Improved feasibility of fixed-priority scheduling with deferred preemption using preemption thresholds for preemption points

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SAN

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Where innovation starts

RTNS-2013 (Sophia Antipolis, France)

Background and motivation

- **Facts about fixed-priority scheduling (FPS):**
  - **described in standards, e.g. OSEK (Automotive);**
  - **supported by most COTS RTOS;**
  - **de facto standard in industry.**

- **Advantages of limited preemptive FPS:**
  - ***Reduced* memory requirements;**
  - ***Reduced* cost of arbitrary preemptions;**
  - ***Improved* schedulability of task sets.**

Background and motivation

- **Non-preemptive jobs (FPNS):**
  - ***Pro*: minimal memory requirements;**
  - ***Pro*: no preemption costs;**
  - ***Cons*: reduced schedulability.**

- **Two main alternatives:**

  1. Sequence of non-preemptive *sub-jobs* (FPDS):
  - ***Preemption points***

  ***2. Preemption thresholds* for *tasks* (FPTS).**

- **Schedulability: neither dominates the other.**

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Background and motivation

- **FPDS:**
  - **highest schedulability ratio;**
  - **generates less preemptions;**
  - **most predictable for estimating preemption costs**
    - **because the number of preemptions and their positions are fixed and known from the code.**

- **Question: can we improve on FPDS?**

[8] Buttazzo, Bertogna, and Yao, IEEE TII, Feb. 2013.

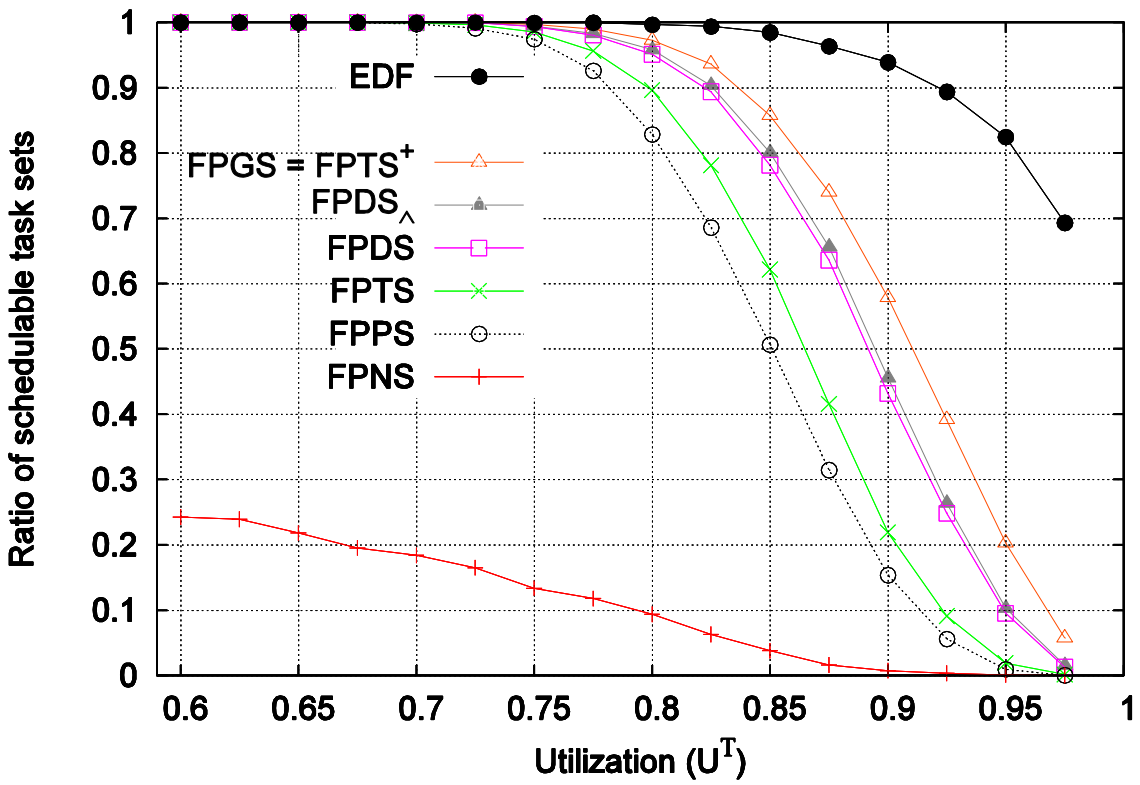
Background and motivation

- **Generalization of FPTS and FPDS (FPGS):**
  - **Preemption thresholds for *tasks* and per *sub-job***
    - ***Pro*: improved schedulability ratio;**
    - ***Cons*: arbitrary preemptions.**

- **Specialization of FPGS ($FPDS_{\wedge}$):**
  - **Preemption thresholds for *tasks* only**
    - ***Pro*: limits preemptions to preemption points;**
    - ***Cons*: limited schedulability ratio improvement.**

[6] R.J. Bril, M.M.H.P. v.d. Heuvel, U. Keskin, and J.J. Lukkien, ECRTS, 2012.

