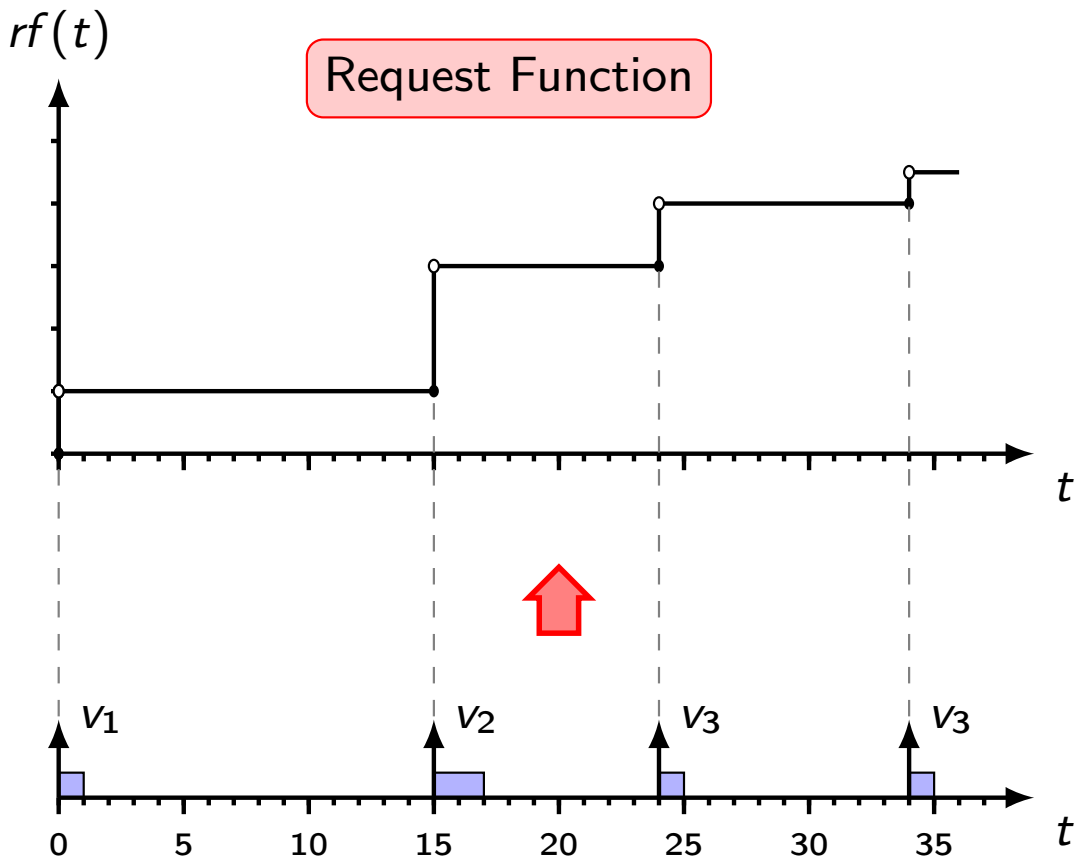

DRT Schedulability Condition

Notation:

- A set of tasks $\tau = \{T_1, T_2, \ldots, T_n\}$
- π_i : A path in T_i's graph

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Theorem (Stigge 2013)

A job with WCET "e" and relative deadline "d" is schedulable under a set of higher priority tasks τ if and only if for all $(\pi_1, \ldots, \pi_n) \in \Pi(\tau)$:

$$\exists t \leq d : e + \sum_{T_i \in \tau} rf_{\pi_i}(t) \leq t \tag{1}$$

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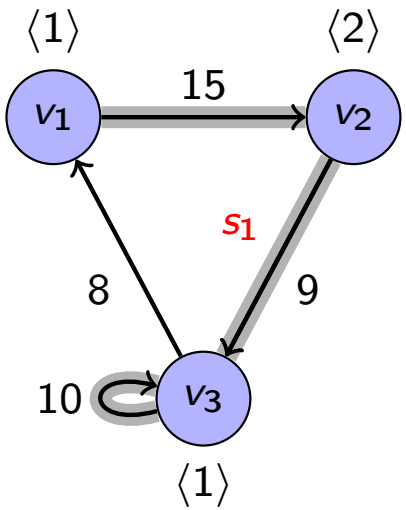
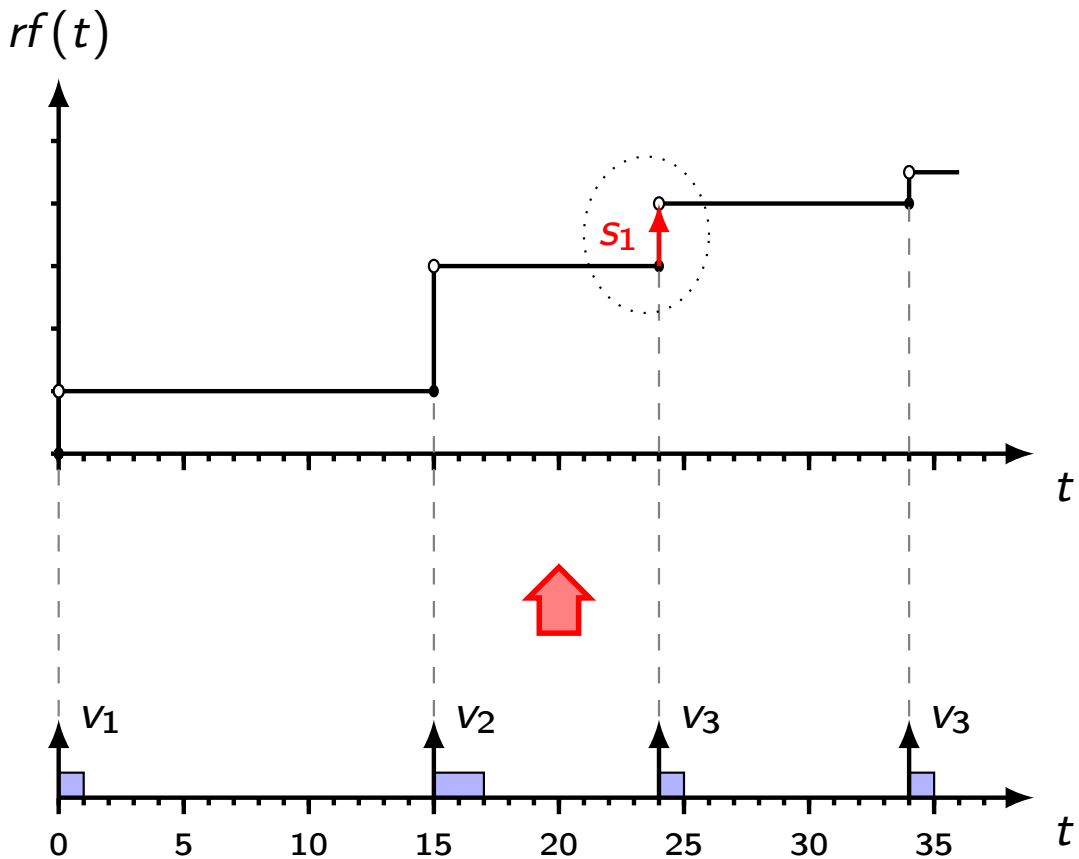
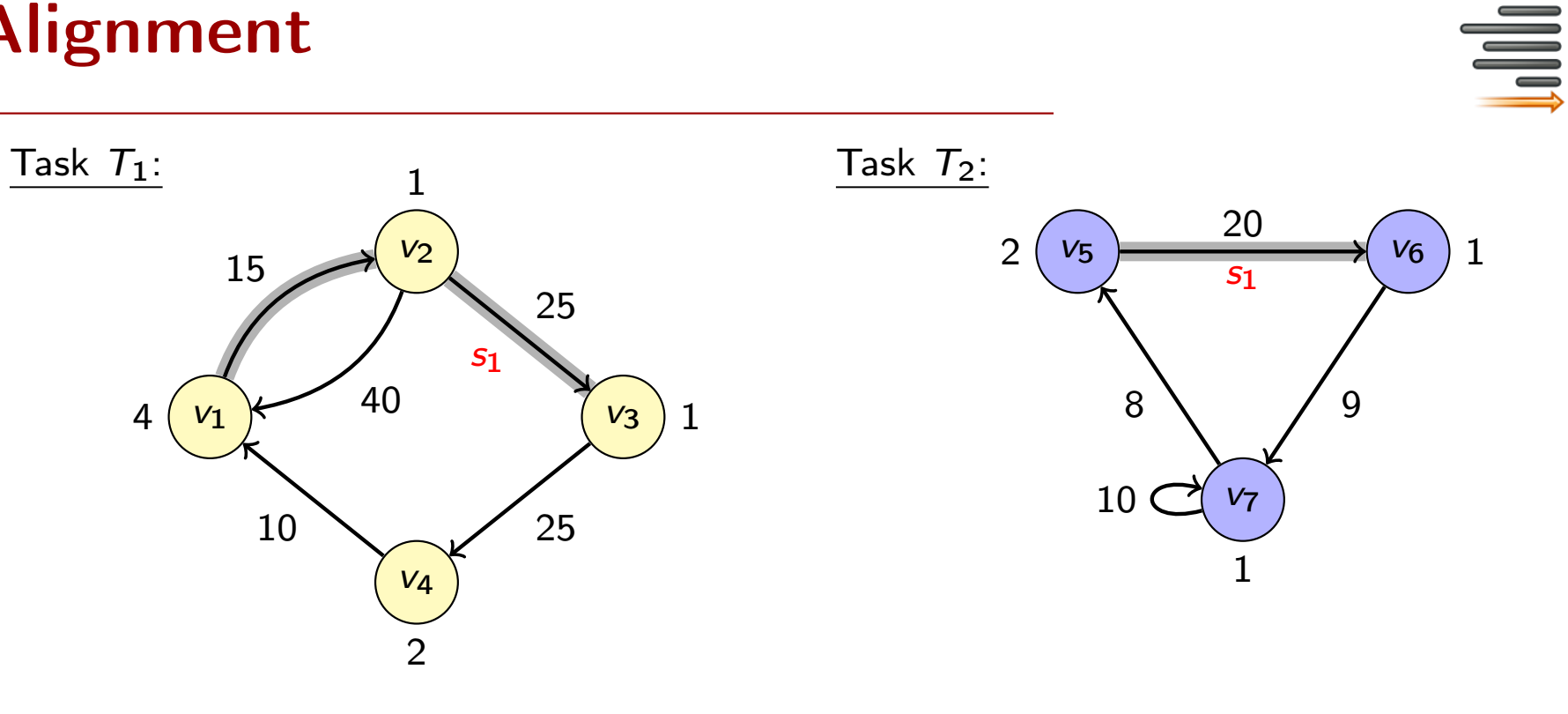
- $rf_{\pi_i}(t)$ could be derived independently.

