ICCD 2020

Chain-Based Fixed-Priority Scheduling of Loosely-Dependent Tasks

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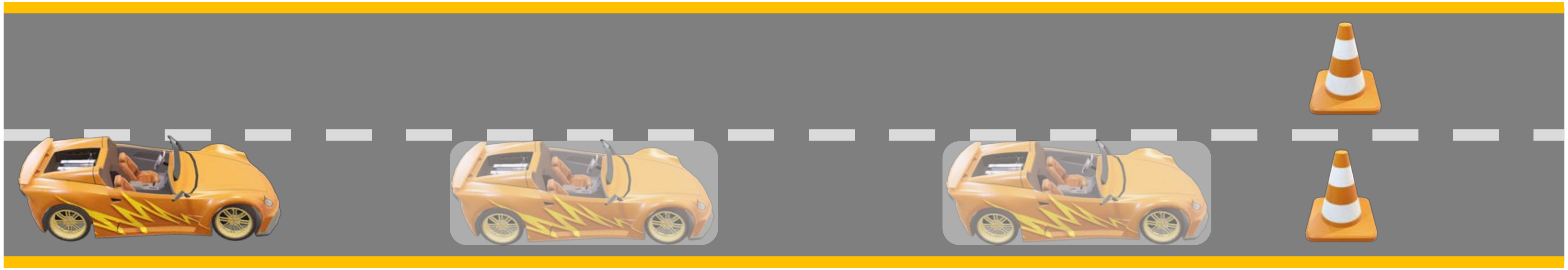
Motivational example



Perception reaction distance (A)

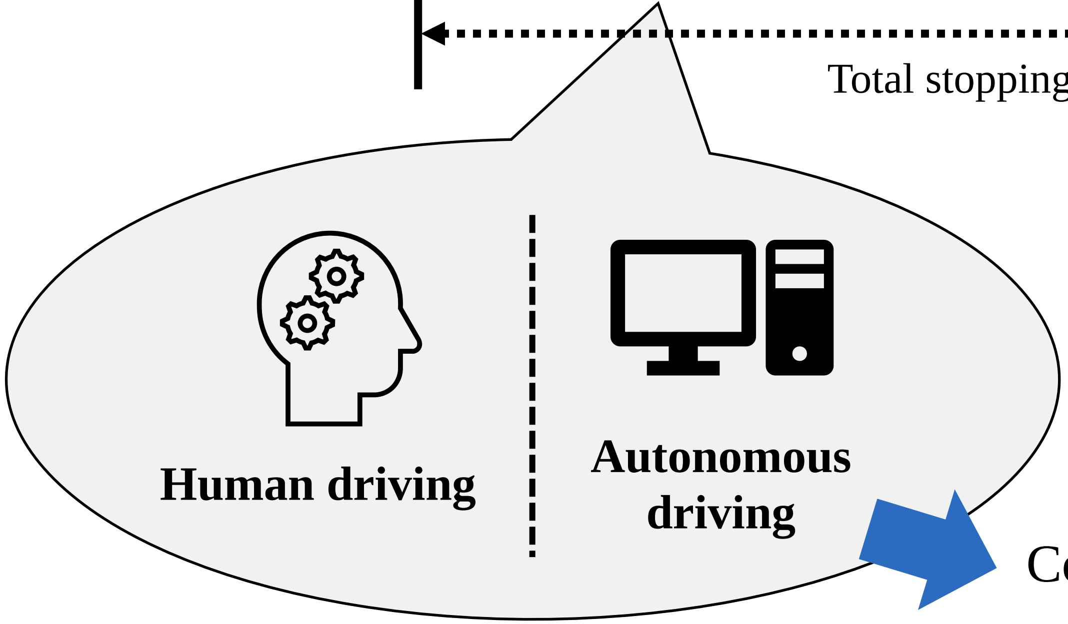
Braking deceleration distance (B)

Total stopping distance (C)

Stopped completely

Speed (mph)	A (feet)	B (feet)	C (feet)
55	121	144	265
60	132	172	304
65	143	202	345