Background and motivation



8 tasks, 5.000 task sets,
$T_i \in$ [100, 10.000] (uniform), U_i by UUnifast ($\Rightarrow C_i$),
$D_i \in$ [0.5(T_i + C_i), T_i] (uniform);

Background and motivation

- **Goal:**
  - **Limited preemptive FPS scheme**
    - **schedulability ratio comparable to FPGS;**
    - **preemptions limited to preemption points.**

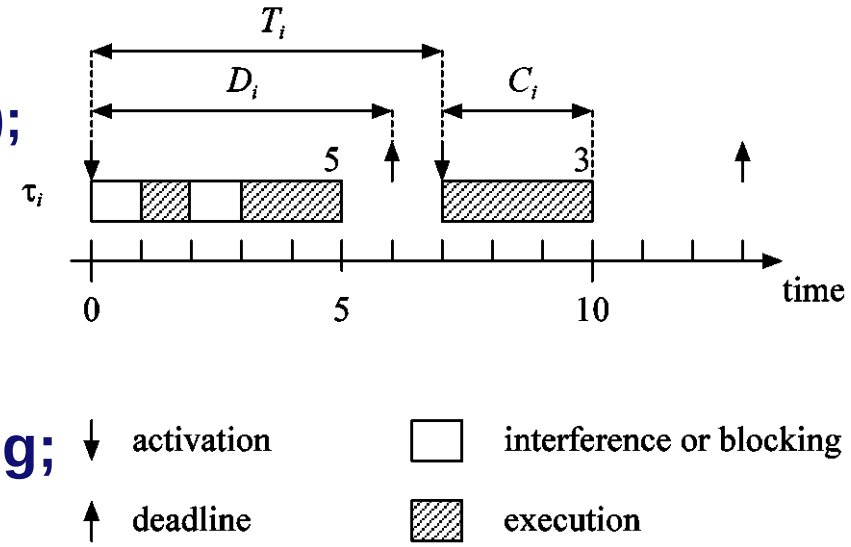
- **Approach:**
  - **Preemption thresholds per *preemption point*.**

Overview

- Background and motivation
- Real-time scheduling model (FPS)
  - Basic model
  - Enhanced model
  - Generalization graph
- An example
  - A schedulable configuration
  - Determining the configuration
- Contributions
- Conclusion

Basic FPS – model

- **Events: implicit**
- **Tasks (τ):**
  - **independent, no self-suspension**
  - **characteristics (R^+):**
    - **minimal inter-arrival time (T);**
    - **computation time (C);**
    - **deadline (D);**
- **Scheduling algorithm:**
  - **fixed-priority (π) & non-idling;**
  - **[non-] preemptive**
- **Platform: single CPU**



Enhanced FPS – model

- **Existing enhancements:**
  - **Job of τ_i is a sequence of m_i sub-jobs.**
  - **Preemption threshold**
    - **per task: θ_i, where $\pi_i \leq \theta_i \leq \pi_1$;**
    - **per sub-job: $\theta_{i,k}$, where $\pi_i \leq \theta_{i,k} \leq \pi_1$.**

- **Novel enhancement:**
  - **Preemption threshold**
    - **per *preemption point*: $\theta^{\bullet}_{i,k}$, where $\pi_i \leq \theta^{\bullet}_{i,k} \leq \pi_1$**
    - **superseding θ_i.**

Generalization graph for FPS algorithms

Job as a sequence of m_i sub-jobs.

	$m_i = 1$	$m_i \geq 1$		
		$m_i > 1 \Rightarrow \theta^{\bullet}_{i,a} = \pi_i$		
$\theta_{i,k} = \pi_i$	**FPPS** ←	**FPPS⁺**		
$\theta_{i,k} = \pi_1$	**FPNS** ←	**FPDS**		

[7] A. Burns, in *Advances in Real-Time Systems*, 1994

[5] R. Bril, J. Lukkien, and W. Verhaegh, ECRTS, 2007.