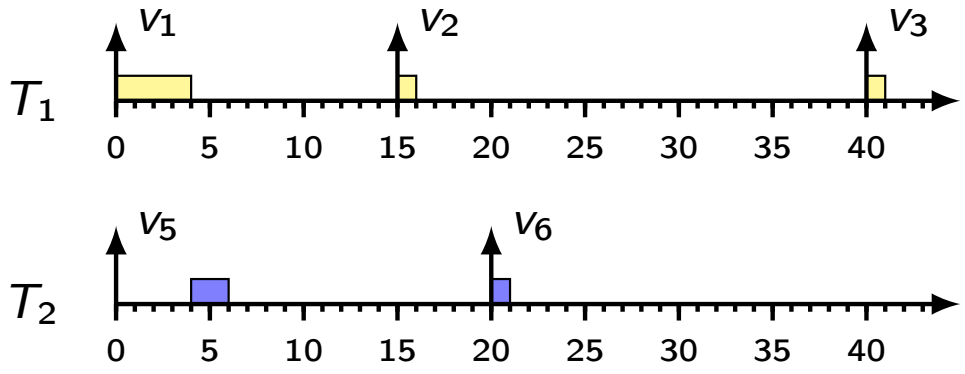
SDRT Schedulability



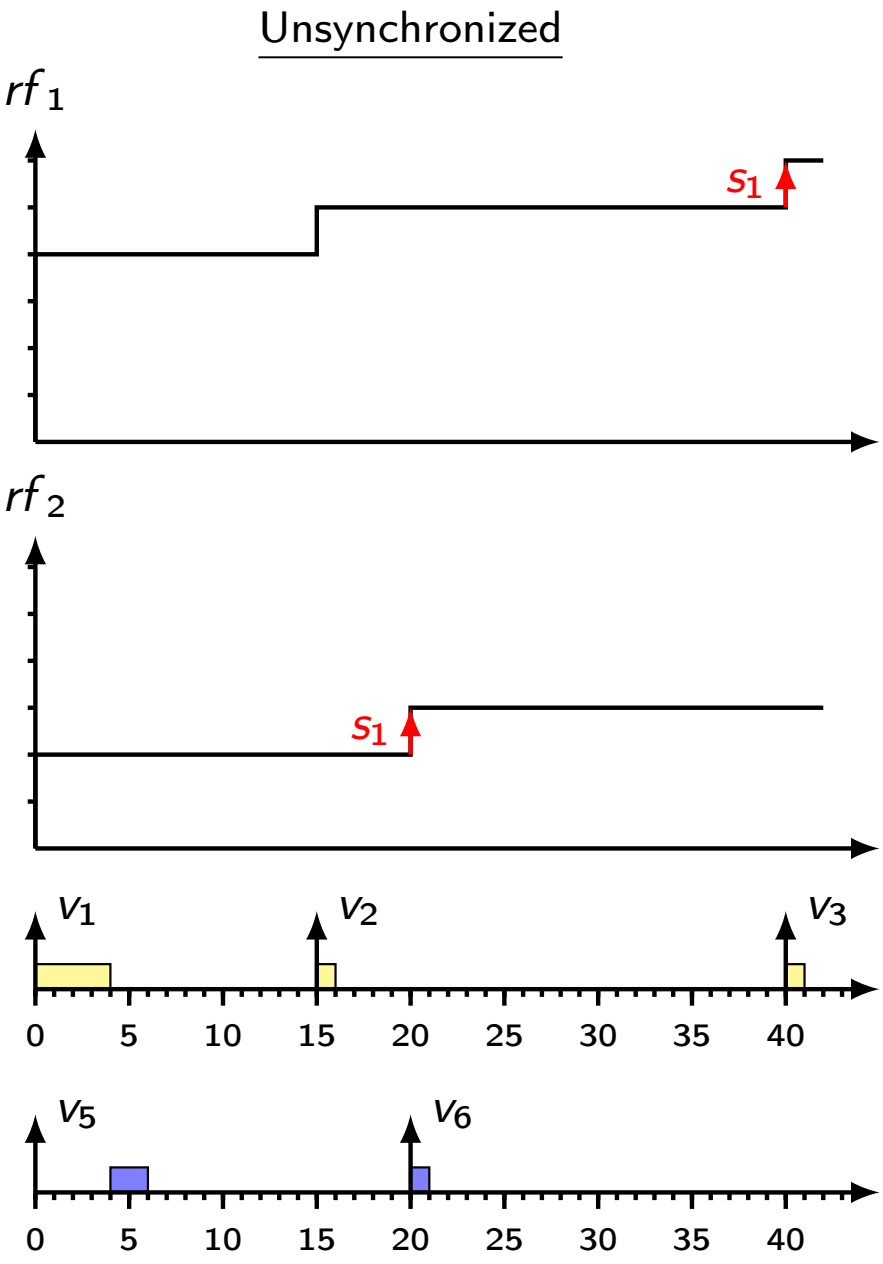


Alignment

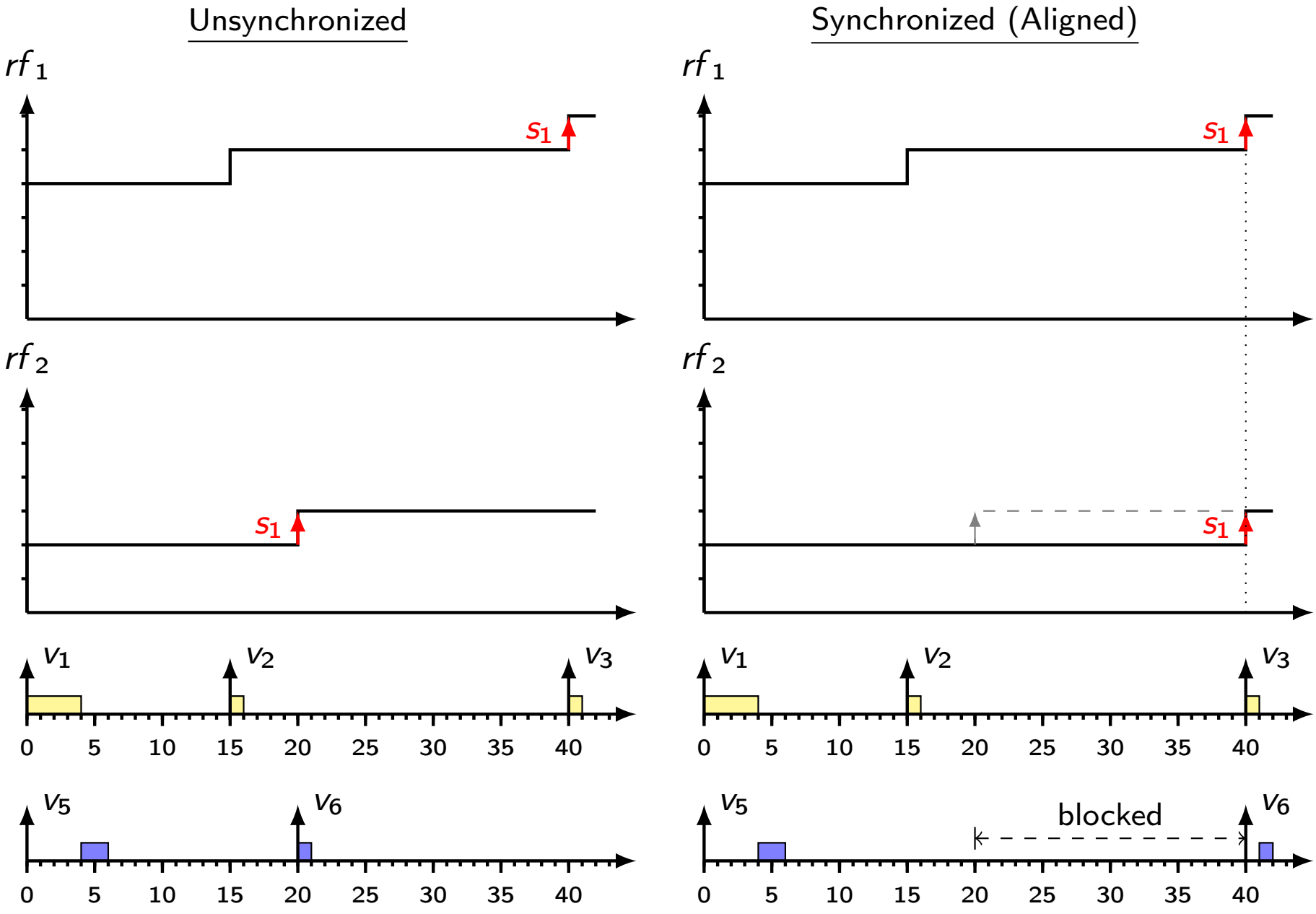

Task T_1:
1
v_2
15
25
s_1
4
v_1
40
v_3
1
10
25
v_4
2
Task T_2:
2
v_5
20
v_6
1
s_1
8
9
10
v_7
1


v_1
v_2
v_3
T_1
0
5
10
15
20
25
30
35
40
v_5
v_6
T_2
0
5
10
15
20
25
30
35
40

Alignment


Unsynchronized
rf_1
s_1
rf_2
s_1
v_1
v_2
v_3
0 5 10 15 20 25 30 35 40
v_5
v_6
0 5 10 15 20 25 30 35 40

Alignment


Unsynchronized
Synchronized (Aligned)
rf 1
rf 2
s1
v1
v2
v3
v5
v6
blocked
0
5
10
15
20
25
30