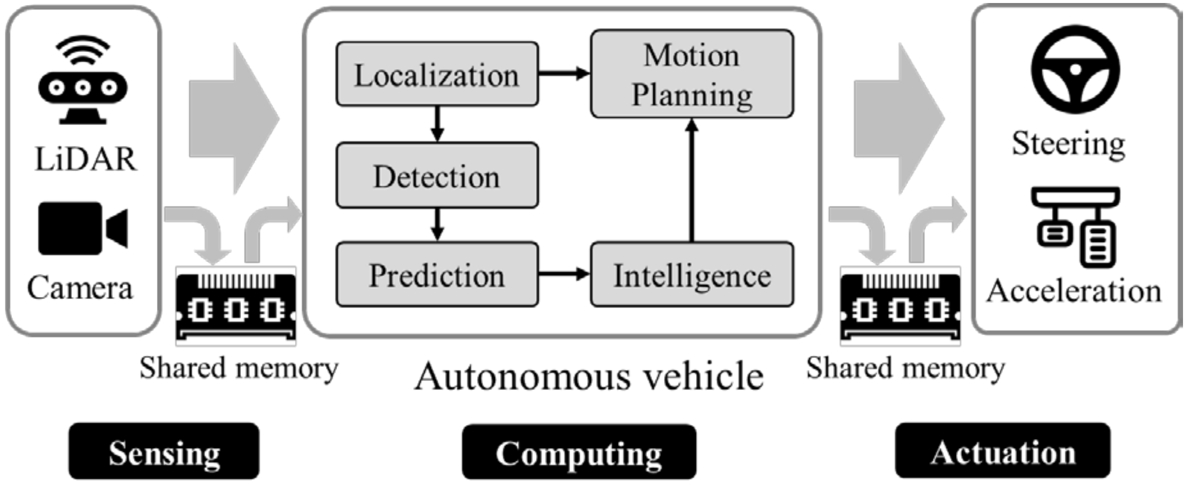
< Vehicle stopping distance by National Association of City Transportation Officials (NACTO), 2015 >



Complex information flows implemented with chains of tasks

Loosely-dependent task chains

- Each task executes and produces output at its own rate
  - Based on most recent input data from a preceding task
  - e.g., publisher-subscriber in ROS, read-execute-write in AUTOSAR
- Give flexibility in system design, scheduling, and information sharing



Goal: Minimize the end-to-end latency of loosely-dependent chains

Contributions

- Propose a **new chain-based fixed-priority scheduler** that identifies ***effective chain instances*** producing valid and updated chain outputs.
- Present an analytical method to **upper-bound the end-to-end latency** of chains under the proposed scheduler.
- Significantly outperforms the state-of-the art chain-unaware schedulers
  - **Up to 83% reduction in end-to-end latency** with a shorter update rate of valid chain output.

Prior Work:

- Chain-unaware schedulers
- Upper bound on latency based on the WCRT

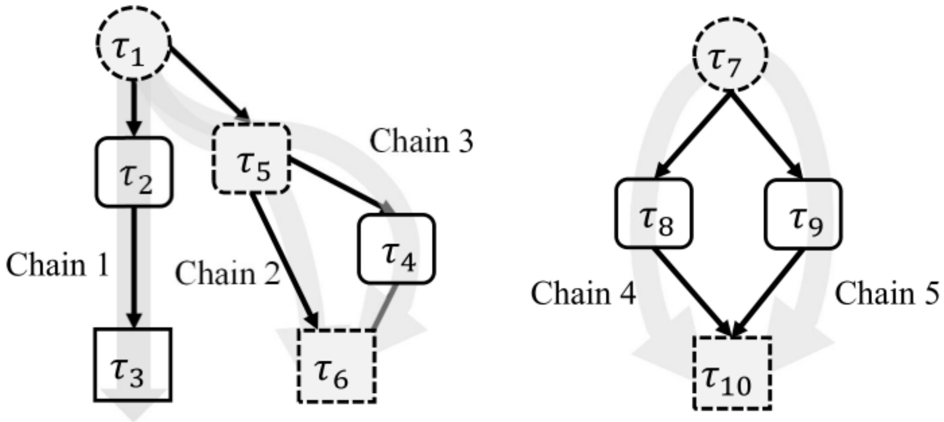
Abdullah et al. [DATE 2019]
Kloda et al. [ETFA 2018]
Becker et al. [RTCSA 2016]