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Generalization graph for FPS algorithms

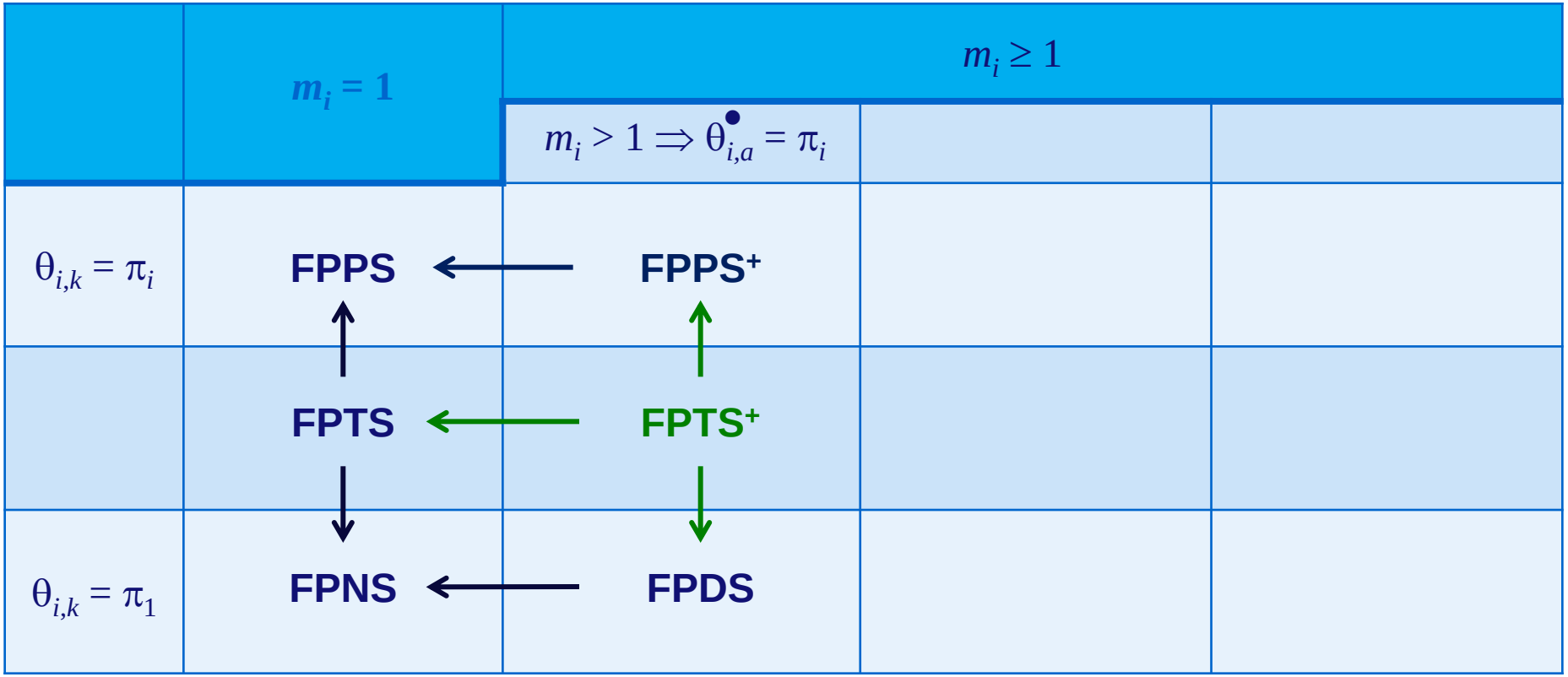
Preemption threshold per task.

	$m_i = 1$	$m_i \geq 1$		
		$m_i > 1 \Rightarrow \theta_{i,a} = \pi_i$		
$\theta_{i,k} = \pi_i$	**FPPS**	**FPPS⁺**		
	FPTS			
$\theta_{i,k} = \pi_1$	**FPNS**	**FPDS**		

[20] Y. Wang and M. Saksena, RTCSA, 1999.
[17] J. Regehr, RTSS, 2002.