35
40

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Theorem

A job with WCET "e" and relative deadline "d" is schedulable under a set of tasks τ if and only if for all $\pi = (\pi_1, \ldots, \pi_n) \in \Pi(\tau)$, $\forall R \in RF_\pi$:

$$\exists t \leq d : e + \sum_{\substack{rf_i \in Synch(R) \\ T_i \in \tau_{hp}}} rf_i(t) \leq t$$

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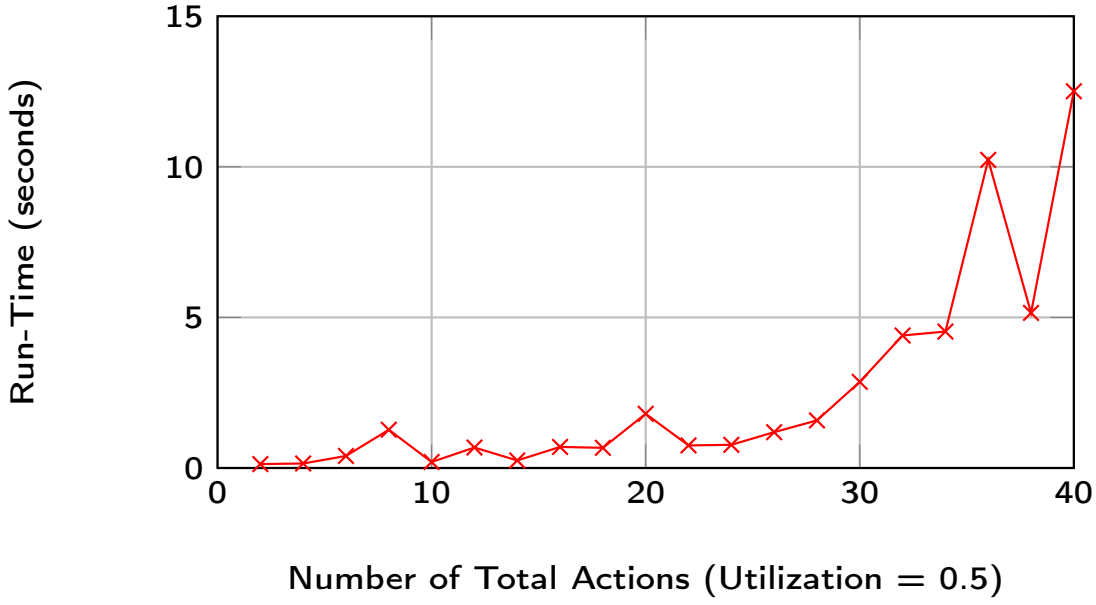
Efficient Exploration

- Removing dominated request function
- Search using an "abstraction and refinement" approach