- Limitations of DAG-based schedulings (inapplicable to tasks running asynchronously with different periods and priorities)

Ayan et al. [ICCPS 2019]
Han et al. [RTSS 2009]

System model

- Multi-core system with partitioned fixed-priority scheduling
- Task model: $\tau_i \coloneqq (BC_i, WC_i, D_i, T_i, o_i, \pi_i)$
  - BC_i: The best-case execution time of a job of τ_i
  - WC_i: The worst-case execution time of a job of τ_i
  - D_i: The relative deadline of τ_i $(D_i \leq T_i)$
  - T_i: The period of τ_i
  - o_i: The period of τ_i
  - π_i: The priority of τ_i
- Chain model: $\Gamma^c \coloneqq [\tau_s, \tau_{m1}, \tau_{m2}, \dots, \tau_e]$
  - τ_s: The start task of a chain Γ^c
  - τ_{m*}: The intermediate task of a chain Γ^c
  - τ_e: The end task of a chain Γ^c



< Example of chains >

Chain-based fixed-priority scheduler (1/2)

- Offline part: find effective chain instances from candidates

Definition 1.

An ***effective instance*** *of a chain* Γ^c *is* ***the earliest instance*** *producing a valid and updated final output using the* ***most recently updated input data****. The i-th effective instance of* Γ^c *is denoted as* $E^c[i]$.

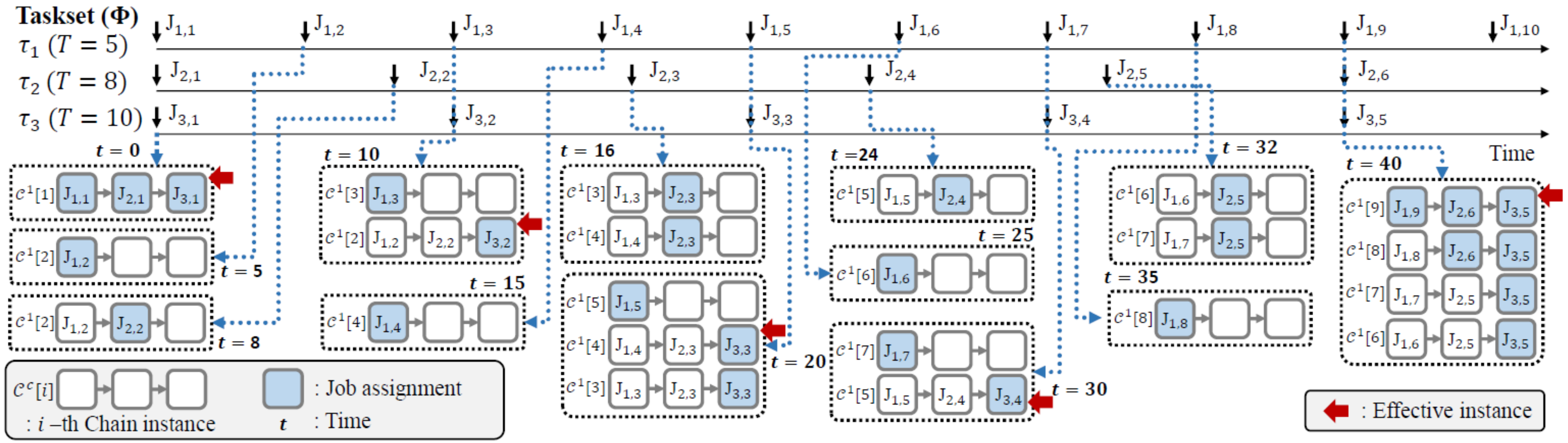
Step 1: Initialize chain instance candidates

Create instances for job releases from the start task of a chain

Step 2: Build chain instances

Add each job of intermediate tasks to eligible chain instances

< Synthesis of chain instances and effective instances for the taskset >



Chain-based fixed-priority scheduler (2/2)