Generalization graph for FPS algorithms

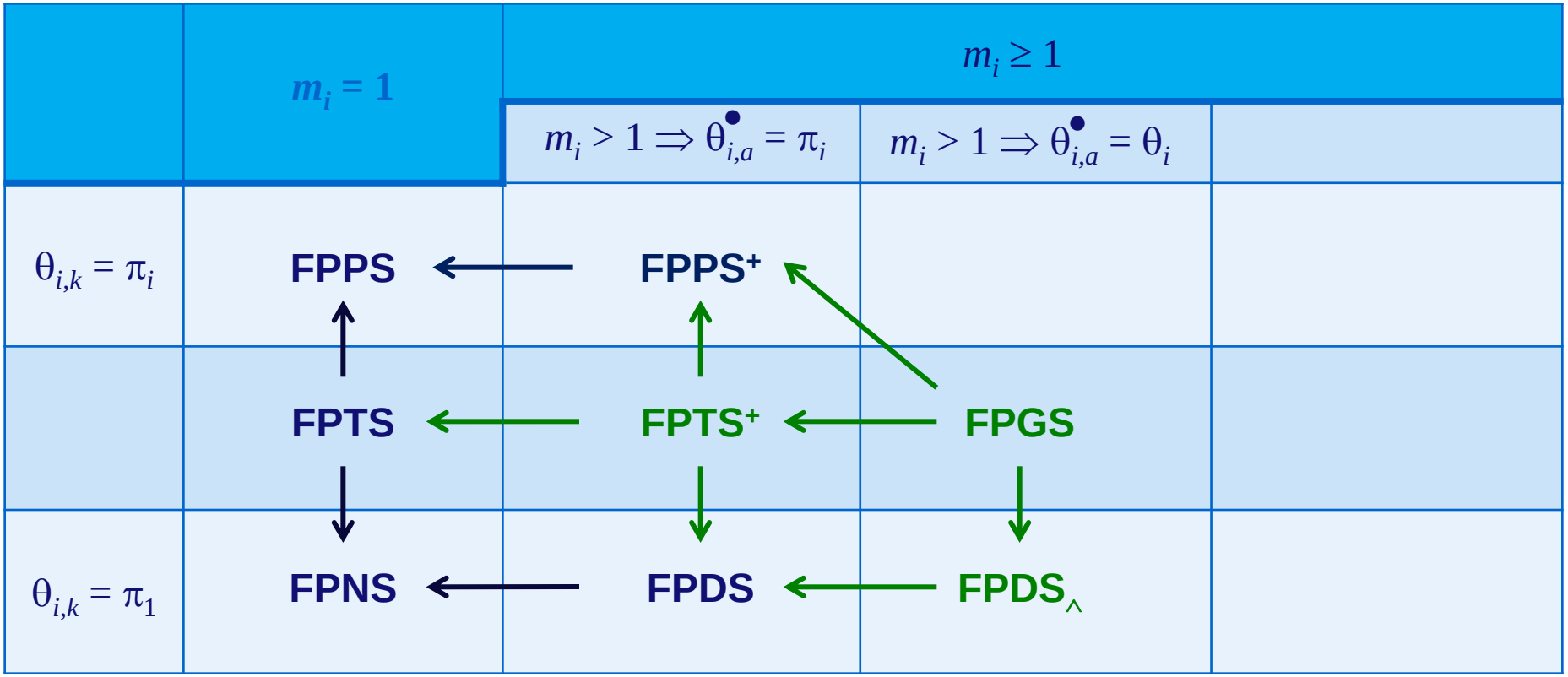
Preemption threshold per sub-job (only).



[12] U. Keskin, R.J. Bril, and J.J. Lukkien, ETFA, 2010.
[21] G. Yao and G. Buttazzo, EMSOFT, 2010.

Generalization graph for FPS algorithms

Preemption threshold per task and per sub-job.



[6] R.J. Bril, M.M.P.H. v.d. Heuvel, U. Keskin, and J.J. Lukkien, ECRTS, 2012.