Experiments: Analysis Efficiency



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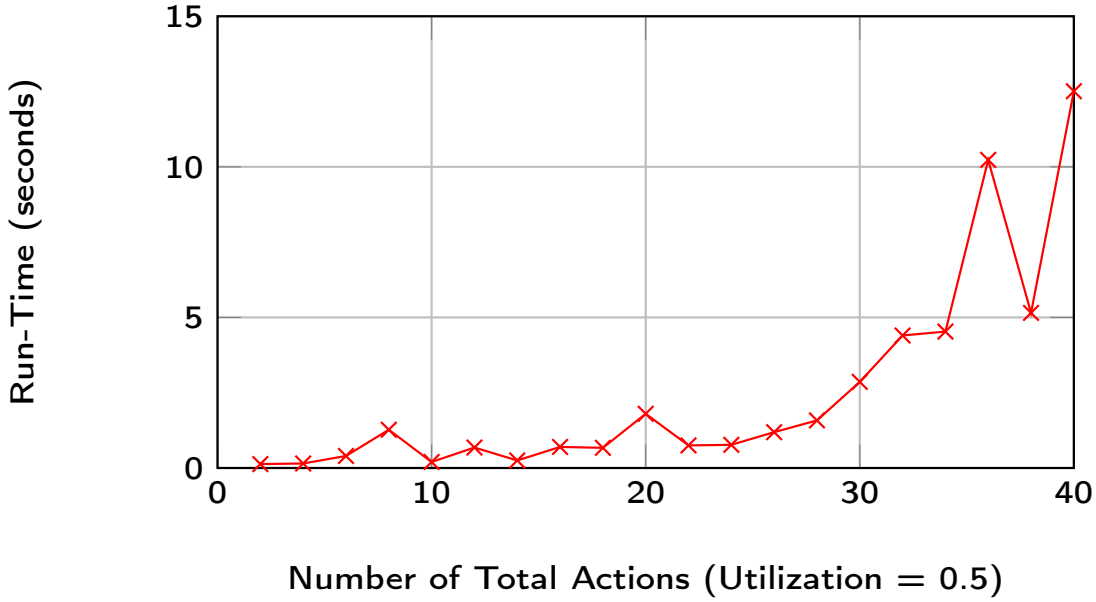
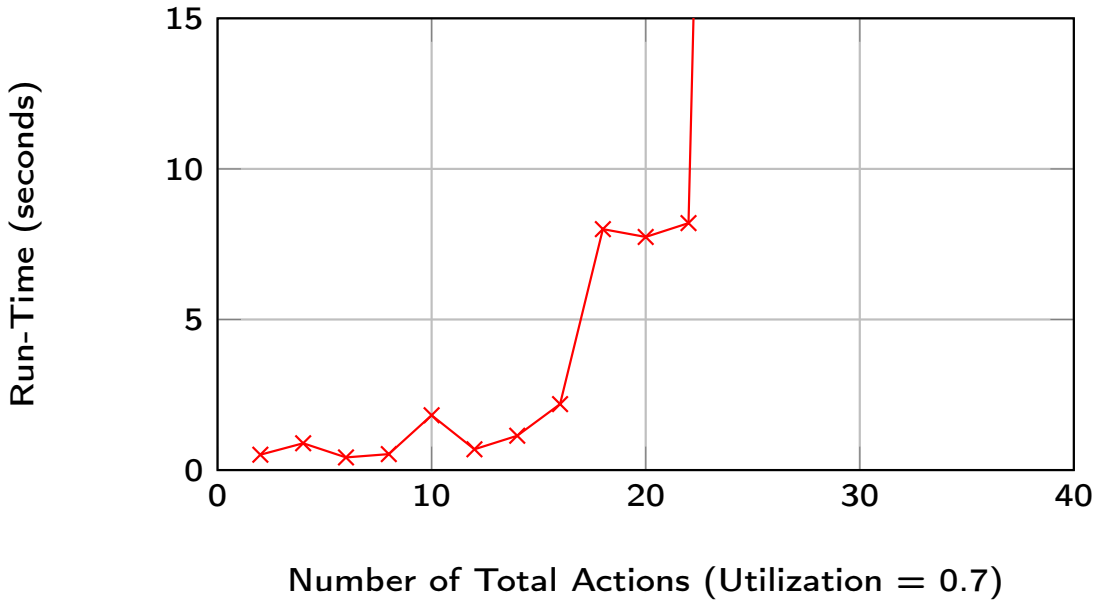
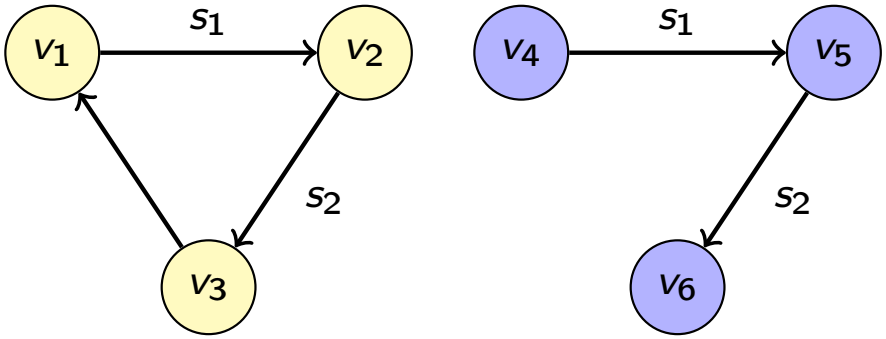
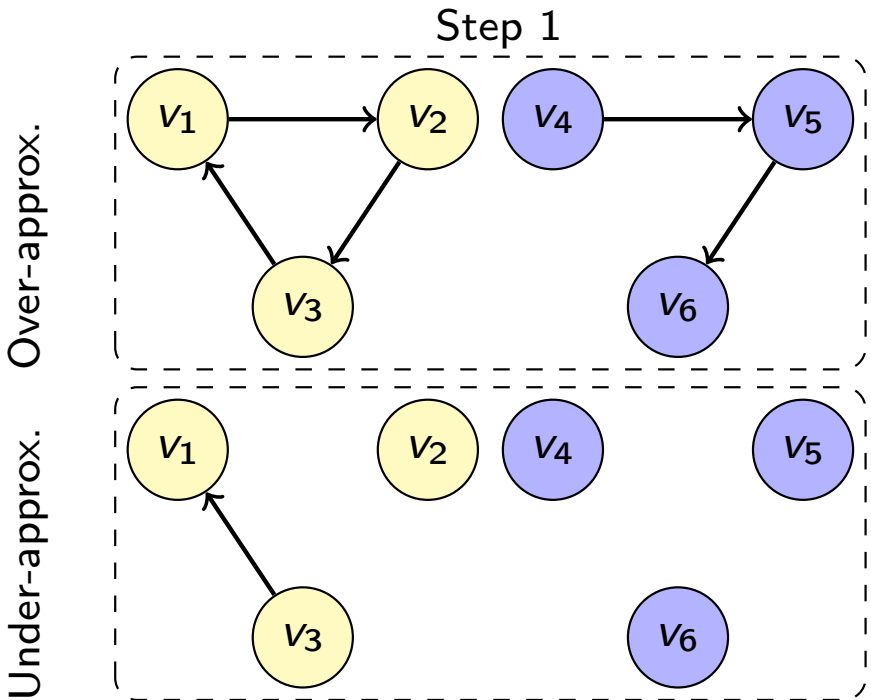
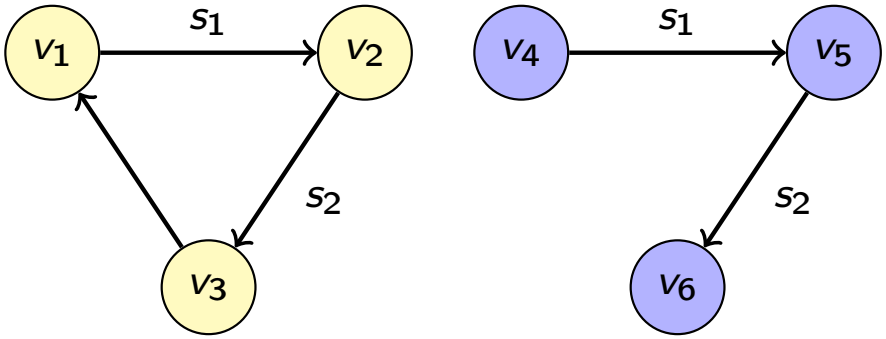
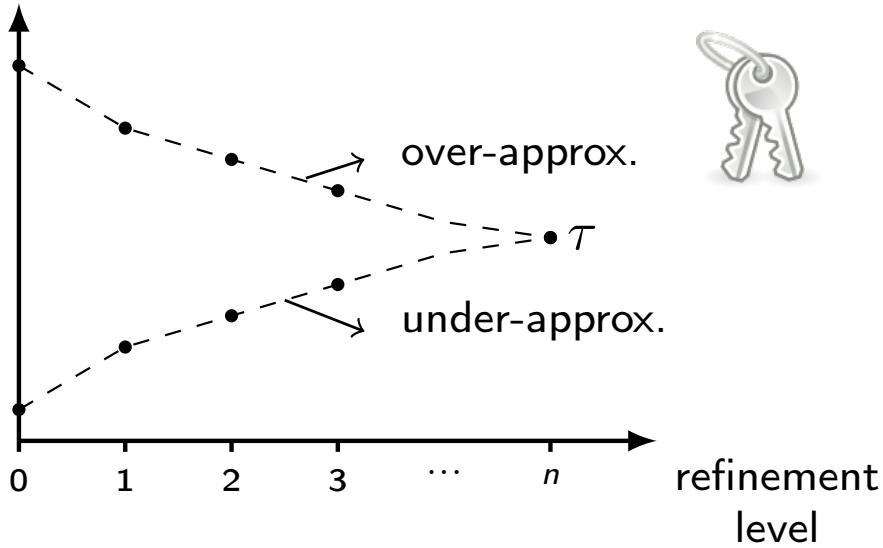