- Runtime part: *Release-and-Ready* (RNR) policy
  - Prevent unnecessarily early start of job execution
  - **Two step-phases**
    - ✓ Release phase : arrival of a job according to its period, but cannot start execution
    - ✓ Ready phase : when previous jobs of the same chain instance have completed their execution

Rule 1. Job $E^c[i,j]$ in a single chain

- $E^c[i,j-1]$ complete, if $j \neq 1$
- Most recent job of $E^c[i-1]$ to the same CPU, if $j = 1$

Rule 2. Job $E^c[i,j]$ in multiple chains

- Rule 1 is satisfied for all of its effective instances

Rule 3. Job $E^c[i,j]$ not in effective instance

- Default: dropped (skipped)

< 3 categories of jobs for ready phase of effective chain instance >

End-to-end latency analysis

Step 1. Lower bound start-time and upper bound finish-time of a job

- Consider self-suspension effect caused by release phase
- Interference from high priority jobs of other chains
- Iterate until converge upper- and lower-bounds

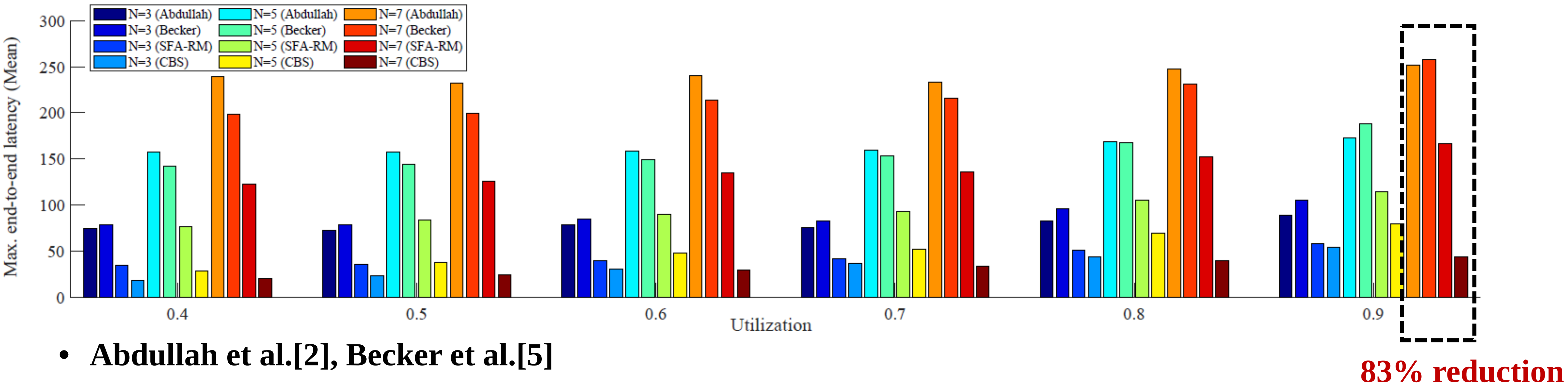
Step 2. Compute end-to-end latency of effective chain instance

- $L^c = \max_{\forall i} \bar{\mathcal{F}}^c[i, N_c] - \mathcal{S}^c[i, 1]$

Our analysis framework can also be used to analyze end-to-end latency under conventional chain-unaware fixed-priority schedulers

Evaluation

- Comparison with the state-of-the-art (single chain)