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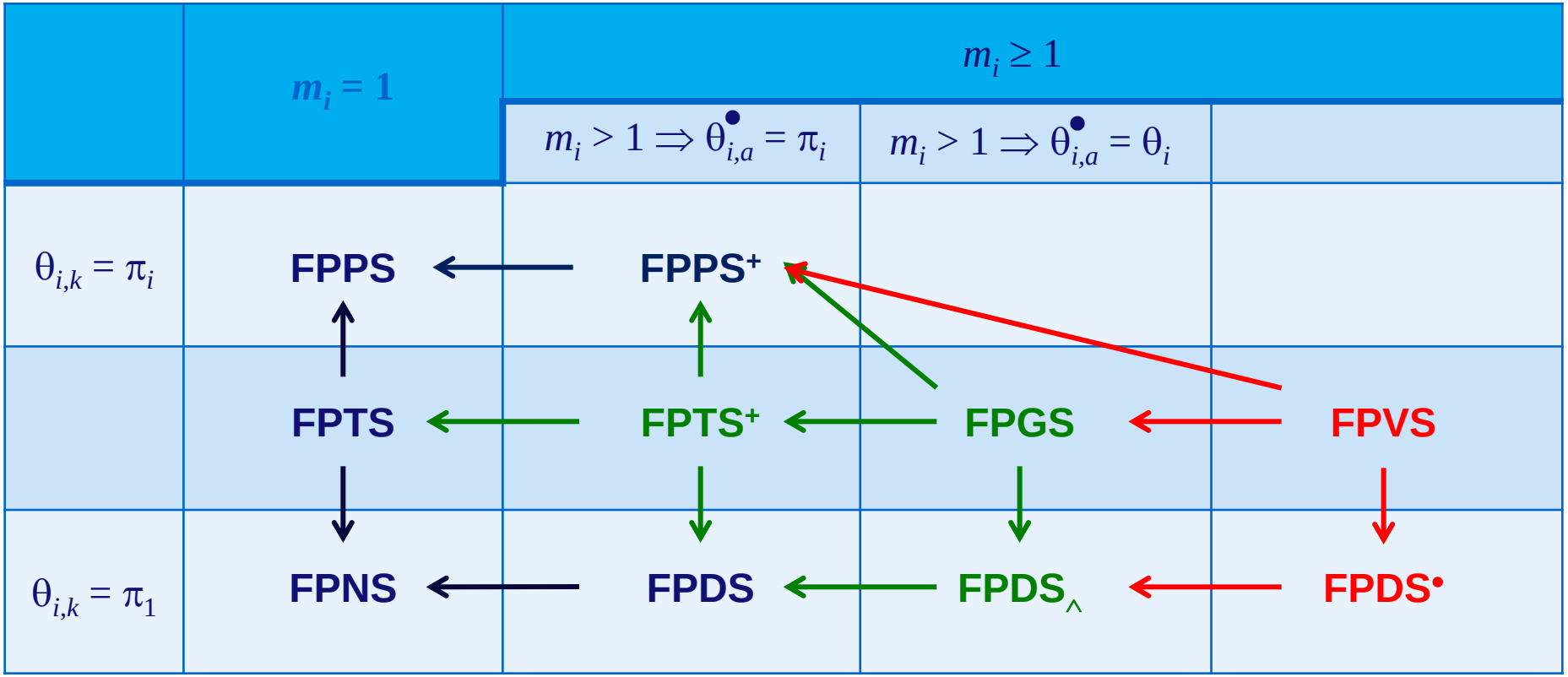
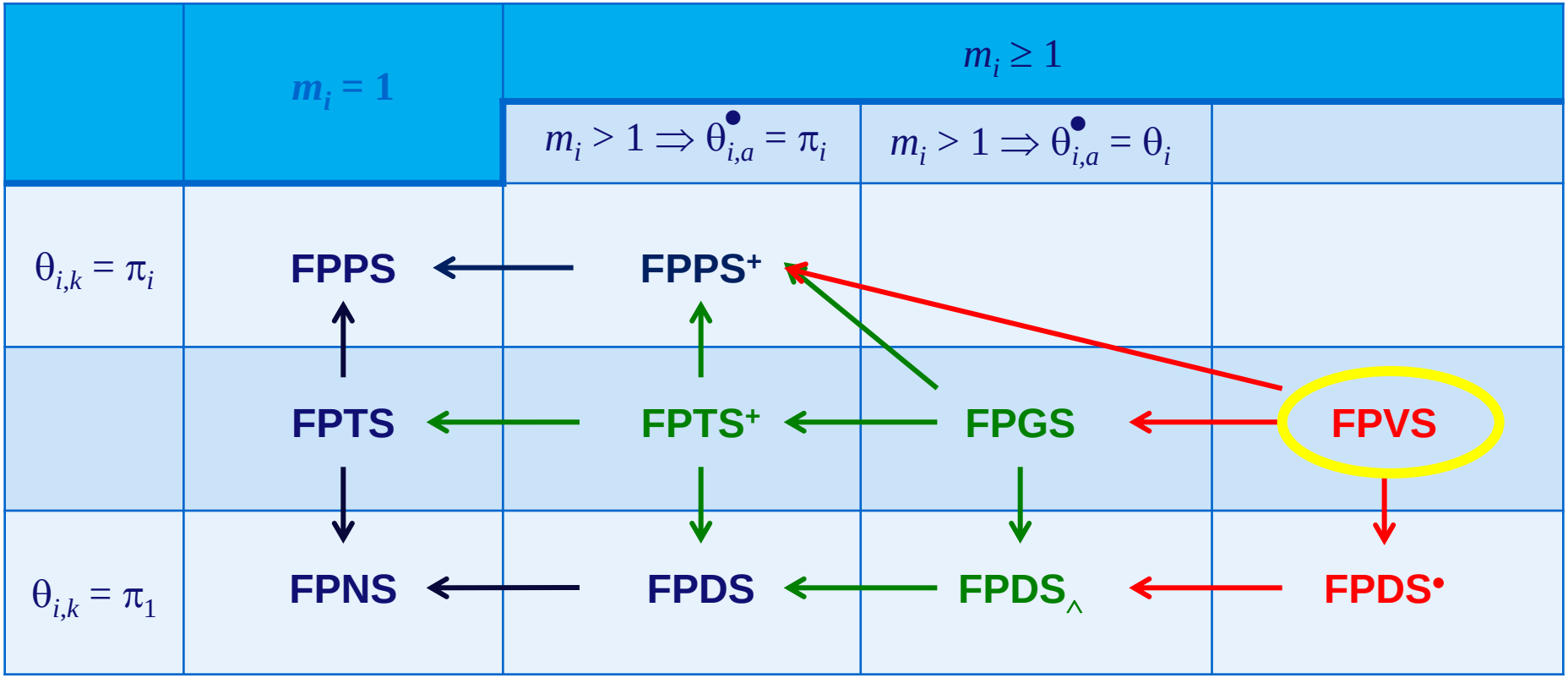
Generalization graph for FPS algorithms

Preemption threshold per sub-job and per preemption point.