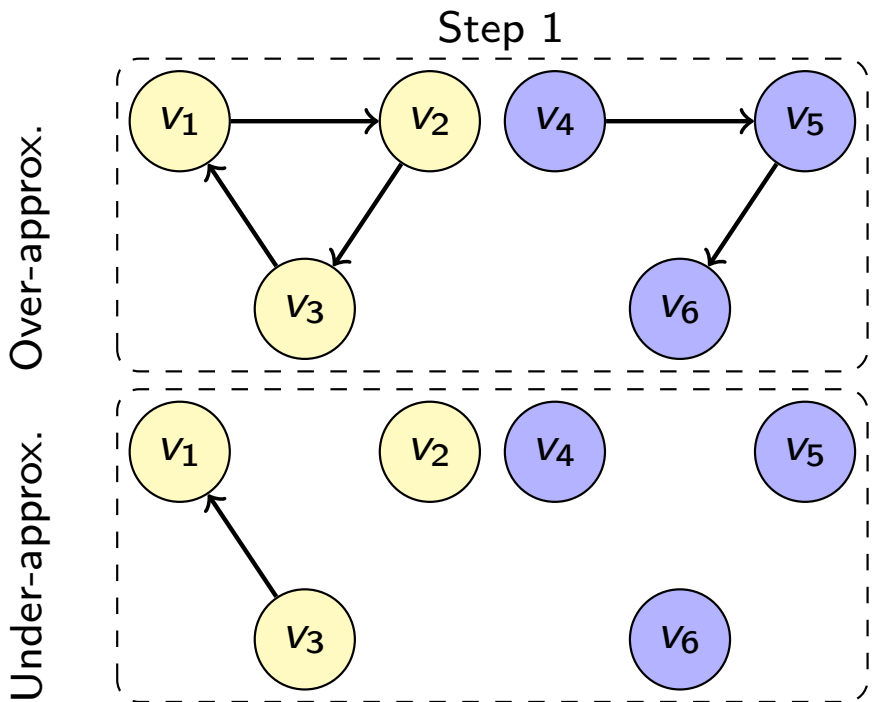


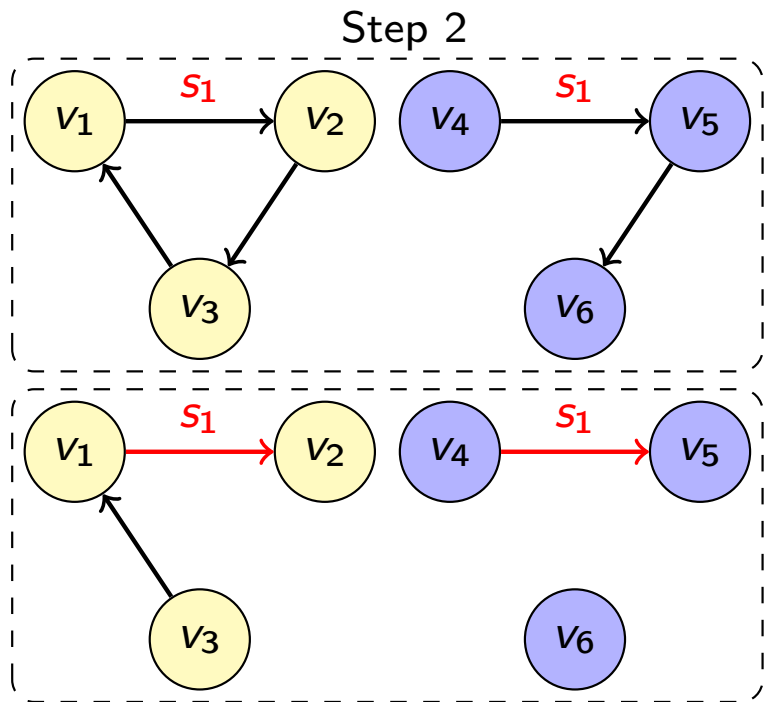

v_1
s_1
v_2
s_2
v_3
v_4
s_1
v_5
s_2
v_6


Step 1
Over-approx.
v_1
v_2
v_4
v_5
v_3
v_6
Under-approx.
v_1
v_2
v_4
v_5
v_3
v_6

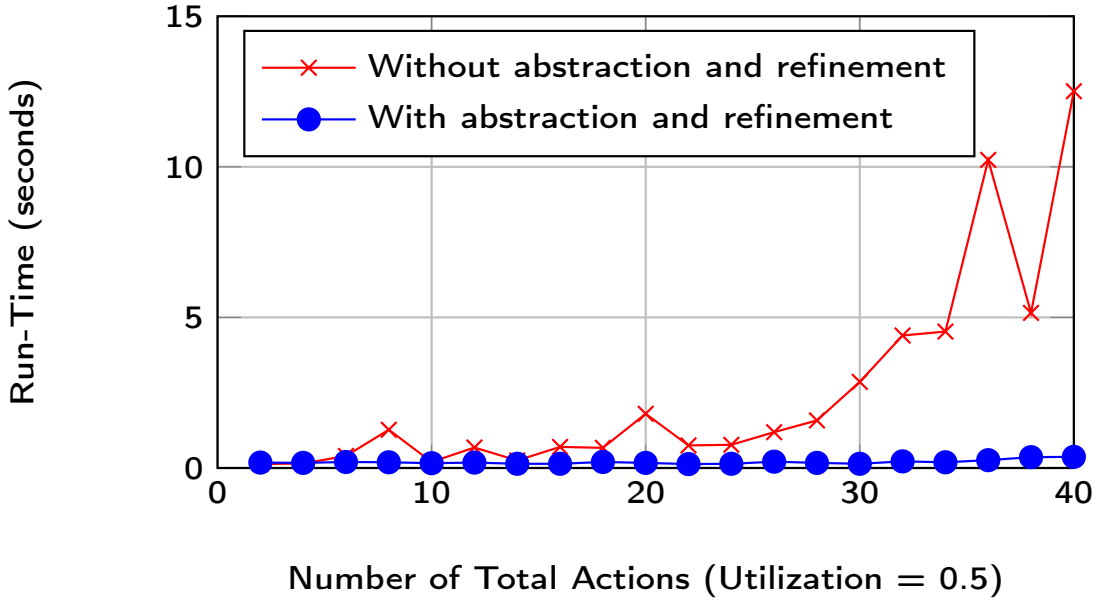

v_1
s_1
v_2
s_2
v_3
v_4
s_1
v_5
s_2
v_6

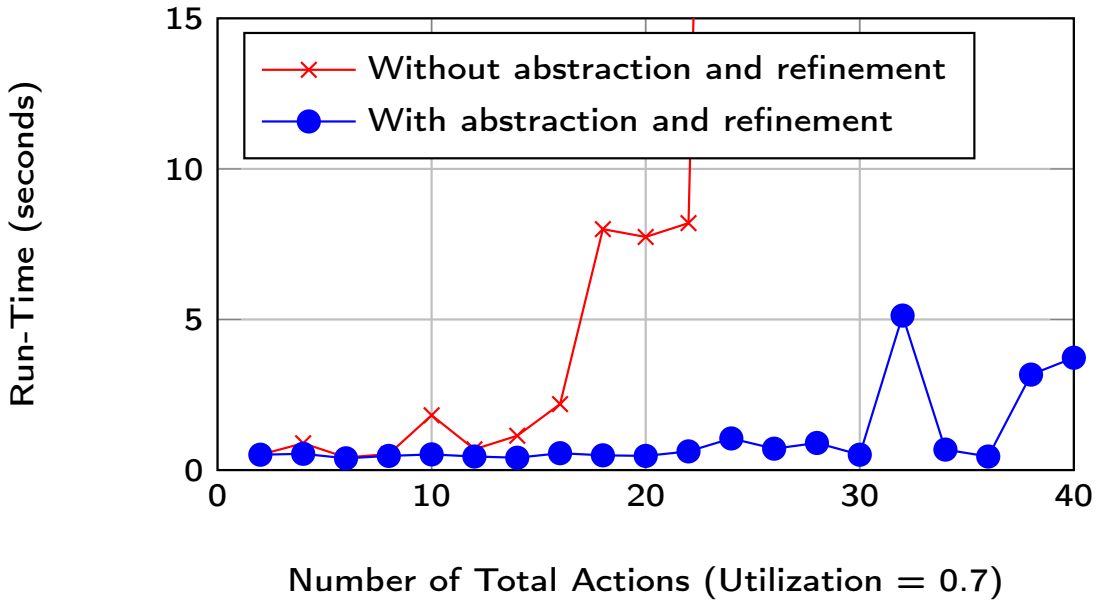

over-approx.
$\mathcal{T}$
under-approx.
0
1
2
3
...
n
refinement level


Step 1
Over-approx.
Under-approx.
v_1
v_2
v_4
v_5
v_3
v_6


Step 2
v_1
s_1
v_2
v_4
s_1
v_5
v_3
v_6

Experiments

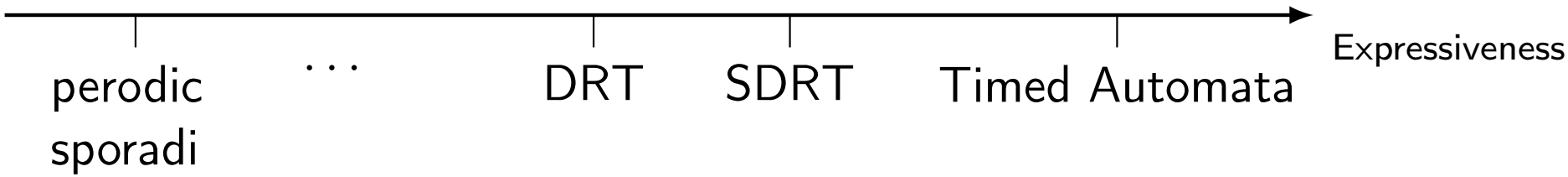




Outline

Conclusion and Future Work

- SDRT as an extension of DRT



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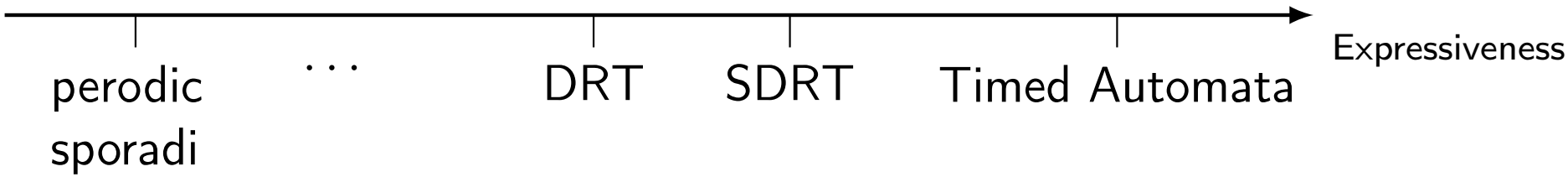

- Multicore Scheduling
  - Task-level paritioning
  - Job-level paritioning

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Thanks!