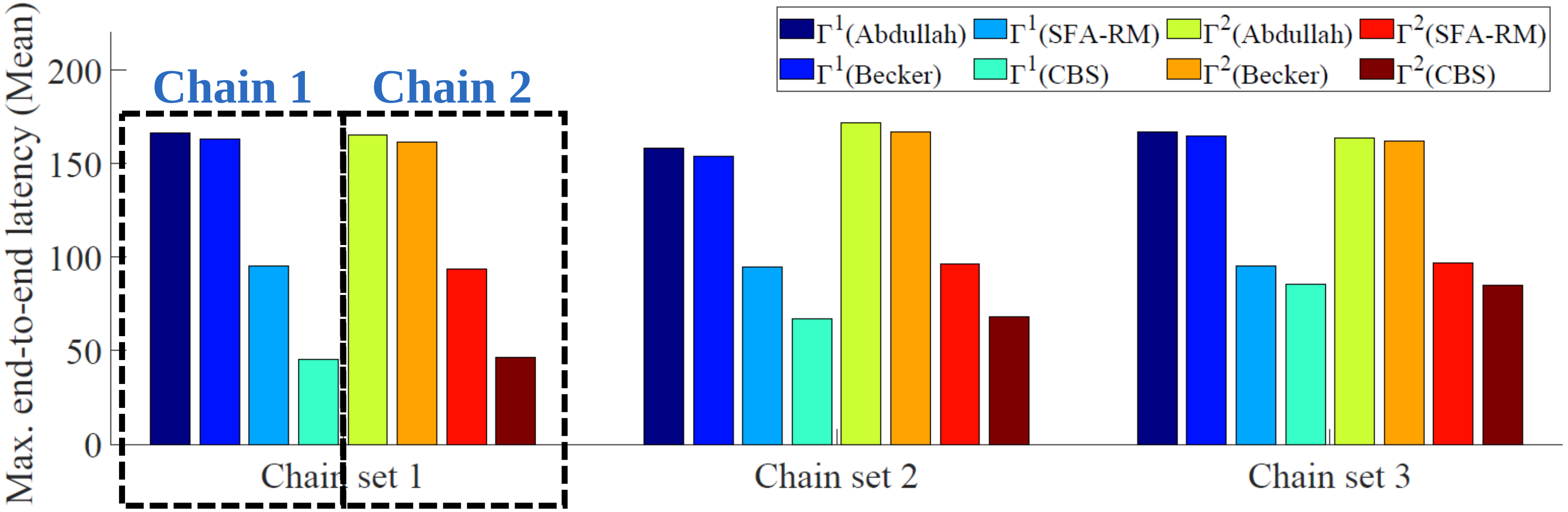
  - **Abdullah et al.[2], Becker et al.[5]**
  - **SFA-RM** : start- and finish-time based analysis under chain-unaware rate monotonic scheduling
  - **CBS** : proposed analysis framework under chain-based scheduler

- Use 500 tasksets with 7 tasks each for each utilization
- A chain with N tasks, left tasks are hard real-time tasks (i.e., modeled single-task chains)

[2] Worst-case cause-effect reaction latency in systems with non-blocking communication (DATE 2019)
[5] Synthesizing job-level dependencies for automotive multi-rate effect chains (RTCSA 2016)

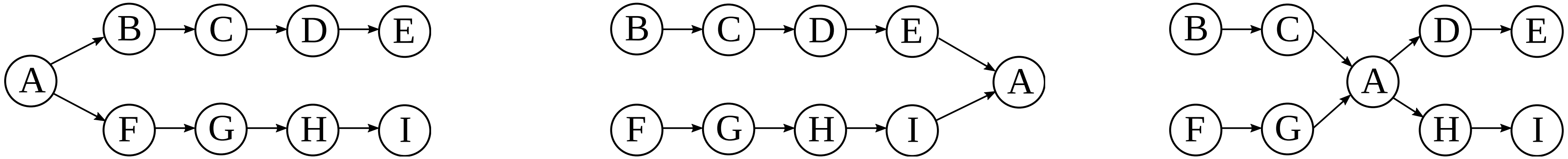
Evaluation

- Comparison with the state-of-the-art (multiple chains with a mutual task)



  - Utilization of 0.8 with 9 tasks that forms 2 chains
  - Mutual task's position

Chain set 1: start task, *Chain set 2* : end task, *Chain set 3* : intermediate task



Conclusion and future work

- Conclusion
  - New chain-based fixed-priority scheduling and analysis of end-to-end latency of chains
  - The proposed scheduler outperforms the state-of-the-art with respect to end-to-end latency
  - Our analysis framework can also be used for conventional chain-unaware scheduling policies

- Future work
  - Apply proposed scheduler to robotic platforms
  - Investigate the timing unpredictability caused by shared memory resources in multi-core platforms

Thank you

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Q & A