[0] This presentation/paper.

Generalization graph for FPS algorithms



FPVS: *Pro*: highest schedulability ratio;
Cons: potential of arbitrary preemptions;
Cons: potential of higher memory requirements.

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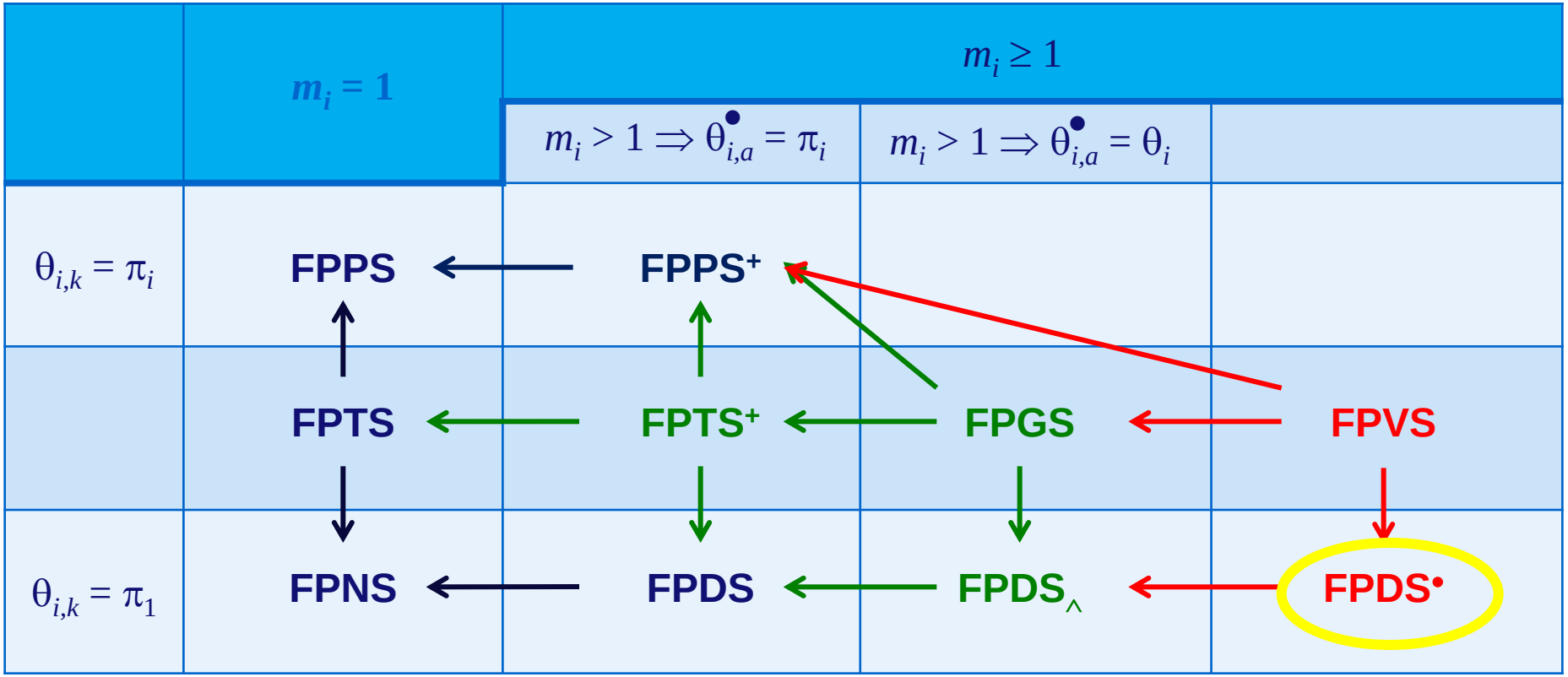
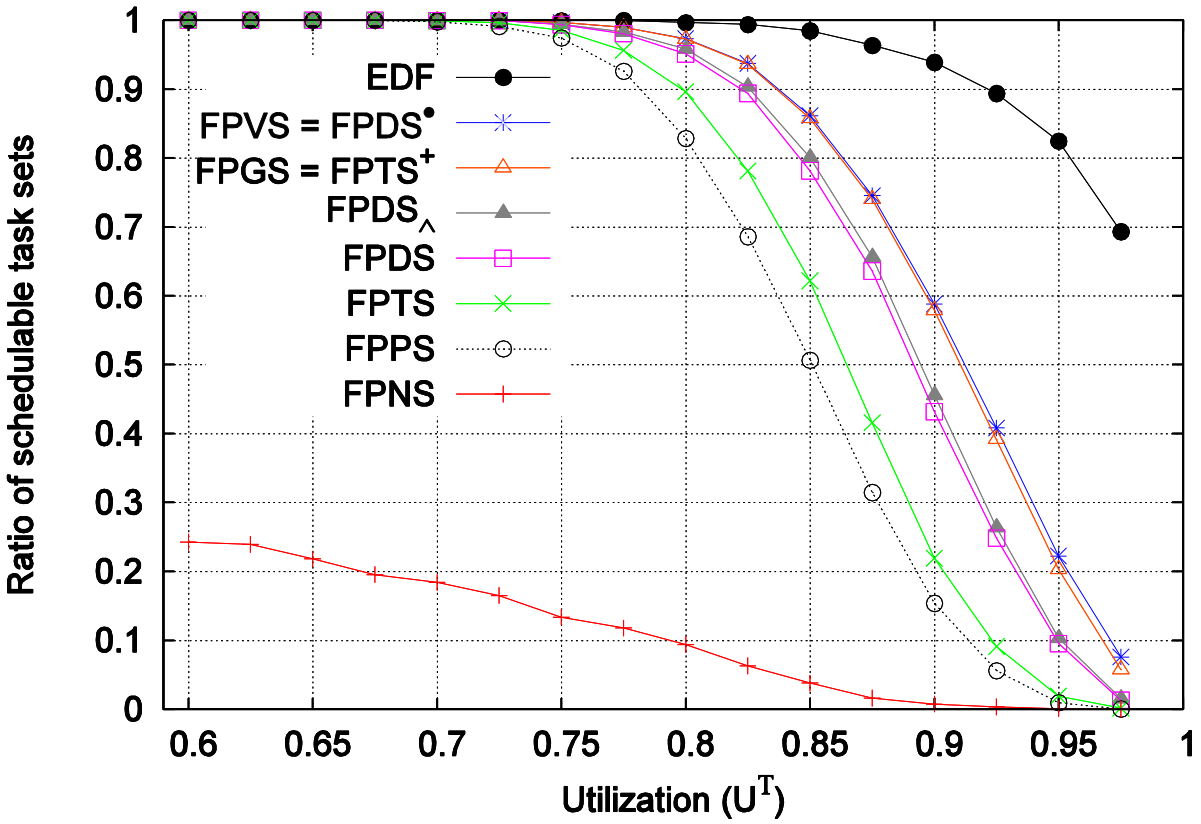
Generalization graph for FPS algorithms