Appendix

- Request Function Dominance
- Abstraction and Refinement
- Experiment Setting
- Experiments: Path Combinations (RF Dominance)
- Experiments: Acceptance Ratio
- Why Synchronized Release?
- Multirate Tasks
- Critical Instant
- SDRT vs. DAG

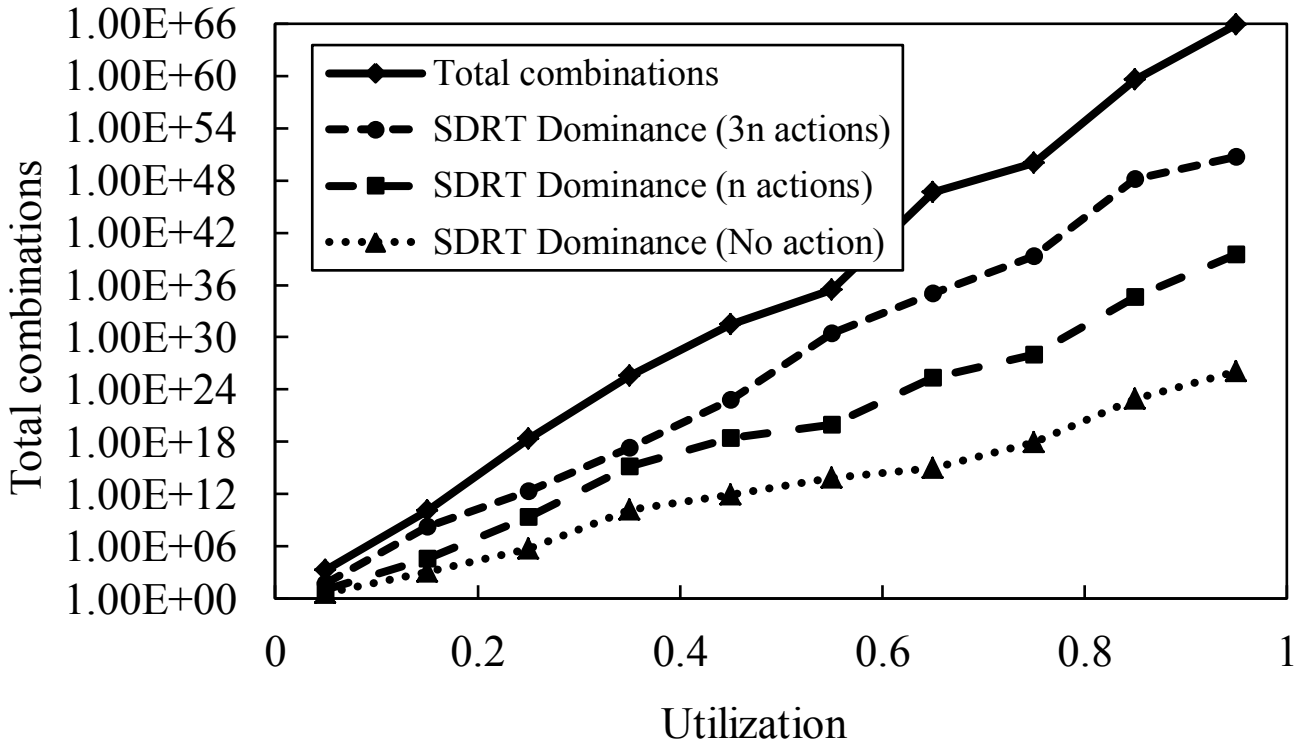
Experiment Settings

Table: Task set parameters

Task Type	Small	Medium	Large
Vertices	$[3, 5]$	$[5, 9]$	$[7, 13]$
Branching degree	$[1, 3]$	$[1, 4]$	$[1, 5]$
p	$[50, 100]$	$[100, 200]$	$[200, 400]$
e	$[1, 2]$	$[1, 4]$	$[1, 8]$
d	$[25, 100]$	$[50, 200]$	$[100, 400]$

Number of Path Combinations

- Number of path combinations that should be considered in schedulability analysis



Schedulability Analysis Results

- Schedulability analysis results for different number of synchronizations

	Acceptance Ratio			Tested Combinations		
Util.	No act.	n act.	$3n$ act.	No act.	n act.	$3n$ act.
0.35	1	1	1	37	37	37
0.4	1	1	1	52	52	52
0.45	1	1	1	70	70	70
0.5	0.94	0.96	0.96	116	165	14768
0.55	0.6	0.77	0.85	154	218	46694
0.6	0.1	0.19	0.26	225	392	59114
0.65	0	0	0.05	178	372	19167

Why Execution-Independent Synchronization?

- Separation of **Computation** and **Communication**
  - More predictability

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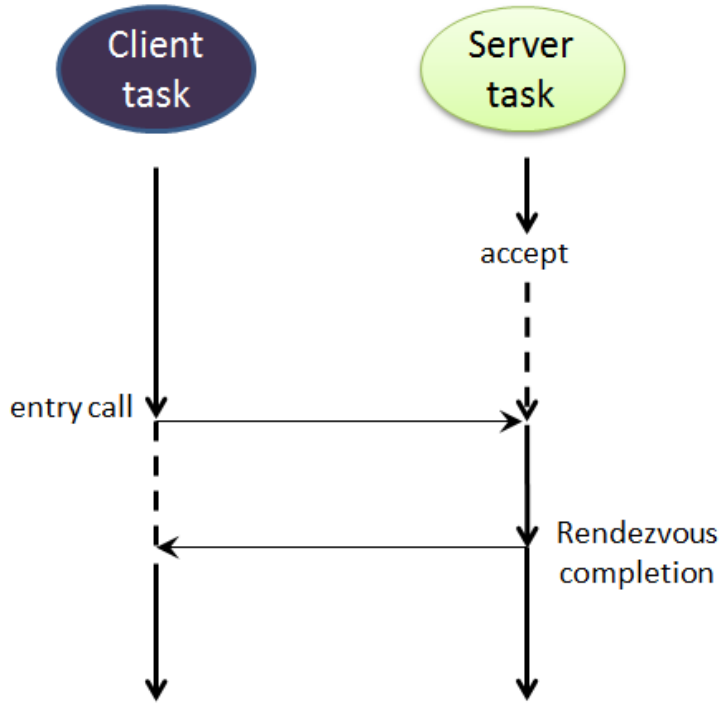
- Separation of **Computation** and **Communication**
  - More predictability
- Ada's **Rendezvous** mechanism
- Fixed input/output instants

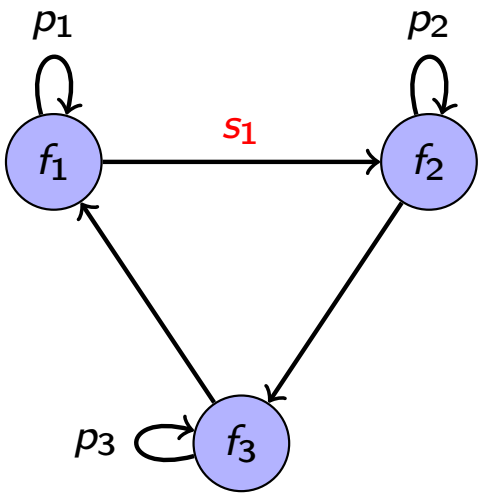


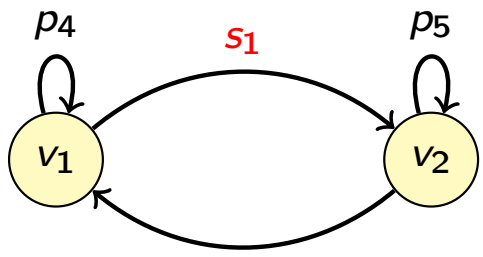
SDRT Modeling Usage

- Engine control tasks (Davis-2014, Biondi-2014)
- Multirate controllers

```
TASK T1 {
    f1();
    if(rpm < 2000)
        f2();
}
```