FPDS•: *Pro*: high schedulability ratio;
Pro: predictable preemptions costs;
Pro: predictable memory requirements.

Evaluation



8 tasks, 5.000 task sets,
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An example task set $\mathcal{T}$

Task	T_i	D_i	C_i	π_i	$C_{i,a}$	$\theta_{i,a}$	$\theta^{\bullet}_{i,a}$
τ_1	7	7	2	3	2	3	-
τ_2	23	23	8	2	3, 5	3, 3	2
τ_3	29	25	10	1	1, 4, 5	3, 3, 3	1, 2

- **Task set $\mathcal{T}$ is**
  - ***not schedulable* with any existing limited preemptive FPS scheme, not even under any other priority assignment.**
  - ***schedulable* with both FPVS and FPDS$^{\bullet}$.**

- **Conclusion:**
  - **FPVS strictly dominates all existing schemes.**

An example task set $\mathcal{T}$ – configuration

Task	T_i	D_i	C_i	π_i	$C_{i,a}$	$\theta_{i,a}$	$\dot{\theta}_{i,a}$
τ_1	7	7	2	3	2	3	-
τ_2	23	23	8	2			
τ_3	29	25	10	1			

- **Determining the configuration of task τ_1.**

An example task set $\mathcal{T}$ – configuration

Task	T_i	D_i	C_i	π_i	$C_{i,a}$	$\theta_{i,a}$	$\dot{\theta}_{i,a}$	β_i
τ_1	7	7	2	3	2	3	-	**5**
τ_2	23	23	8	2	3, **5**			
τ_3	29	25	10	1				

- **Determining the configuration of task τ_2.**

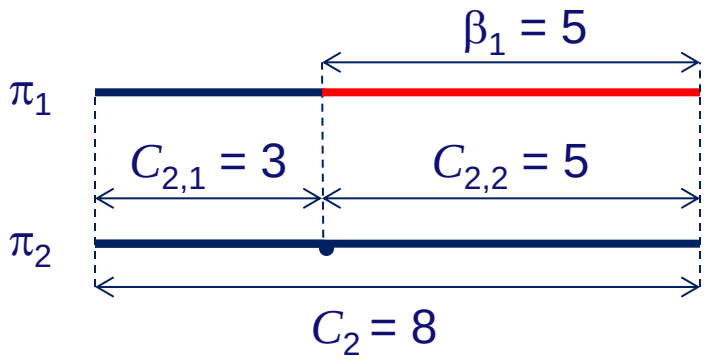
- ***Blocking tolerance*** **(β_i) [1]:**
  - **the maximum amount of time that a task (τ_i) can be blocked without missing its deadline (D_i).**

[1] V.B. Lortz and K.G. Shin, IEEE TSE, 1995.

An example task set $\mathcal{T}$ – towards analysis

Task	T_i	D_i	C_i	π_i	$C_{i,a}$	$\theta_{i,a}$	$\dot{\theta}_{i,a}$	β_i
τ_1	7	7	2	3	2	3	-	**5**
τ_2	23	23	8	2	3, **5**	3, 3	2	
τ_3	29	25	10	1				

- **Determining the configuration of task τ_2.**

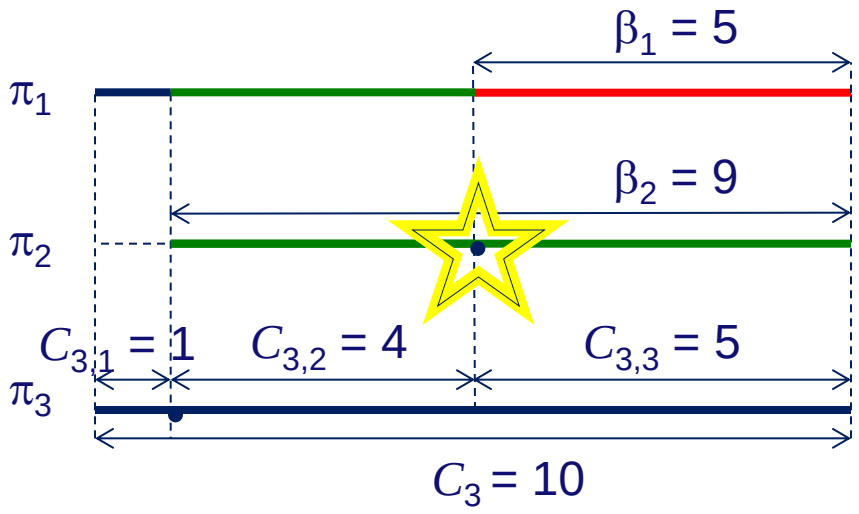


FPTS⁺ configuration
&
FPDS configuration

An example task set $\mathcal{T}$ – towards analysis

Task	T_i	D_i	C_i	π_i	$C_{i,a}$	$\theta_{i,a}$	$\theta^{\bullet}_{i,a}$	β_i
τ_1	7	7	2	3	2	3	-	**5**
τ_2	23	23	8	2	3, **5**	3, 3	2	**9**
τ_3	29	25	10	1	1, **4**, **5**	3, 3, 3	1, 2	1

- **Determining the configuration of task τ_3.**



FPVS configuration
&
FPDS• configuration

Contributions

1. **Novel scheduling algorithms: FPVS**
   - **Sub-jobs (similar to FPDS);**
   - **preemption thresholds**
     - **for sub-jobs and preemption points;**
   - **generalizes existing FPS algs.**
2. **Schedulability analysis for FPVS (similar to [11])**
   - **specializes to all existing FPS algs;**
3. **Algorithm to maximize schedulability under FPS:**
   - **given: T_i, D_i, C_i, and π_i;**
   - **determine: $C_{i,a}$, $\theta_{i,a}$, $\theta^{\bullet}_{i,a}$ (inspired by [8]).**
4. **Evaluation: FPVS dominates existing FPS algs.**

[11] M. González Harbour et al., RTSS, 1991.
[2] M. Bertogna, G.C. Buttazzo, G. Yao, RTSS, 2011.

Conclusion (significance of the result)

- **FPVS and FPDS•**
  - **have highest schedulability ratio;**
  - **can be emulated, e.g. with OSEK-standard (Automotive).**
- **FPDS• meets our goal:**
  - **Schedulability comparable to FPGS;**
  - **Preemptions limited to preemption points.**
- **If `schedulable`($\mathcal{T}$, FPDS) then FPDS• may have**
  - **reduced memory requirements;**
  - **tighter preemption cost estimation;**
  - **reduced power consumption.**

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