Rate-dependent behaviour





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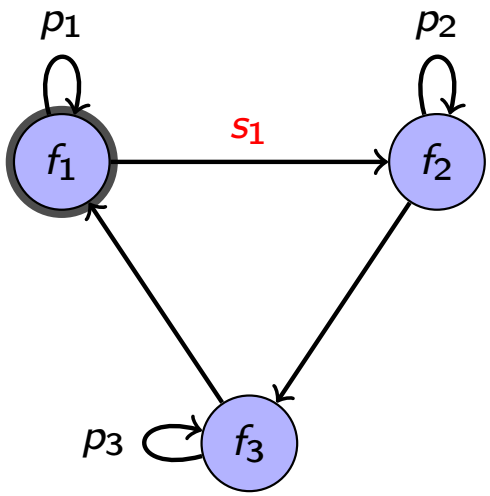
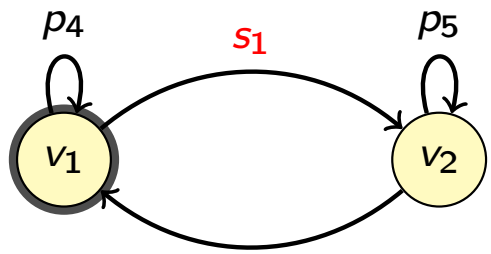


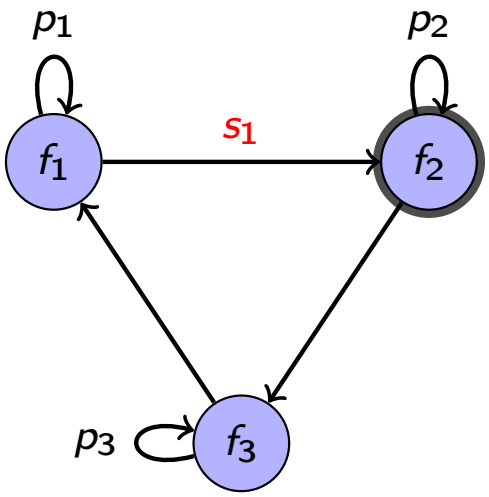


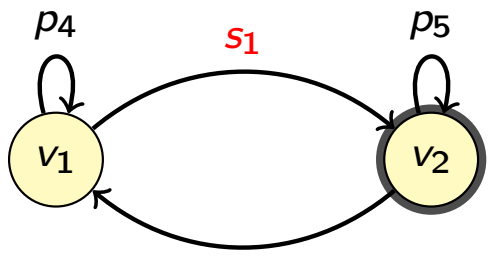
SDRT Modeling Usage

- Engine control tasks (Davis-2014, Biondi-2014)
- Multirate controllers

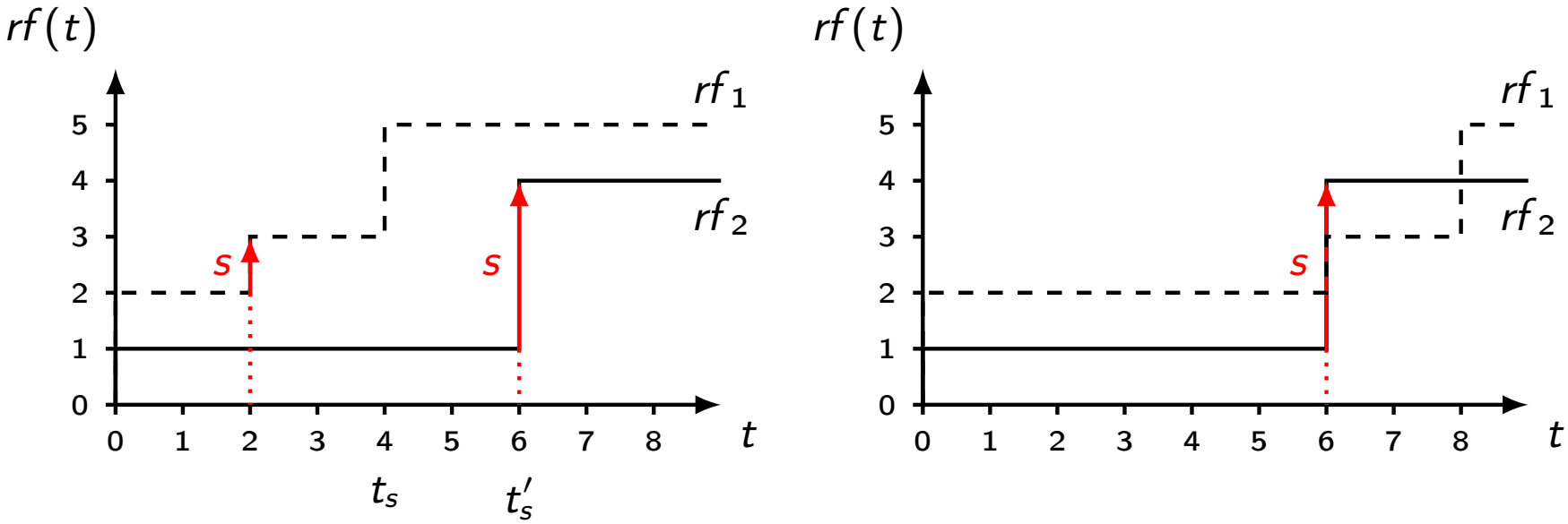
```
TASK T1 {
    f1();
    if(rpm < 2000)
        f2();
}
```

Rate-dependent behaviour





Request Function Dominance



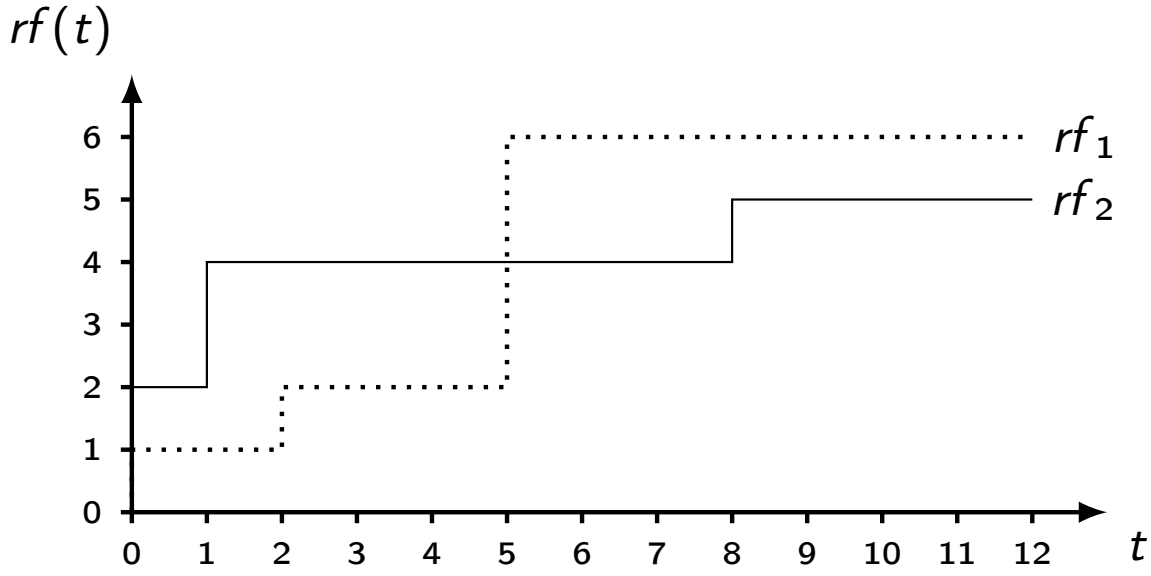
Lemma

A request function rf_1 dominates a request function rf_2 if:

1. $\forall t : rf_1(t) \geq rf_2(t)$,
2. *rf_1 and rf_2 contain the same sequence of actions, and*
3. *(AS_{rf_1} is empty) or ($t_s \leq t'_s$ and $rf_1(t_s) \geq rf_2(t'_s)$ and rf'_1 dominates rf'_2), where $(s, t_s) = AS_{rf_1}[0]$, $(s, t'_s) = AS_{rf_2}[0]$, and rf'_1 and rf'_2 are obtained by $Align\_and\_Pop(rf_1, rf_2, s)$.*

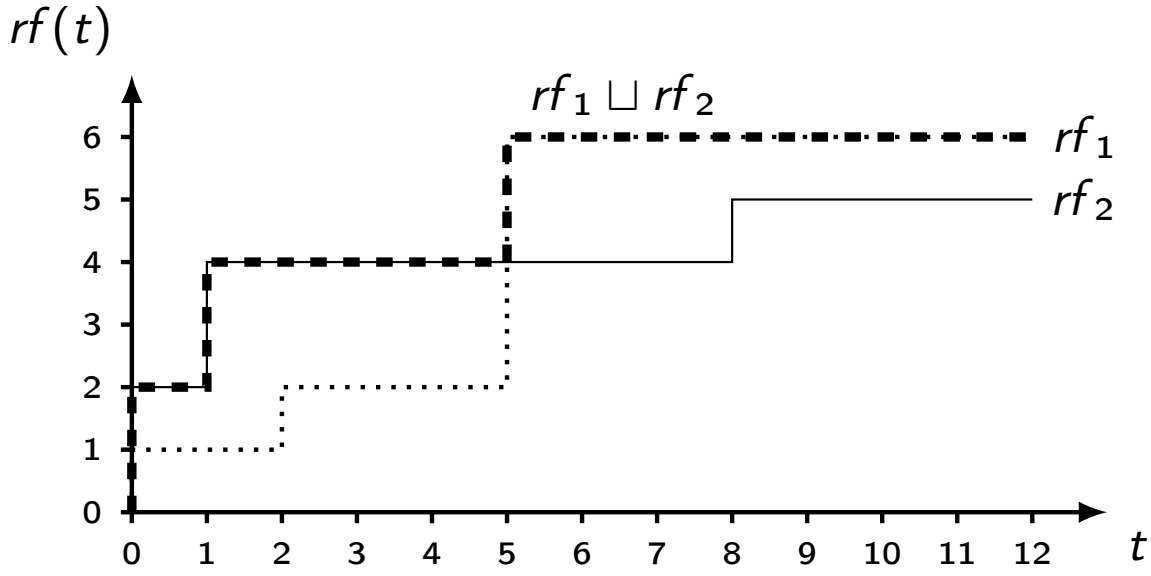
Abstraction and Refinement

- Abstraction:



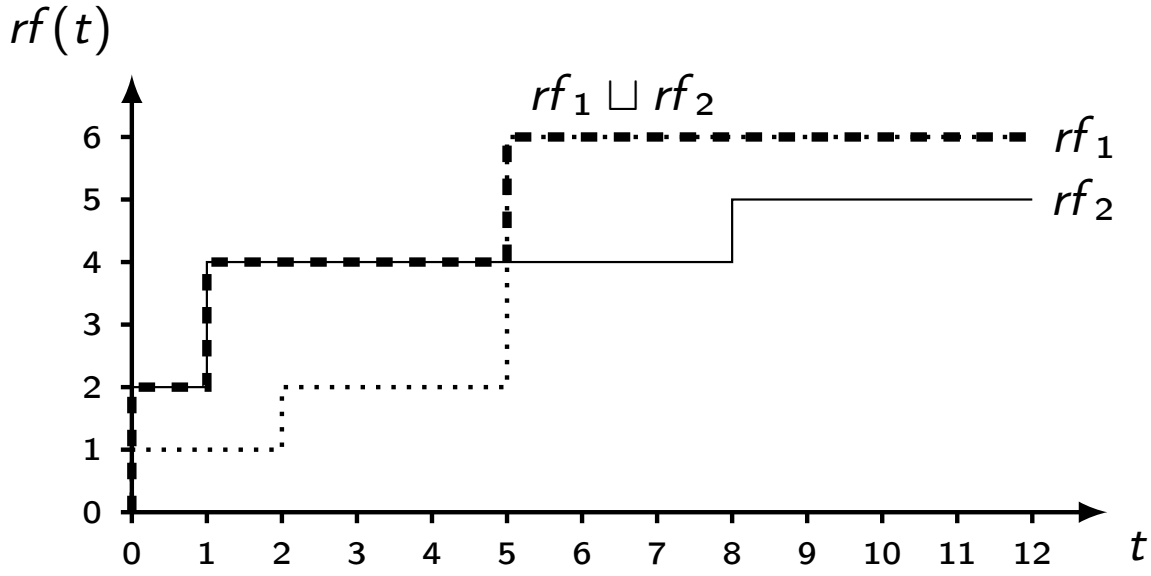
Abstraction and Refinement

- Abstraction:



Abstraction and Refinement

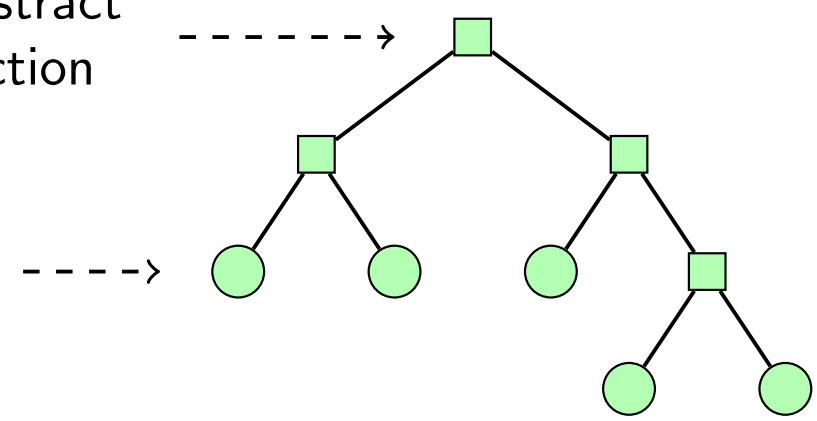
- Abstraction:



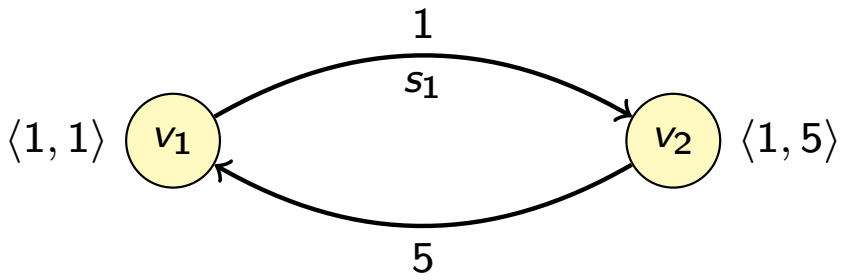
- Refinement:

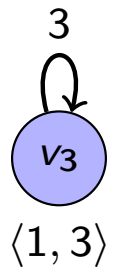
The most abstract request function

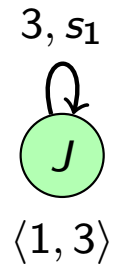
Concrete request functions

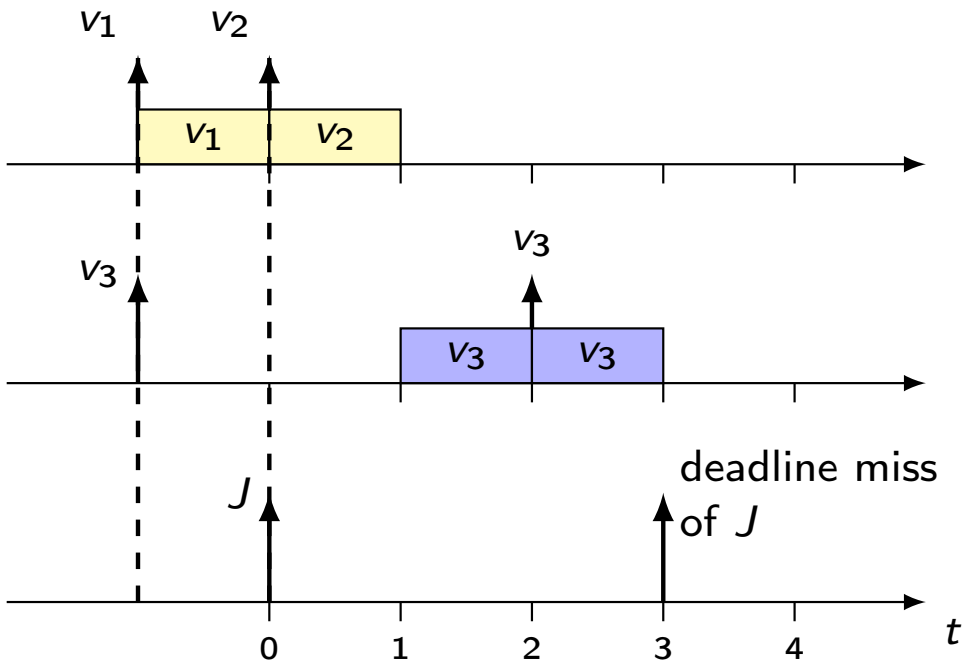


Critical (Scheduling) Instant









The critical instant for J is not necessarily when all the tasks are released simultaneously with J.

Future Work

- Broadcast synchronization
- Critical instant for the general case

References

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